Universitat Autònoma de Barcelona

Early detection and prediction of health disorders in cattle using an activity monitoring system

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AUTONOMOUS UNIVERSITY OF BARCELONA

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SERGIO CALSAMIGLIA BLANCAFORT, como Catedrático del Departament de Ciència Animal i dels Aliments de la Facultat de Veterinària de la Universitat Autònoma de Barcelona,

CERTIFICO:

Que la memoria titulada "**Early detection and prediction of health disorders in cattle using an activity monitoring system**", presentada por Mohammed Anouar Belaid, ha sido realizada bajo mi dirección y, considerada finalizada, autorizo su presentación para que sea juzgada por la comisión correspondiente.

Y para que conste a los efectos que correspondan, firmo el presente certificado en Bellaterra, de 23 Mayo 2020.

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List of abbreviation

AUC: area under the curve

BRD: bovine respiratory diseases

BW: body weight

DA: displaced abomasum

DCAD: dietary cation-anion difference

DIM: days in milk

DMI: dry matter intake

FDR: false discovery rate

FOR: false omission rate

FNR: false negative rate

FPR: false positive rate

LSM: least squares means

MF: milk fever

RP: retained placenta

SD: standard deviation

Se: sensitivity

SE: standard error

SEM: standard error of the mean

Sp: specificity

UE: European Union

Summary

Three experiments were conducted to determine if an activity-monitoring systems could be used for an early predictor of the risk of sickness in cattle. In the first experiment, Friesian male calves (n = 330; 30 ± 9 d of age, 65 ± 15 kg) were fitted with accelerometers to be monitored from 30 to 90 d of life. Calf health status was controlled daily and all incidences recorded. A descriptive analysis was conducted to describe the normal behavior, a matched pair design was conducted from d -10 to +10 relative to the diseases diagnostic to compare sick versus healthy calves, and a multivariate logistic regression was performed on the days before the disease event to develop a prediction model. Over the entire period, healthy calves did daily 1,476 ± 195 steps, spent 185 ± 32.5 min at the feed bunk, did 10 ± 1.1 meals, 19.5 ± 1.8 lying bouts and spent 978 ± 30.5 min lying. Sick calves during the 20 d around the disease event did fewer steps, had 18% less meals on d -1 and 0, spent less time at the feed bunk on d -10 and -1 and had 15% less lying bouts from d -2 to +9 compared with healthy calves. The prediction model developed for d -10 had a sensitivity of 67%, a specificity of 67%, and accuracy of 67%. The false discovery rates and the false omission rates were 60% and 14%, respectively. Results indicate that the occurrence of diseases can be predicted in advance and a preventive treatment can be applied only to animals at risk. In the second experiment, young bulls fitted with accelerometers (n = 770, 127 ± 53 d of age) were monitored during the first three months after their arrival to the feedlot. Bulls were examined daily for health status. A descriptive analysis was conducted to describe the normal behavior of healthy bulls. To compare sick and healthy bulls, a matched pair design was performed in the 20 d around the diseases event and a multivariate logistic regression model was built to develop a prediction model. The dataset was randomly split in two parts: 70% to develop the prediction model, and the remaining 30% for the validation. Bulls did over the entire period on average 2,422 ± 128.3 steps/d, attended the feed bunk 8 ± 0.15 times/d for a total of 95 ± 8.2 min/d, had 27.8 ± 0.76 lying bouts/d and spent

889 ± 12.5 min/d lying. From the total of bulls enrolled, 71 were diagnosed sick. Sick bulls did fewer steps, less meals, spent less time in the feed bunk, had less lying bouts and spent less lying time compared with healthy bulls. The best prediction model was able to predict sick bulls at 9 d before the clinical symptoms with a sensitivity and specificity of 79.2 and 81.3%, respectively. The validation of the model resulted in a 50% false discovery rates and 7% false omission rates. Results suggest that activity monitoring systems may be useful in the early identification of sick bulls. However, the high false positive rate may require further refinement. In the third experiment, Holstein dry cows (n = 456) fitted with accelerometers were monitored from d –21 to the day of calving (d 0). Cows postpartum health status was monitored from 0 to 30 DIM. A univariate analysis (ANOVA) was performed to describe the normal behavior of dry cows and a multivariate linear mixed model was built from d –21 to the day of calving to compare sick vs. healthy cows. A multivariate logistic regression model was developed to predict metritis. On average, over the entire prepartum period, healthy cows (n = 341) did 1,627 ± 56 steps, spent 184 ± 10.6 min at the feed bunk, did 8.5 ± 0.3 meals, did 10 ± 0.5 lying bouts and spent 743 ± 18.4 min lying per day. Sick cows (n = 115) did 1,644 ± 89 steps, spent 183 ± 10 min at the feed bunk, did 8 ± 0.4 meals, did 11 ± 0.6 lying bouts and spent 740 ± 40 min lying per day. Differences in behavior between sick and healthy cows were more pronounced when considering specific postpartum disease separately. A prediction model for metritis was developed combining all prepartum days. This model at the highest sensitivity (73%) and specificity (86%), had 83.7% accuracy, 48.4% false discovery rates and 6.1% false omission rates. Results indicate that the occurrence of metritis can be predicted in advance and preventive treatment can be applied only to animals at risk.

Resumen

Se llevaron a cabo tres experimentos para determinar si el sistema de monitoreo de la actividad podría usarse como un predictor temprano del riesgo de enfermedad en bovinos. En el primer experimento, terneros Frisones (n = 330; 30 ± 9 días de edad, 65 ± 15 kg) fueron monitorizados mediante un acelerómetro durante los 60 d posteriores a su llegada a la granja. Se controló su estado sanitario y se registró la incidencia de enfermedades. Se realizó un análisis descriptivo para describir el comportamiento normal de los terneros, se usó un diseño de emparejamiento (*Matched-pair design*) en un periodo de interés de 10 d antes y después del diagnóstico de la enfermedad para comparar terneros sanos contra enfermos, y se realizó un modelo de regresión logística en los días previos a la aparición de la enfermedad para desarrollar un modelo de predicción. A lo largo de todo el ciclo de crecimiento, los terneros sanos hicieron un promedio diario de 1476 ± 195 pasos/d, estuvieron un total de 185 ± 32,5 min/d en el comedero, hicieron 10 ± 1,1 vistitas/d al comedero, 19,5 ± 1,8 cambios de posición de pie a tumbado/d y estuvieron 978 ± 30,5 min/d tumbados. Los terneros enfermos durante los 20 d alrededor de la enfermedad, hicieron menos pasos, tuvieron 18% menos visitas al comedero en los días -1 y 0, dedicaron menos tiempo a comer en los días -10 y -1, y tuvieron 15% menos cambios de postura de pie a tumbado entre los días -2 a +9 comparado con los terneros sanos. El modelo de predicción desarrollado para día -10 tenía una sensibilidad del 67%, una especificidad del 67% y una precisión del 67%. La tasa de falsos positivos y la tasa de falsos negativos fueron 60% y 14%, respectivamente. Los resultados indican que la aparición de enfermedades se puede predecir con antelación y que se puede aplicar un tratamiento preventivo a los animales en riesgo. En el segundo experimento, terneros pasteros equipados con acelerómetros (n = 770, 127 ± 53 días de edad) fueron monitoreados durante los primeros tres meses desde su llegada a la granja. Su estado de salud fue controlado diariamente y la incidencia de enfermedades fue registrada. Se realizó un análisis descriptivo del comportamiento normal de los terneros sanos. Para comparar

terneros enfermos y sanos, se realizó un diseño de emparejamiento (*Matched-pair design*) en los 20 d alrededor de la enfermedades y se construyó un modelo de regresión logística para desarrollar un modelo de predicción. Se seleccionaron al azar el 70% de la base de datos para desarrollar modelos de predicción, y se aplicó el mejor modelo a la base de datos de validación (30% restante). A lo largo del ciclo de crecimiento, los terneros hicieron un promedio de 2422 ± 128,3 pasos/d, visitaron los comederos 8 ± 0,15 veces/d para un total de 95 ± 8,2 min/d, tuvieron 27,8 ± 0,76 cambios de posturas/d y estuvieron 889 ± 12,5 min/d tumbados. Del total de terneros registrados, 71 fueron diagnosticados enfermos. Los terneros enfermos se caracterizaron por estar menos tiempo en el comedero y menos tiempo tumbados que los sanos. También hicieron menos cambios de postura de pie a tumbados, menos pasos y frecuentaron menos el comedero en comparación con los terneros sanos. El mejor modelo de predicción fue capaz de predecir terneros en riesgo de enfermarse 9 d antes de los síntomas clínicos con una sensibilidad y especificidad del 79,2% y 81,3%, respectivamente. La validación del modelo resultó en 50% de falsos positivos y 7% de falsos negativos. Los resultados sugieren que los sistemas de monitoreo de actividad pueden ser útiles en la identificación temprana de terneros enfermos. Sin embargo, la alta tasa de falsos positivos puede requerir un mayor refinamiento de la metodología. En el tercer experimento, vacas Holstein (n = 456) equipadas con acelerómetros fueron monitoreadas desde el día –21 hasta el día del parto (0 d). Su estado de salud fue controlado diariamente hasta el día 30 postparto. Se realizó un análisis univariado (ANOVA) para describir el comportamiento normal y se construyó un modelo mixto lineal multivariado desde día –21 hasta el día del parto para comparar vacas enfermas y sanas. Se desarrolló un modelo de regresión logística multivariante para predecir la metritis. En promedio, durante el preparto, las vacas sanas (n = 341) realizaron 1627 ± 56 pasos/d, visitaron los comederos 8,5 ± 0,3 veces/d para un total de 184 ± 10.6 min/d, hicieron 10 ± 0,5 cambios de postura de pie a sentado/d y pasaron 743 ± 18,4 min/d tumbados. Las vacas enfermas (n =

115) hicieron en promedio 1644 ± 89 pasos/d, visitaron los comederos 8 ± 0,4 veces/d para un total de 183 ± 10 min/d, tuvieron 11 ± 0,6 cambios de posturas/d y dedicaron 740 ± 40 min/d tumbados. Las diferencias en el comportamiento entre vacas enfermas y sanas fueron más pronunciadas cuando se consideraron las enfermedades postparto por separado. Se desarrolló un modelo de predicción para la metritis. El modelo con la mayor sensibilidad (73%) y especificidad (86%), tenía una precisión del 83,7%, una tasa de falsos positivos del 48,4% y una tasa de falsos negativos del 6,1%. Los resultados indican que la metritis postparto se puede predecir con antelación y que el tratamiento preventivo se puede aplicar sólo a los vacas en riesgo.

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To whom they passed away but their memories still around, my grandfather ***Mohammed Seguir Kedadra*** *and my friend* ***Adel Al Jeaidi***

Chapter I

Introduction

1. The Dairy and Beef Cattle Industry in Spain

Spain is the sixth country in the European Union (UE) in cattle census with 6.739.687 bovines. According to the last statistics of the Ministry of Agriculture, within the 28 European countries, Spain occupies the eighth position in milk production and the firth position in meat production (MAPA, 2020). At the national level, beef and dairy cattle sectors contribute to 17% and 16%, respectively, to the total value of the final livestock production being the second after the swine sector (MAPA, 2019). The beef and dairy production sector has evolved enormously towards a more intensive system, geographically-concentrated, and commercially oriented. Currently, the intensive beef and dairy cattle production system has been widely adopted in Spain (MAPA, 2019).

Under this production system, farmers are always under pressure to produce most efficiently, which means that they have to control all factors involved in the production process. Health control is one of the major concerns in the intensive production system. As farms' size have increased and farm personnel is now asked to manage a large number of animals, the time devoted to controlling animals individually becomes limited. Many sick animals can go unnoticed by the control and lead to big losses. Only preventative treatments to avoid these losses costs the US cattle industry over $3 billion annually (Griffin, 2006; Snowder et al., 2007). Farmers and producers are aware of such a problem. Therefore, it’s necessary to look for alternative methods to identify sick animals and to reduce the losses generated by the occurrence of these diseases.

2. The Receiving Phase, a Critical Period for Feedlot Cattle

The receiving phase, the first weeks after a calf arrives at the feedlot, is a critical period because it is always accompanied by a high incidence of diseases (Duff and Galyean, 2007).

Edward (1996) reported that approximately 65 to 85 % of morbidity in feedlot cattle occurs during the first 45 days. Pardon et al. (2012) found that the mortality risk was highest in the first weeks after arrival. The economic losses due to diseases during the receiving phase have an important impact on farm profitability. The bovine respiratory diseases, the main cause of morbidity (up 70-80%) and mortality (up to 40-50%) in feedlot cattle (Loneragan et al., 2001; Edwards, 2010) is estimated to cause the American feedlot industry between $800 to $900 million annually in economic losses (Chirase and Greene, 2000). In Europe, as in the US, it’s considered also the pathology with the highest economic impact in the beef cattle industry (Ackermann et al., 2010; Edwards, 2010; Buchanan et al. 2016). The cause of this high susceptibility to diseases in the receiving phase comes from the stressful factors that accompany this phase. Stress is recognized as a factor that can challenge the immune system, thus, decreasing the tolerance to diseases (Loerch and Fluharty, 1999).

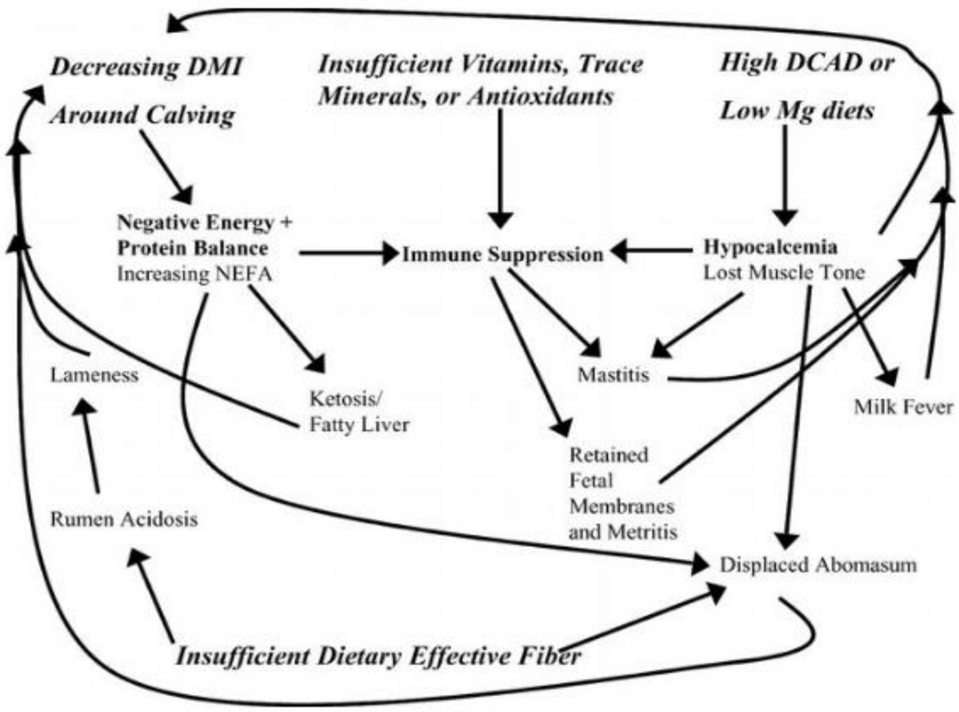
Calves arriving to the fattening farm are subjected to many stress factors (Sheridan et al., 1994). They are bought from auction markets or collected from farms to be transferred to the fattening farm. During their transport, calves are confined, grouped with unfamiliar calves in an unknown environment, fasted for a long time, and exposed to multiple environmental stressors such as motion, noise, heat and/or cold (Van Engen and Coetzee, 2018). After transport, calves at their arrival are mixed with sick calves from other farms and this can provide an opportunity for the diseases to be spread in the entire group (van der Fels-Klerx et al., 2000; O’Connor et al., 2001). Furthermore, calves once at the fattening farm have to adapt to their new housing facility with a different environment, feed, water, handlers and management and this may cause additional psychological and physiological stress. For these reasons, the receiving phase is considered a critical period in feedlot cattle where a high incidence of diseases is present and the goal should be to reduce the risk, identify animals at risk and treat them as soon as possible.

3. The Transition Phase, a Critical Period for Dairy Cattle

The transition period, which corresponds to the passage from a pregnant non-lactating state to a non-pregnant lactating state, is a critical demanding phase for dairy cows. Its relevance has been highlighted in several reviews due to its importance in determining future health, milk production, and reproductive success of the dairy cow (Drackley, 1999; Ingvartsen et al., 2003; Block, 2010). During this phase, a number of metabolic changes occur, leading to a high incidence of metabolic, infectious and reproductive disorders (Piccione et al., 2012). According to LeBlanc (2010), 50% of diseases occur in the transition period and 30% to 50% of high-producing cows may be affected by at least one health disorder. Ingvartsen et al. (2003) summarized data of 151,000 cows and reported that the maximum incidence of diseases occurred during the transition period and more especially in the first 10 days after calving.

Kelton et al. (1998) reported that the incidence rate of some postpartum diseases such as clinical hypocalcemia, retained placenta, metritis, ketosis, displaced abomasum, and mastitis increased considerably from 1979 to 1995. The economic losses of these diseases can affect significantly farm profitability by reducing milk production, altering milk composition, reducing reproductive performance, increasing treatment costs, or reducing the life expectancy of the cow. Liang et al. (2017) reported that the cost per case (average ± SD) for primiparous cows was $426.50 ± 80.27 for mastitis, $333.17 ± 68.76 for lameness, $262.65 ± 56.15 for metritis, $313.49 ± 64.66 for retained placenta, $639.51 ± 114.10 for left displaced abomasum, $180.91 ± 63.74 for ketosis and $246.23 ± 52.25 for hypocalcemia. But the costs of these individual postpartum diseases may be much higher because the appearance of one disease can increase the risk of developing other postpartum diseases (Goff, 2006). For example, subclinical hypocalcemia may lead to loss of muscle tone, resulting in an increased risk of retained placenta and/or displaced abomasum. Figure 1 presents the interrelationship between different periparturient disorders in dairy cows. Therefore, in order to decrease these risk factors related to postpartum diseases, good management of cows during the transition period is required (Grummer, 1995; Drackley, 1999; Ingvartsen et al., 2003).

Figure 1. Interrelationship between a different periparturient disorders in dairy cows (Goff, 2006).



4. Prevention Strategies: Importance, Challenges, and Possible Improvement

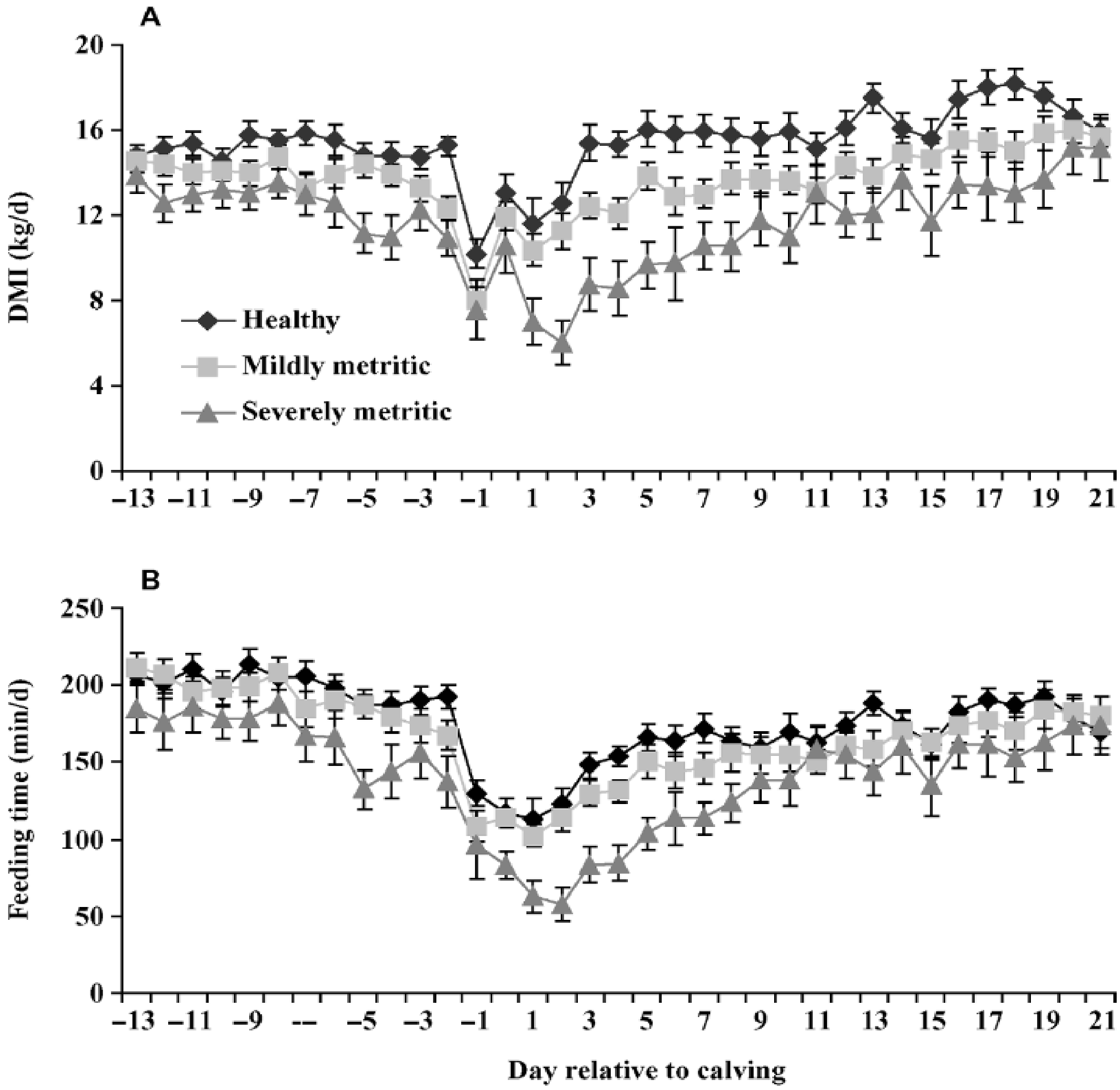
The negative effect of diseases in feedlot and dairy cattle performance are high and can have big important economic implications. To reduce these impacts many authors highlight the importance of prevention and not disease treatment (LeBlanc et al., 2006). Diseases treatment was used in traditional veterinary medicine with the assumption that if all sick animals are managed properly, a healthy herd will result (Ken Nordlund, 1998). LeBlanc et al. (2006) stated: “Perhaps the single biggest advance in dairy health in the last 25 years has been the paradigm shift from treatment of clinical illness to disease prevention”. This shift becomes a requirement as the size of farms increase and farmers and veterinarians have to manage groups and herds of cows instead of individual cows. Furthermore, disease prevention may be more beneficial compared with disease treatment.

Many preventive measures are currently used to control diseases in cattle such a dietary cation-anion difference (DCAD) to reduce the risk of hypocalcemia (NRC, 2001; Goff and Horst, 1997; Block, 1994), or vitamin E as an antioxidant to maximize health and immune function (Bouwstra et al., 2010). However, these preventive treatments could be costly if they are applied to all animals for many days. For example, the use of propylene glycol in the postpartum is recommended to prevent or reduce the incidence of ketosis. However, its cost is relatively high when it has to be administrated to all cows instead to only cows with high risk that require such treatment. Moreover, some preventive treatment such as the prophylactic antimicrobial treatments, widely used in newly received feedlot cattle, could create antimicrobial resistance in animals with possible transmission to humans (Catry et al., 2016; OIE-WHO-FAO, 2004). Consumers now are aware of such a problem. Therefore, there is a needs to develop management strategies to decrease the unnecessary use of antibiotics in healthy animals (Torrence, 2001).

5. Behavioral Changes Before the Onset of the Clinical Disease

Sick animals change their behavior as a reflection to pathologies (Weavy et al., 2009). These changes could be used to identify sick animals at an early stage. For example, Basarab et al. (1996) reported that the monitoring of feeding and/or drinking behavior in cattle may offer an alternative method to visual observation for detecting sick cows. Sowell et al. (1999) found that healthy steers spent more time at the feed bunk and had more feeding bouts compared with subsequently morbid steers. These differences in behavior could be used as a predictor of sickness. Quimby et al. (2001) reached a similar result in newly received calves. Morbid calves were detected 4.1 d earlier than the appearance of the clinical symptom of the disease based on the decreased time at the feed bunk. Similar changes have also been found in dairy cattle. Urton et al. (2005) reported that for every 10 min decrease in average daily eating time, cows were twice as likely to be diagnosed with metritis. Huzzey et al. (2007) found that cows with severe metritis spent less time eating and ate less compared with healthy cows beginning 2 wk before the observation of clinical signs of infection (Figure 2).

Figure 2. The arithmetic mean (±SE) daily dry matter intake (kg/d; A) and feeding time (min/d; B) of healthy (n = 23), mildly metritic (n = 27), and severely metritic (n = 12) Holstein dairy cows from 13 d before until 21 d after calving (Huzzey et al., 2007).



Goldhawk et al. (2009) determined that changes in feeding and social behavior of cows during the transition period were associated with subclinical ketosis during the first week after calving. Animals diagnosed with subclinical ketosis ate less and spent less time at the feed bunk compared with healthy animals and, for every 10 minutes reduction, the risk of subclinical ketosis was multiplied by 1.9. Proudfoot et al. (2009) reported that cows with dystocia consumed 1.9 kg less during the 48 h before calving compared with cows with eutocia, and this difference increased to 2.6 kg in the 24 h before calving.

The previous studies focused predominantly on feeding behavior of cattle because of its obvious link with production, but other behavioral indexes like number of steps, number of lying bouts or time lying could also be informative of the risk of diseases if they were considered. Pillen et al. (2016) found that standing time, number of steps and lying bouts started to decrease 4 to 6 days before the appearance of clinical symptoms of bovine respiratory diseases (BRD) in cattle, and reductions were more pronounced the day before the identification of the clinical disease. Therefore, Pillen et al. (2016) concluded that behavior activity could be useful in the diagnostic of BRD. Neave et al. (2018) showed that cows diagnosed later with metritis had reduced lying time and bouts 3 days before clinical diagnostic compared with healthy cows.

Previous results demonstrate that animals change their behavior before the appearance of the clinical signs of diseases. Therefore, it would be useful to use these changes as early indicators of animals at risk of becoming sick. Treating animals in an early stage of diseases may increase the treatment effectiveness allowing for prompt recovery and improve animal welfare (Schoening et al., 2005). Moreover, identifying animals at risk of becoming sick would allow planning selective preventive treatment to only those animals with a high risk of sickness. Thus, the cost of preventive treatment would be reduced and its effectiveness improved.

6. Advanced Technologies to Monitor Cattle Behavior

In the last century, agriculture has been transformed to support the large population food demands (Marchesi, 2012). Precision agriculture, which refers to the automation of agriculture processes, has become a powerful strategy to face this challenge. Precision livestock farming is also developing fast. It consists on the use of advanced information and technologies to improve animal management and performance (Bewley, 2010, 2012). Technologies such as automated milking systems and automatic calf feeders are already implemented in some farms. Technology could also be applied to monitor animal health to help farmers control animals' health status as the time devoted to observe individual animals is limited (Berckmans, 2004). Moreover, clinical signs of diseases expressed by animals might be difficult to detect by traditional observation. Furthermore, the identification of sickness using subjective criteria could leave sick animals unnoticed (Heuwieser et al., 2010).

Many automated monitoring system technologies have been developed and customized to be used in precision livestock farming to provide support to producers. Currently, the use of automated technologies such as sensors is becoming increasingly utilized in farms. Those sensors are used to measure several indexes such as ruminal temperature to detect BRD episodes (Timsit et al., 2011), ruminal pH for early detection of ruminal acidosis (Marchesini et al., 2013), activity for heat detection (Frost et al., 1997; Friscke et al., 2014), or several indexes to detect diseases (Rutten et al., 2013). Swartz et al. (2017) reported that the information provided by automated calf feeder and accelerometers was able to predict sick calves 2 days before their diagnostic by the farm personal. However, the use of automated calf feeder is not common in farms, and its use is limited to pre-weaned calves. Other tools can be used in cattle without the age limitation. Pedometers are used to identify oestrus behavior in cows by measuring step numbers (Løvendahl and Chagunda, 2010). These pedometers have recently been adapted to measure others behavior indexes such as lying bouts, feeding time or number of visits to the feed bunk, and are already available in many farms. Therefore, their use can be a good alternative to monitor cattle behavior.

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Chapter II

Objectives

The general objective of this thesis is the early prediction of health disorders in cattle using an activity monitoring system able to measure the feeding behavior and activity. Therefore, we planned three different studies with specific objectives.

I. First study (chapter III):

- To determine if activity-monitoring systems that measure daily activity and frequency and time of visits to the feed bunk could be used as an early predictor of the risk of sickness in young calves.

II. Second study (chapter IV):

- To determine if feeding behavior, together with steps counts, lying time, and lying bouts, could be useful in the early identification of newly received bulls at risk of becoming sick.

III. Third study (chapter V):

- To determine if the prepartum feeding and activity behavior could be useful to identify cows at risk of postpartum diseases, and to develop prediction models able to anticipate their occurrence.

Chapter III

Published Papers

Using behavior as an early predictor of sickness in veal calves

M. A. Belaid, M. Rodriguez-Prado, D. V. Rodriguez-Prado, E. Chevaux, and S. Calsamiglia. 2020. Using behavior as an early predictor of sickness in veal calves. J. Dairy Sci. 103:1874-1883. https://doi.org/10.3168/jds.2019-16887

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Using behavior as an early predictor of sickness in veal calves

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ABSTRACT

The objective of this study was to analyze whether changes in behavior can be a good early predictor of sickness in calves. Friesian males calves (n = 325; 30 ± 9 d of age; 65 ± 15 kg) were monitored with an activity-monitoring device from 30 to 90 d of life in 4 periods corresponding to 4 seasons. The activity-monitoring device measured number of steps, number of lying bouts, lying time, and frequency and time of visits to the feed bunk. Calf health status was monitored daily and all incidences were recorded. To compare sick and healthy calves, a matched pair design was used to assign calves into the healthy group. Day 0 was defined as the day of sickness diagnosis. For each sick calf, 3 calves with no signs of sickness during the entire period (healthy calves) on the same date, in the same season, and of similar age (±4 d) and weight at entry were identified. A multivariate linear mixed model was used from d −10 to +10 relative to the sickness diagnosis to describe differences between sick and healthy calves. A multivariate logistic regression model was used for predicting sick calves on the days before the diagnosis. Significance was declared at $P < 0.05$. Daily, healthy calves had 1,476 ± 195 steps, spent 185 ± 32.5 min at the feed bunk, consumed 10 ± 1.1 meals, had 19.5 ± 1.8 lying bouts, and spent an average of 978 ± 30.5 min lying. The difference in behavior between sick (n = 33) and healthy calves (n = 99) began to be evident on d −10. Sick calves had fewer steps and numbers of visits to the feed bunk on d −1 and 0 and spent less time at the feed bunk on d −10 and −1 compared with healthy calves. From d −2 to d 9, sick calves had 15% fewer lying bouts, with no difference in lying time except on d −10, when sick calves spent more time lying. The best prediction model was for d −1 and included season and age at entry as qualifying variables, and frequency of visits to the feed bunk, steps, and lying time as behavior predictors (69% sensitivity, 72% specificity, 72% accuracy, 55% false discovery rate, and 12% false omission rate). However, an earlier prediction would be more useful to reduce the negative effect of sickness on production and welfare. The prediction model for d −10 had 67% sensitivity, 67% specificity, 67% accuracy, 60% false discovery rate, and 14% false omission rate. Results indicate that the occurrence of sickness can be predicted in advance, and an automated alarm system could be used to identify calves at risk of becoming sick and apply a preventive treatment.
Key words: calf behavior, activity-monitoring system, sickness prediction

INTRODUCTION

Mortality and morbidity in calves represent an important cost for farmers and a significant welfare issue (Ortiz-Pelaez et al., 2008; Mohd Nor et al., 2012). Upon arrival at the farm, calves are often exposed to sickness challenges and experience stress resulting from commingling, transportation, new housing facilities, and adaptation to a new diet (Mormede et al., 1982; Van der Fels-Klerx et al., 2000). Prophylactic treatments, including antibiotics, are often used to prevent or treat respiratory or enteric infections (Quigley et al., 1997; Silbergeld et al., 2008). Currently, the use of antimicrobials in calves is high (Pardon et al., 2012) and is partly responsible for the development of microbial resistance to antibiotics (Silbergeld et al., 2008; Catry et al., 2016). The World Health Organization and the European Union recommend a reduction in the use of antibiotics for animal production (European Commission, 1998; Ferber, 2003). Moreover, there is pressure from the medical community and consumers to reduce antimicrobial use in animal agriculture, which provides an additional motivation to raise cattle without antibiotics. Therefore, it would be advantageous to encourage the development of management strategies to prevent or minimize sickness and reduce the use of antibiotics (Torrence, 2001) by targeting only calves at risk. Identifying morbid calves at an early stage may increase treatment effectiveness, promote a prompt recovery, and improve animal welfare (Schoening et al., 2005).

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However, the intensification of production systems decreases human–animal interactions, which further complicates the visual diagnosis of sicknesses (Frost et al., 1997; Berckmans, 2004).

Monitoring cattle behavior using automated devices, such as wearable accelerometers and automatic calf feeders, can be a good option for easy identification of animals at risk of sickness (Trénel et al., 2009). Quimby et al. (2001) reported that feeding behavior could also be useful to predict morbidity in calves 4 d before its diagnosis by farm personnel. Svensson and Jensen (2007) found that sick calves had fewer unrewarded visits to the feeder than healthy calves on the day that they were diagnosed sick by farm personnel. Borderas et al. (2009) also reported that calves fed a high milk allowance decreased their daily average milk intake when sick and were less active and had reduced lying times when diagnosed with respiratory sickness compared with healthy calves 1 to 2 d before having clinical symptoms. Another study reported that calves with neonatal calf diarrhea tended to have fewer unrewarded visits to automatic milk feeders, lower milk consumption, and fewer lying bouts than healthy calves (Sutherland et al., 2018). These previous studies focused predominantly on feeding behavior related to milk consumption. Feeding behavior corresponding to concentrate consumption has rarely been studied in milk-fed calves and after weaning. New activity-monitoring devices are being developed that measure and record activity, rumination, and number of visits and time at specific locations in the farm (Borchers et al., 2016).

We hypothesized that measuring activity and time and frequency of visits to the feed bunk would allow the early identification of calves at risk of becoming sick. The aim of this study was to determine whether activity-monitoring systems that measure daily activity and frequency and time of visits to the feed bunk could be used as an early predictor of risk of sickness in young calves.

MATERIALS AND METHODS

Animals, Feeding, and Management

The experiment was conducted from March 2017 to January 2018. A total of 325 veal calves originating from surrounding dairy farms were enrolled in the study and distributed in 4 groups of calves that arrived on the farm in March (n = 85), June (n = 85), September (n = 80), and October (n = 75). Friesian male veal calves (n = 325, 30 ± 9 d of age at arrival, and 65 ± 15 kg of BW) were monitored throughout the first 60 d after their arrival at the farm. On the day of arrival, calves were weighed with a digital scale (Agroterra, Valencia, Spain) and divided into 3 groups of 25 ± 5 calves based on BW. They received vaccines against infectious bovine rhinotracheitis (Hiprabovis, Hipra, Amer, Spain), bovine viral diarrhea virus (Bovela, Boehringer Ingelhem, Sant Cugat del Valles, Spain), and an external and internal antiparasitic treatment (ivermectin, Promectine, Proyma, Ciudad Real, Spain). Calves were housed in a straw-bedded, covered, open-side barn with natural ventilation and in pens that provided a space allowance of approximately 3 m^2/calf.

During the first 5 wk after arrival, calves were bottle-fed with 2 L of milk replacer (130 g/L; 22% protein, 19% fat; Denkavit, Lleida, Spain) twice daily at approximately 0700 and 1900 h. Calves had ad libitum access to a texturized calf starter (16% protein, 3.8% fat; Super's Diana, Parets del Valles, Spain), and grass hay provided ad libitum in a 20-m-long feed bunk along each pen. Water was provided through an automatic waterer. Orts of the dry food were removed daily from the feed bunk before new fresh dry food was provided. Calves were weaned after 5 wk and remained in their location for an additional 3 wk, where they had ad libitum access to dry concentrate, hay, and water.

Data Collection

When calves arrived at the facility, an activity-monitoring device previously validated for steers (Fedometer system, FEDO; ENGS, Rosh Pina, Israel; Wolfger et al., 2015) was fitted onto the front left leg at the level of the metacarpus. Calves were monitored throughout the whole period (9 ± 2 wk) and the FEDO was removed at the end of the experiment. The FEDO recorded activity (number of steps, number of lying bouts, and lying time) and duration and frequency of visits to the feed bunk. The feed bunk was equipped with an electromagnetic field–generating antenna that detects the proximity of animals to the feed bunk (30 ± 2 cm in front of the feed bunk) and, thus calculates the number of visits and duration at the feed bunk. Data were recorded continuously and transmitted wirelessly every 6 min to a computer with system-specific software (Eco-herd software; ENGS). The system was checked periodically for proper functioning. Calf identification, birth date, BW, and group entry date were recorded for each animal. At the end of each period, data were downloaded into an Excel spreadsheet (Microsoft Corp., Redmond, WA) and summarized by day.

Each calf was observed twice daily individually at feeding times by the same farm manager for signs of sickness. The standard operating procedures of the farm included a checklist of criteria used to identify sick calves. A calf was diagnosed as having respiratory sickness when observed with crackly breath, rapid breathing, or coughing, or had ocular or nasal discharge; with digestive problems when they had diarrhea (feces with a loose to watery consistency, presence of loose fecal matter on the top of the tail or legs, strong odor, and dehydration); or with no specific diagnosis when depressed and with a rectal temperature >39.5°C. Calf diagnosis and treatment were done by the attending veterinarian within 12 h of the diagnosis, and treatments were applied for at least 3 consecutive days. Calves with respiratory disease were treated with antibiotics, and the remainder were treated with a combination of antibiotics and anti-inflammatories. The date of diagnosis and the time of each treatment were recorded for each morbidity event.

Statistical Analyses

All statistical analyses were performed with SAS (version 9.4; SAS Institute Inc., Cary, NC). Healthy calves were those that had no clinical signs during the whole experimental period. For the normal behavior of healthy calves, descriptive statistics were recorded for the entire period with all calves not diagnosed sick (n = 290). A matched pair design was used to assign calves into the healthy group for the development of prediction models. Day 0 was defined as the day of sickness diagnosis. For each sick calf, we identified 3 healthy calves on the same date in the same season, of a similar age (±4 d) and approximately the same BW at entry. Most previous reports have measured activity 4 to 5 d before the diagnosis but, in most cases, the difference in activity between healthy and sick calves was already apparent (Borderas et al., 2009; Swartz et al., 2017; Sutherland et al., 2018). Therefore, data analysis was conducted from 10 d before to 10 d after diagnosis and the first treatment. For sick calves that were treated multiple times, only the first treatment event was considered. Once the database was generated, a multivariate linear mixed model was built to describe differences in each behavioral index between sick and healthy calves. The model included calf health status (healthy or sick), season, age at entry, days around the diagnostic event from d −10 to +10, the interaction between days and health status as fixed effects, and the animal as a random effect. When an interaction was significant, the SLICE option was used to evaluate it.

To verify the usefulness of behavior indexes for predicting sick calves, a multivariate logistic regression model was used on the days before the treatment event to identify variables associated with health status. This model included the fixed effects of season (month of entry), age at entry, and all behavior indexes. All predictors with $P < 0.20$ were initially included in the model. The backward stepwise procedure was used to eliminate variables from the regression model until all remaining predictors were significant. For each model, the sensitivity (**Se**) and specificity (**Sp**) were calculated for each possible cut-off point, as described by Dohoo et al. (2003), and the cut-off point that yielded the highest combination of Se and Sp was selected. Diagnostic test characteristics included accuracy, false discovery rate (**FDR**), and false omission rate (**FOR**; Dohoo et al., 2003). The Se is defined as the probability that a positive alert is a true indicator of sick calves, and the Sp is the probability that a negative alert is a true indicator of healthy calves. The FDR was defined as the proportion of calves that were diagnosed incorrectly as being sick and expressed as a percent of sick calves. The FOR was defined as the proportion of calves that were diagnosed incorrectly as being healthy and expressed as percent of healthy calves. Accuracy was defined as the proportion of healthy and sick calves diagnosed correctly (Dohoo et al., 2009). Models with an area under the curve (**AUC**) >0.70 were chosen to construct the final prediction models.

RESULTS

In total, 33 (10%) calves were diagnosed sick, of which 17 (51%) were treated with antibiotics against bovine respiratory sickness and 16 (49%) had no specific diagnosis and received a general treatment based on antibiotics and anti-inflammatories. Most calves became sick within the first 5 wk (20 ± 10 d) after arrival at the receiving facility. Only 2 calves died within the first 2 wk, one with intestinal torsion and the other with serious lung injuries, representing a mortality rate of 0.61%.

Normal Behavior

A total of 290 healthy calves were used to describe daily normal behavior during the experimental period (Figure 1). Over the entire period, on average (mean ± SD), each day calves had 1,476 ± 195.2 steps and visited the feed bunk 10.5 ± 1.1 times, where they spent 185 ± 32.5 min. They had 19.5 ± 1.75 lying bouts and spent, on average, 978 ± 30.5 min lying. Over the time of the trial, calves increased their daily steps and frequency and duration of visits to the feed bunk and lying bouts (Figure 1A, B, C, and D); lying time remained constant (Figure 1E).

Sick Versus Healthy Calves

The comparison between sick (n = 33) and healthy (n = 99) calves from 10 d before and after the first

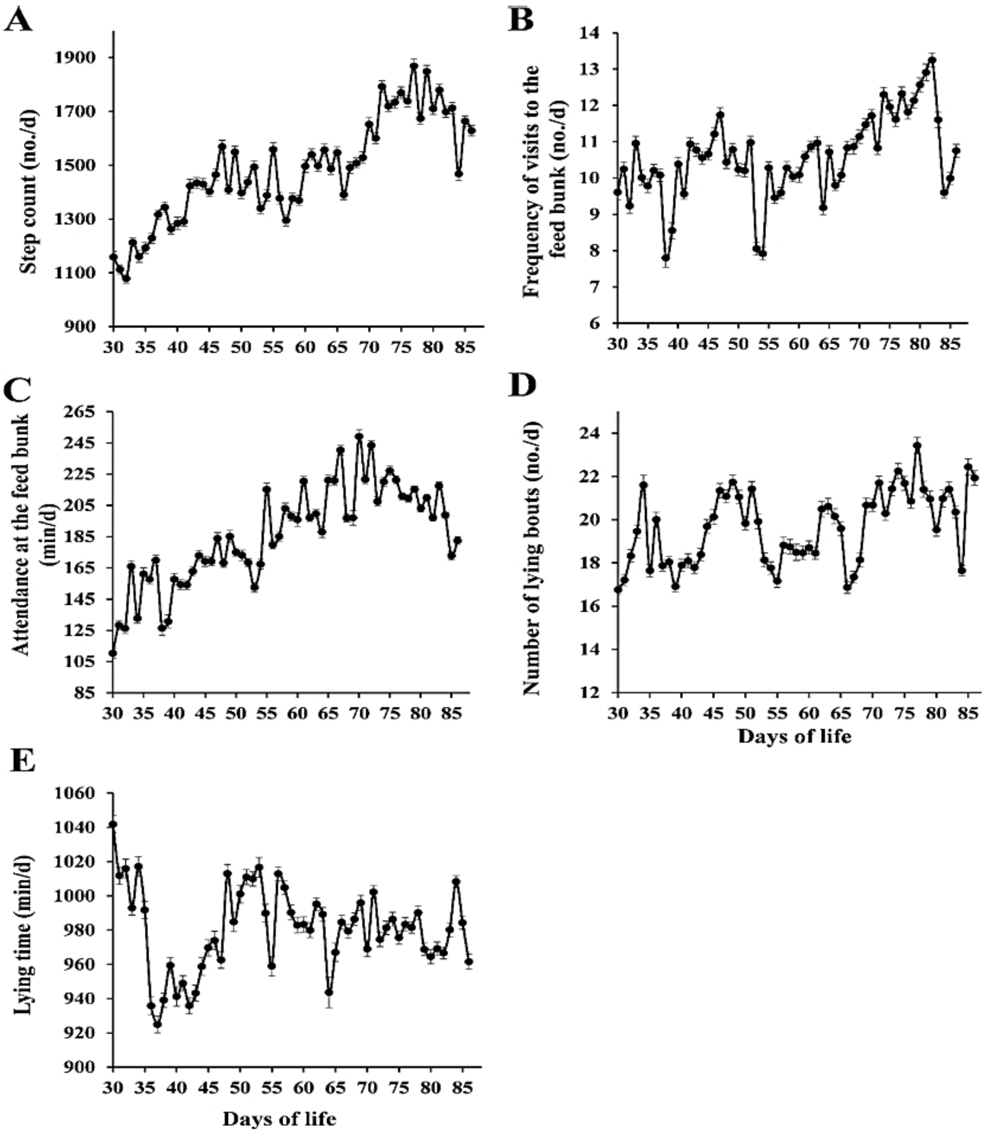

Figure 1. Daily step counts (A; no./d), frequency of visits to the feed bunk (B; no./d), duration of visits at the feed bunk (C; min/d), number of lying bouts (D; no./d), and lying time (E; min/d) in healthy calves from 30 to 90 d in life. Error bars indicate SEM.

treatment event (step counts, frequency and duration of visits to the feed bunk, lying bouts, and lying time) are presented in Figure 2. In general, sick calves were less active than healthy calves. The change in behavior was already evident on d −10. Step counts, frequency of visits to the feed bunk, and lying bouts were the most affected by health status. Table 1 shows *P*-values for the effect of health status, days of sickness, season, age, and the interaction between health status and days of sickness for all behavioral indexes. During the 20 d around the initial sickness diagnosis, sick calves had fewer steps than healthy calves (1,164 ± 75.6 vs. 1,390 ± 50.6 steps/d, respectively). From d −10 to d +10, the difference observed was either significant (d −10, −7, −5, −2, −1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10) or tended to be significant (d −6 and −4). Sick calves also visited the feed bunk less, by almost 18%, in the days preceding and the day before being diagnosed sick compared with healthy calves. Differences were either significant (d −10, −9, −8, −6, −3, −2, −1, and 0) or tended to be significant (d −7 and −5). After medical treatment, differences in the frequency of visits to the feed bunk decreased, being only a tendency on d 4. Sick calves spent less time at the feed bunk than healthy calves on d −10 (117 ± 15.3 vs. 160 ± 9.8 min/d, respectively) and on d −1 (140 ± 12.9 vs. 180 ± 8.7 min/d, respectively). Differences in lying bouts were significant on d 3, 4, 5, 6, and 8; and tended to differ on d −2, −1, 0, 2, 7, and 9, with sick calves having 15% fewer lying bouts than healthy calves. No difference in lying time was detected between sick and healthy calves, either before or after the sickness was diagnosed, except on d −10, when sick calves spent more time lying than healthy calves (1,077 ± 21.3 vs. 1,012 ± 13.4 min/d, respectively).

Prediction Models

Outcomes of the diagnostic test characteristic resulting from all of the statistical models are summarized in Table 2. Prediction models with AUC >0.70 were found for d −10, −2, and −1. The best predictor model was found for d −1 (Se = 69%; Sp = 72%). This model included season and age at entry as qualifying variables, and steps, lying time, and the frequency of visits to the feed bunk as remaining predictors from the stepwise process. Using the cut-off point chosen from the highest Se and Sp, the model had 72% accuracy, 55% FDR, and 12% FOR. The prediction models for d −2 and d −10 were similar, and both included season and age at entry as qualifying variables, and step count as the only remaining predictor from the stepwise process. The prediction model for d −10 had 67% Se, 67% Sp, 67% accuracy, 60% FDR, and 14% FOR, and the prediction model for d −2 had 72% Se, 67% Sp, 68% accuracy, 58% FDR, and 12% FOR. Table 3 presents the result of the analysis of maximum likelihood estimates for the prediction models of d −10, −2, and −1.

DISCUSSION

The change in behavior of animals in response to sickness is well established (Hart, 1988) and includes reduced activity, decreased feed intake, and lethargy. This change in behavior serves as a survival strategy to direct most of the animal's energy to immune defense mechanisms, and the physiological reactions involved in the development of such changes have been well described (Dantzer and Kelley, 2007). We hypothesize that this change in behavior could be used to predict animals at risk of becoming sick well in advance of the development of clinical symptoms. Because limited data are available on the normal behavior of young calves limit-fed milk replacer in group housing systems, the discussion will address the behavior of healthy calves, the comparison of healthy and sick calves, and the usefulness of prediction models to identify calves at risk of becoming sick.

Normal Behavior

To our knowledge, no studies have specifically measured daily steps in calves of similar age as in the present study. Devant et al. (2012) reported that young bulls (age = 166 ± 0.4 d) had an average of 1,152 steps/d throughout a study, including the castration period, which was lower than the value observed in our study (185 ± 4.24). This lower activity was attributed to the effect of castration in response to pain. Surprisingly, the average number of steps in healthy adult cattle is similar to those reported for the calves herein (1,440 steps/d; Chapinal and Tucker, 2012). Most studies have focused on milk feeding behavior of calves, but only a few have measured feeding behavior in relation to consumption of concentrate in milk-fed calves. The average frequency of visits to the feed bunk reported in our study was similar to those reported for milk consumption visits, where the frequency of visits to the automatic milk-feeding machine in calves ranged from 4 to 10 meals per day (Senn et al., 2000; De Paula Vieira et al., 2010; Wojciech, 2013). However, the comparison is difficult because, in our trial, milk was fed restricted (2× daily), whereas in the other research used for comparison, milk was fed ad libitum. Jezierski (1987) reported that healthy calves at 30 to 60 d of age consumed concentrate feed on average during 150 min/d. Our results agree with their finding, because although the average in the current study was 180 min/d, calves were monitored from d 30 to 90, but if calculated for d 30 to 60, the average in our study was 161 min/d. The lying bouts were similar to those found by Sutherland et al. (2017). The lying time reported herein (16.8 h/d) was similar to that reported by Chmielnik et al. (1988; from 16 to 18 h/d), Chua et al. (2002; 16.8h/d), and Sutherland et al. (2017; from 16.8 to 17.3 h/d). The increase in these activities with age for most of the indexes should be taken into account when designing algorithms to predict the incidence of sickness at any age. Because the paired design used animals of the same age and BW, the model used in the present paper was adequate.

Sick Versus Healthy Calves

Most research on the use of step counts to predict sickness before clinical signs become visible has been conducted in adult dairy cows with lameness, but only a few studies have been conducted in calves. In our study,

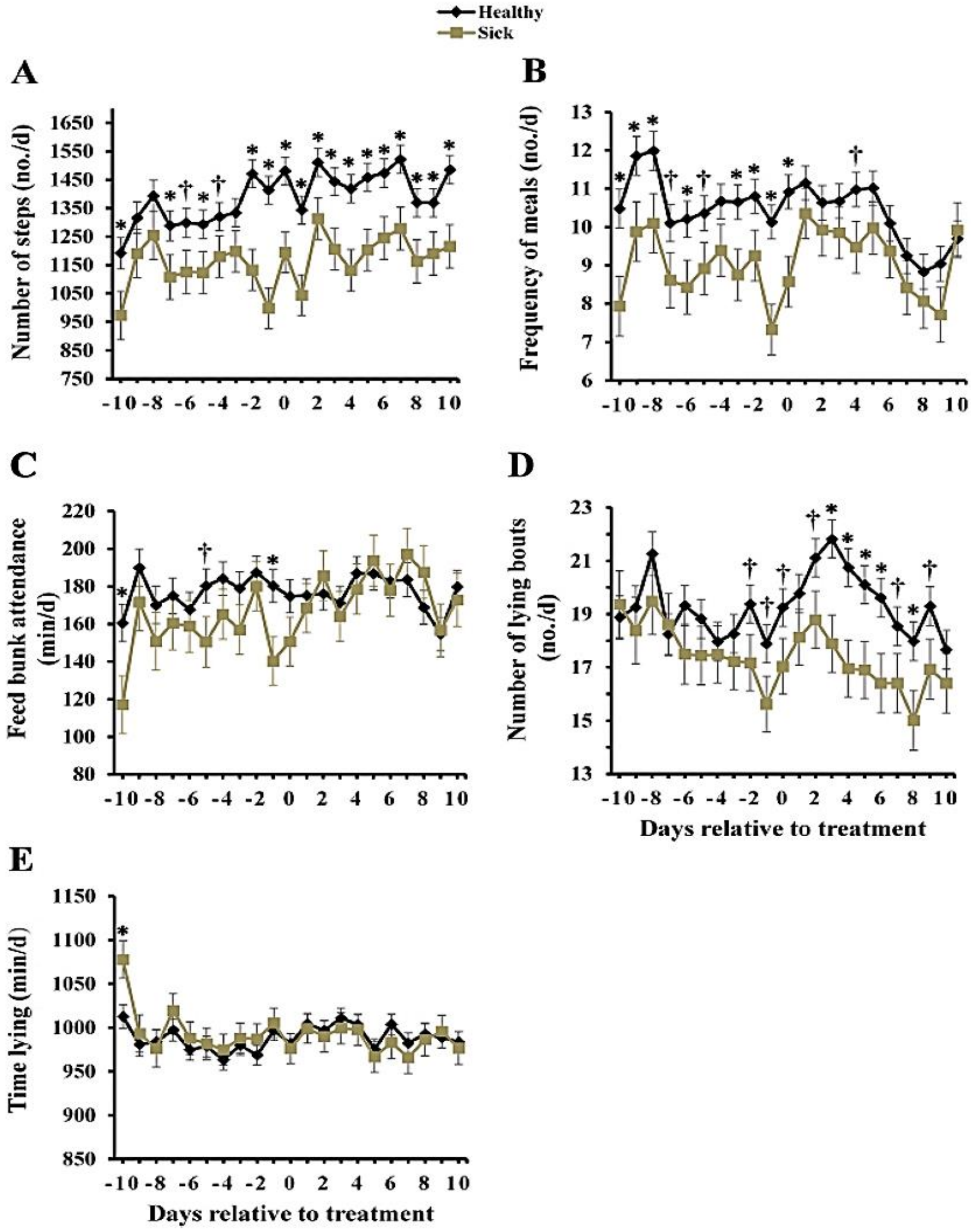

Figure 2. Daily step counts (A; no./d), frequency of visits to the feed bunk (B; no./d), duration of visits at the feed bunk (C; min/d), number of lying bouts (D; no./d), and lying time (E; min/d) for matched pairs of sick bulls (n = 33) vs. healthy bulls (n = 99) from 10 d before to 10 d after the treatment event. The day of sickness diagnosis and initial treatment is d 0. Means within day differ (*$P < 0.05$) or tended to differ († $0.05 < P < 0.10$). Error bars indicate SEM.

sick calves were less active than healthy calves, with an average reduction in step counts of 17%. Swartz et al. (2017) reported that step activity in preweaning calves declined 1 d before clinical signs of respiratory sickness and remained low until 3 d after treatment. Marchesini et al. (2018) reported that activity and rumination in sick beef cattle during the fattening period (367 ± 67 d of age) were lower 3 to 6 d before the onset of clinical

Table 1. The *P*-values for the effect of health status, days before sickness, season, and interaction between health status and days of sickness on the daily steps counts (no./d), frequency of visits to the feed bunk (no./d), duration of visits at the feed bunk (min/d), number of lying bouts (no./d), and lying time (min/d) for matched pairs of sick calves (case; n = 33) versus healthy control calves (case; n = 99)

Item	Step counts	Frequency of visits to the feed bunk	Attendance to feed bunk	Lying bouts	Lying time
Season	<0.05	<0.05	<0.05	<0.05	<0.05
Age	<0.05	0.1	<0.05	0.1	0.9
Days	<0.05	<0.05	<0.05	<0.05	<0.05
Health status	<0.05	<0.05	0.3	<0.05	0.8
Days × health	<0.05	<0.1	<0.05	<0.1	0.6

signs of sickness. Fröhner et al. (2011) reported that locomotion activity was lower in milk-fed sick calves, suggesting that this reduction could be used as an early prediction of sickness. Our results generally agree with these previous findings. A reduction in activity serves a survival strategy to devote most energy to the immune defense mechanisms (Hart, 1988; Dantzer and Kelley, 2007).

Sick calves performed 15% fewer lying bouts 2 d before the onset of the sickness diagnosis compared with healthy calves, and this difference persisted until 9 d after treatment. Similar to our findings, Swartz et al. (2017) observed that preweaning calves diagnosed with respiratory sickness began to decrease their lying bouts 2 d before having any symptom of sickness, and continued until 3 d after treatment. Sutherland et al. (2018) also reported that sick calves tended to have fewer lying bouts 5 d before having clinical signs of neonatal calf diarrhea. However, we observed no difference in lying time between sick and healthy calves except on d −10, when sick calves spent more time lying than healthy calves. In general terms, most research reported no or only small effects of calves' health status on lying time (Swartz et al., 2017). Therefore, there seems to be general agreement that sick calves spend the same time lying but with fewer lying bouts.

Previous studies have predominantly focused on how milk feeding behavior is affected by sickness. To our knowledge, only 2 studies have addressed the effect of sickness on concentrate consumption behavior. Basarab et al. (1996) reported that feeding behavior and total time at the feed bunk were reduced when calves were sick, suggesting that monitoring feeding behavior could be a good method to detect sick calves instead of visual observation. Quimby et al. (2001) also studied behavior of concentrate feeding in newly received calves and reported that it could be used as a criterion to detect morbid animals 4 d before the diagnosis of the disease. The failure to see any change in feeding behavior in sick calves earlier than 4 d before the sickness diagnosis in this earlier study may be related to the fact that calves had restricted access to concentrate. Studies reporting feeding behavior of milk consumption had similar results. Calf had fewer visits and consumed less milk than healthy calves 1 to 4 d before the diagnosis (Borderas et al., 2009; Sutherland et al., 2018). The same results were found by Swartz et al. (2017), studying sick calves with respiratory sickness, where sick calves

Table 2. Outcomes of diagnostic test characteristics resulting from final prediction models from days before the diagnosis of a sick calf

Day[1]	Test characteristic[2]					
	AUC	Accuracy (%)	Se (%)	Sp (%)	FDR (%)	FOR (%)
−10	0.74	66.7	66.7	66.7	60.0	14.3
−9	0.69	65.3	72.2	63.0	60.6	12.8
−8	0.67	59.7	66.7	57.4	65.7	16.2
−7	0.66	65.2	60.9	66.7	62.2	16.4
−6	0.68	63.0	72.0	60.0	62.5	13.5
−5	0.68	64.3	60.7	65.5	63.0	16.7
−4	0.60	53.3	63.3	50.0	70.3	19.6
−3	0.67	61.8	63.3	61.3	65.5	16.2
−2	0.73	68.0	71.9	66.7	58.2	12.3
−1	0.81	71.5	68.8	72.4	55.1	12.3

[1]Day relative to the sick calf diagnosis.

[2]AUC = area under the curve; Se = sensitivity; Sp = specificity; FDR = false discovery rate; and FOR = false omission rate.

Table 3. The analysis of maximum likelihood estimates for the prediction models on d −10, −2, and −1

Parameter	Estimate	SEM	*P*-value
Day −10			
Intercept	0.3320	1.7708	>0.10
Season	0.1826	0.3760	>0.10
Age at entry	0.0254	0.0420	>0.10
Step counts	−0.0023	0.0009	<0.05
Day −2			
Intercept	1.0446	1.2751	>0.10
Season	0.2313	0.2628	>0.10
Age	0.0202	0.0269	>0.10
Step counts	−0.0026	0.00066	<0.05
Day −1			
Intercept	11.1638	3.9319	<0.05
Season	0.2298	0.3013	>0.10
Age	0.0389	0.0310	>0.10
Step counts	−0.0023	0.0007	<0.05
Frequency of visits to the feed bunk	−0.3836	0.1242	<0.05
Lying time	−0.0079	0.0030	<0.05

consumed less milk than healthy calves on the day of sickness. Knauer et al. (2017) reported that preweaning sick calves 10 d before the sickness diagnosis had fewer visits than healthy calves, and this difference persisted until 10 d after treatment. Our results support those suggesting that feeding behavior could be a good early predictor of health disorders in calves. However, our observations indicate that calves at risk of becoming sick could be identified 10 d before the diagnosis compared with up to 5 d in the earlier studies. This discrepancy is likely related to the number of days before the sickness diagnosis that calves were monitored compared with previous studies (<5 d in most cases; Borderas et al., 2009; Swartz et al., 2017; Sutherland et al., 2018), whereas we analyzed data from d −10. In fact, because most previous research monitored behavior for 4 to 5 d before the diagnosis of the sick calf, we decided to extend the observation time 10 d before the diagnosis. However, differences in the number of steps and frequency and time at the feed bunk were already different from those of healthy animals at d −10 (Figure 2), suggesting that the observation time should be extended further.

Prediction Models

We examined whether it would be possible to identify sick calves before symptoms of sickness appeared through prediction models based on behavior indexes. The early detection of sick calves would allow the timely administration of proper treatment to only calves at risk, leading to a faster recovery, reduced production losses, and reduced use of antibiotics (Thompson et al., 2006; Duff and Galyean, 2007). It is worth mentioning that the diagnosis based on observation criteria was consistent with the day of a large and multi-criteria change in behavior, including reductions in the number of steps and lying bouts and in the number of visits and time at the feed bunk (Figure 2). The best prediction models were found for d −10, −2, and −1. Although the prediction model on d −1 had the highest AUC, prediction on d −10 (with AUC of 74%) may be a better option because this would allow enough time to take advantage of early treatment. The application of the prediction model at d −10 resulted in 67% accuracy, 67% Se, 67% Sp, 60% FDR, and 14% FOR. This FDR means that 60% of calves diagnosed as being sick by the prediction model would receive treatment unnecessarily. However, the system may alert farm staff to check animals as they may be at risk of becoming sick and need individual attention. Also, the system will allow identification of a large group of calves at no risk of becoming sick and, therefore, relieved from any preventive treatment. In contrast, the FOR would result in 14% of calves being undiagnosed; therefore, periodic surveillance of all animals would still be needed to catch sick calves not identified by the system. These predictions at d −10 were obtained using only step counts as the variable, suggesting that many simple pedometers measuring only activity may be suitable and cheaper options for young calves. More research in this field is required to investigate whether other behavior indexes may improve the accuracy of predictions.

To our knowledge, very few studies have determined the effectiveness of automated devices to detect sick calves before clinical symptoms of disease. Most studies have predicted sickness by comparing behavior with baseline values of the same animal before becoming sick (Quimby et al., 2001; Cornou et al., 2008; Marchesini et al., 2018; Knauer et al., 2018). Marchesini et al. (2018) used a 9% reduction in rumination as criterion for the early detection of bovine respiratory sickness in calves

6 d before treatment and reported a higher Se (81%) and Sp (95%). However, the method requires at least 9 d before the onset of clinical sickness to establish the normal behavior of healthy calves in order to recognize changes caused by sickness. This lag time can affect the ability of the method to detect sick calves at arrival, where a high incidence of sickness is common. In contrast, the matched pair method we used could predict sick calves from the beginning without the need to establish a baseline normal behavior in each animal. Furthermore, detecting sickness based on a comparison of what happens today compared with yesterday can have a dramatic effect due to autocorrelation between days. If the changes in daily average of behavioral measures in individual calves from healthy day to a sick day are not large enough to activate a health alarm, the prediction will fail to identify sick calves and lead to a high FOR (Hawkins and Olwell, 1998). Knauer et al. (2018) used feeding behavior with this methodology to predict sick calves and reported that the feeding behavior of preweaning calves did not yield sufficient Se (74.9%) and Sp (27.1%). The comparison of our results with those previous studies is difficult for many reasons, primarily the analytical method. In our study, sick calves were compared with healthy calves using the matched pair method, whereas, in most other studies, sick calves were compared with their own baseline behavior. Moreover, the age of calves among studies were different, making comparisons more difficult because behavior changes with age.

CONCLUSIONS

Sick calves modified their behavior by reducing the number of steps and lying bouts and the frequency and duration of visits at the feed bunk. Our prediction model was able to identify a sick calf at least 10 d before it was diagnosed by farm personnel. However, under the conditions of this methodology, the false discovery and omission rates were relatively high, and the model may require further refinement to improve the accuracy and precision of the method.

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The Use of an Activity Monitoring System for the Early Detection of Health Disorders in Young Bulls

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animals

Article

The Use of an Activity Monitoring System for the Early Detection of Health Disorders in Young Bulls

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Simple Summary: In large intensive beef production systems, the identification of sick animals is difficult. We hypothesized that sick bulls would change daily activities when sick. Thus, the use of activity monitoring devices might allow for the early identification of sick bulls. The device used measured steps counts, lying time, lying bouts, and frequency and time at the feed bunk. Sick bulls started to behave differently from healthy bulls at least 10 days before the appearance of clinical signs. The prediction model identified bulls at risk of becoming sick 9 days before the visual diagnostic based on the time attending to the feed bunk, the time lying, and the frequency of lying bouts. The validation indicated that the prediction resulted in 50% false positives and 7% false negatives. Activity monitoring systems may be useful tools to identify bulls at risk of becoming sick.

Abstract: Bulls (n = 770, average age = 127 days, SD = 53 days of age) were fitted with an activity monitoring device for three months to study if behavior could be used for early detection of diseases. The device measured the number of steps, lying time, lying bouts, and frequency and time of attendance at the feed bunk. All healthy bulls (n = 699) throughout the trial were used to describe the normal behavior. A match-pair test was used to assign healthy bulls for the comparison *vs.* sick bulls. The model was developed with 70% of the data, and the remaining 30% was used for the validation. Healthy bulls did 2422 ± 128 steps/day, had 28 ± 1 lying bouts/day, spent 889 ± 12 min/day lying, and attended the feed bunk 8 ± 0.2 times/d for a total of 95 ± 8 min/day. From the total of bulls enrolled in the study, 71 (9.2%) were diagnosed sick. Their activities changed at least 10 days before the clinical signs of disease. Bulls at risk of becoming sick were predicted 9 days before clinical signs with a sensitivity and specificity of 79% and 81%, respectively. The validation of the model resulted in a sensitivity, specificity, and accuracy of 92%, 42%, and 82 %, respectively, and a 50% false positive and 12.5% false negative rates. Results suggest that activity-monitoring systems may be useful in the early identification of sick bulls. However, the high false positive rate may require further refinement.

Keywords: beef cattle; activity monitoring; behavior; diseases

1. Introduction

Mortality and morbidity at arrival are common in beef production systems [1]. Owners and managers of cattle feedlots are constantly seeking management practices to reduce their incidence to improve profitability. Antibiotics are frequently used in this period to prevent diseases [2]. However, the use of antibiotics in animal production has the potential to increase antimicrobial resistance in humans [3,4]. Therefore, there is an urgent need to develop strategies to reduce the use of antibiotics without compromising health, production, or animal welfare [5].

The early identification of sick animals may allow for an early and targeted therapy and, eventually, decrease antibiotic use [6]. However, in large intensive feedlot operations, the early identification of bulls with health problems by farm personnel is difficult if it is based only on observations.

Recently, a variety of automatic activity monitoring devices have been developed and can assist farm personnel in the early detection of diseases [7,8]. Feeding behavior has been identified as a major behavioral change when young cattle get sick, and because changes occur 4 to 6 days before the diagnostic by farm personnel, it can be used for the early detection of diseases [9–11]. Most of this research focused only on feeding behavior, but other activities were not recorded. We hypothesized that the use of feeding behavior, together with other activities, would improve the ability of monitoring systems to identify animals at risk of becoming sick earlier. Therefore, the objective of this study was to determine if the feeding behavior, together with steps counts, lying time, and lying bouts, could be useful in the early identification of newly received bulls at risk of becoming sick.

2. Materials and Methods

2.1. Animals, Housing, and Management

Crossbred bulls (n = 770; average age = 127 days; standard deviation = 53 days of age) originating from auction markets in northern Spain (National Cattle Market, Torrelavega) were supplied to the receiving facility and monitored during the first three months after their arrival. The experiment was conducted from July 2016 to March 2018. There were four groups of bulls that arrived at the farm in July (n = 33), March (n = 212), June (n = 252), and October (n = 273). All groups were managed in an all-out all-in program between groups. On the day of arrival, bulls were vaccinated against Pasteurella and pneumonia (Neo-bacterina®, Syva, Ciudad Real, Spain) and were treated with an internal and external anti-parasitic treatment (Paramectin®, Syva, Ciudad Real, Spain). Seven days after the first vaccine, all bulls were revaccinated. Bulls were housed in a dirt floor open-air facility with an average space of 7 m^2/bull, and had continuous access to water and dry food. The concentrate (14% crude protein, 4% fat) was offered in a 6 m long feed bunk, straw in a separate 15 m long feed bunk, and water was provided through an automatic waterer. Bulls were monitored in the lots for 12 ± 2 weeks.

2.2. Data Collection

At arrival, bulls were immediately weighed and fitted in the front right leg with an activity monitoring device (Fedometer [FEDO] system; ENGS, Rosh Pina, Israel). The device consists of an accelerometer that measured daily steps counts (n/day), lying bouts (n/day), and lying time (min/day). An electromagnetic field-generating antenna was located along the feed bunk to detect bulls which front leg was less than 30 ± 2 cm from the feed bunk to allow the calculation of the number of visits (n/day) and its duration (min/day) at the feed bunk. Data collected was transmitted wirelessly every 6 min to a computer with a system-specific software (Eco-herd-software; ENGS, Israel). The system has been described in detail and validated for feedlot cattle [12]. Bulls ID, birth date, body weight, and group entry date were recorded for each animal. Bulls were observed daily by experienced farm personnel for clinical signs following a checklist of criteria including appetite, fecal consistency, respiratory efforts, hydration status, and general attitude. All criteria were scored as normal (0), mild (1), or severe (2). A bull was diagnosed with a respiratory disease when observed with a fast or difficult breathing, coughing, nasal mucus, or ocular discharge; with digestive problems when they had signs of diarrhea (feces with a loose to watery consistency and strong odor), presence of loose fecal matter on the top of the tail or legs, and/or dehydration; and with locomotion problems if they had difficulties in walking. When one severe or two mild criteria were observed, rectal temperature was measured, and, if > 39.7 °C, the disease was confirmed. Diagnostic and treatments were conducted under the attending veterinarian supervision within 12 h of the identification of the sick animal.

Antibiotics were used to treat respiratory problems, and the rest were treated with a combination of antibiotics and anti-inflammatory drugs for at least three consecutive days. The date, the time of treatment, and the treated diseases were recorded for each morbidity event. The system was checked periodically for proper functioning.

2.3. Statistical Analyses

All statistical analyses were performed with SAS (v.9.4; SAS Institute Inc., Cary, NC, USA). For the normal behavior, only bulls that had no treatment during all the study were used. A descriptive analysis was conducted for the entire period, and univariate analysis (ANOVA) was performed to identify differences by age for each behavioral index. Significance was declared at $p < 0.05$ and trends reported at $0.05 \leq p < 0.10$.

A matched pair design was used to assign bulls to the healthy group for comparisons. For each sick bull, we identified three healthy bulls that were on the same date, the same group, and similar age (±4 d) and weight at entry (±17 kg). For sick bulls that were treated multiple times, only the first treatment event was considered. Day 0 was defined as the day of sickness diagnosis, and the database contained records from day −10 to day +10. Once the database was generated, a multivariate linear mixed model was built to describe differences for each behavioral index between sick and healthy bulls. The model included bulls health status (healthy, sick), season (summer, autumn, winter, and spring), age at entry, days around the treatment event (from −10 to +10), and the interaction between days and health status as fixed effects. The animal was considered a random effect. When an interaction was significant, the SLICE option of SAS was used to evaluate these differences.

For the development and validation of the model, 70% of the original dataset was used to develop the prediction model, and the remaining 30% was used to measure the performance of the model. To build the prediction model, multivariate logistic regression was performed on the days before the first treatment event to identify variables that were associated with health status. This model included the fixed effects of age at entry, season, and all behavior indexes. Age at entry was included in all prediction models. All predictors with a $p < 0.20$ were initially included in the model. The backward stepwise procedure was used to exclude variables from the regression model until all predictors remaining were significant. For each model, the sensitivity (Se) and the specificity (Sp) were calculated for each possible cutoff point, as described by Dohoo et al. [13]. The cutoff point that yielded the highest combination of Se and Sp was selected, and the model score was defined. Diagnostic test characteristics included the false positive rate (FPR), the false negative rate (FNR), and accuracy [13]. The Se was defined as the proportion of sick bulls that were correctly diagnosed. The Sp was defined as the proportion of healthy bulls that were correctly diagnosed. The FPR was defined as the proportion of calves that were diagnosed incorrectly sick. The FNR was defined as the proportion of calves that were diagnosed incorrectly healthy. Once all prediction models were generated on the days before the first treatment event, the one with the highest area under the curve (AUC) was chosen to evaluate its performance in the validation dataset (30% remaining from the original database). The model was applied on the same day as the validation dataset to obtain the FPR and FNR.

3. Results

3.1. Normal Behavior

Only bulls that had no treatment during all the study were used to describe the normal behavior (n = 699; Figure 1). Bulls age ranged from 127 to 217 days, did an average of 2422 ± 128 steps/day, had 28 ± 1 lying bouts/day, spent 889 ± 12 min/day lying, and attended the feed bunk 8 ± 0.2 times/day for a total of 95 ± 8.2 min/day. Age was significant in all behavior indexes ($p < 0.05$) except in the frequency of meals where no differences were observed ($p > 0.10$). Bulls daily average in step counts and lying bouts (Figure 1A,D) increased ($p < 0.05$), and attendance to the feed bunk and lying time (Figure 1C,E) decreased, with age ($p < 0.05$).

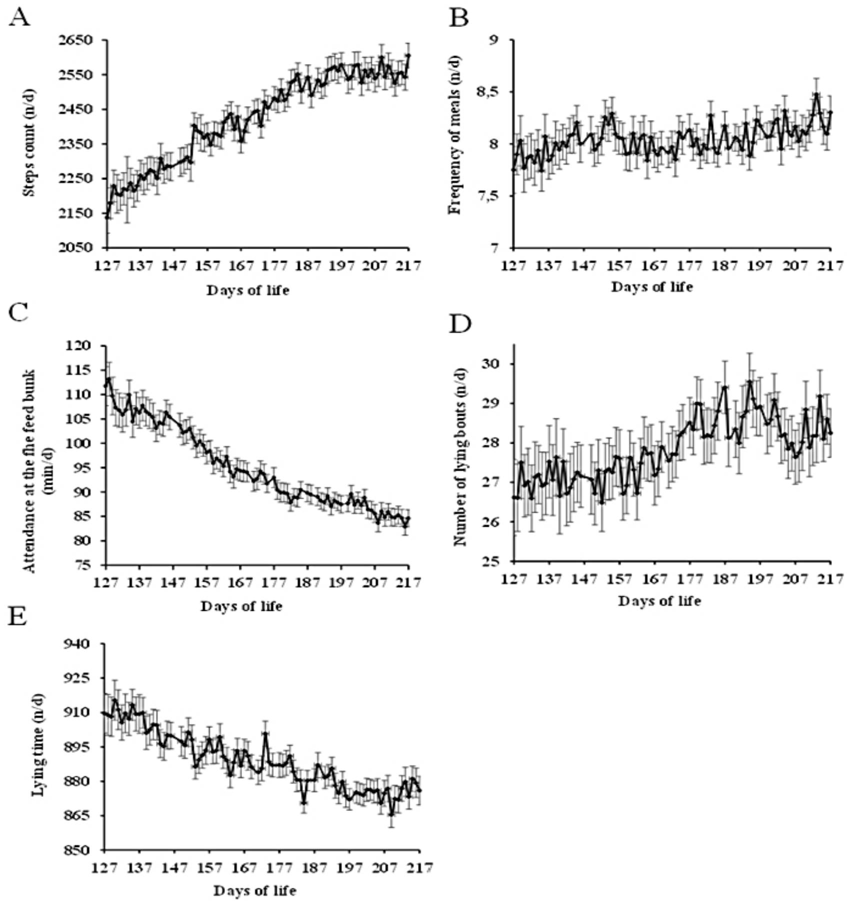

Figure 1. Daily steps counts n/day (**A**), frequency of meals n/day (**B**), attendance at the feed bunk min/day (**C**), number of lying bouts n/day (**D**) and lying time min/day (**E**) in healthy bulls from 127 to 217 days of life.

3.2. Differences in Behavior Between Healthy vs. Sick Bulls

Of the total of 770 bulls enrolled in the study, 71 had at least one episode of sickness, which represents an overall incidence of 9.2%. The mortality rate during this experiment was 1.2% of enrolled bulls. Figure 2 shows the comparison between sick and healthy bulls (n = 71 *vs.* 213, respectively) in all behavior measurements from 10 days before to 10 days after the first treatment event. All behavior indexes were affected by bull's health status.

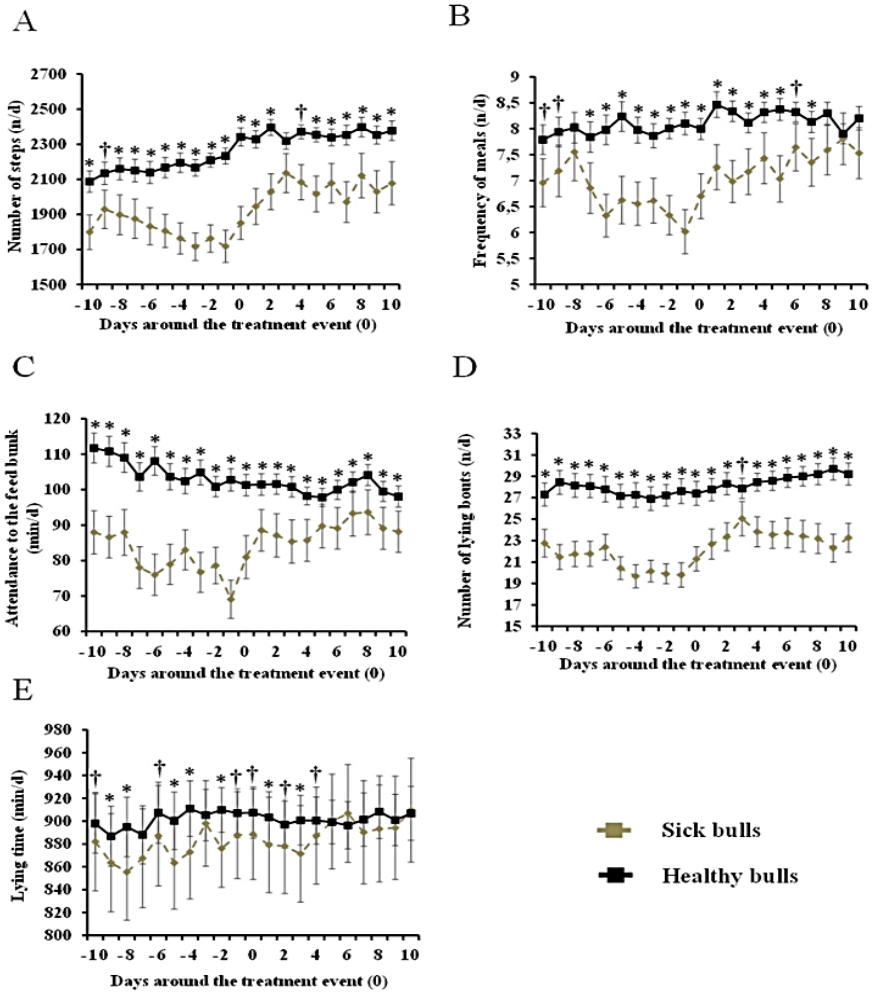

Figure 2. Daily steps counts n/day (**A**), frequency of meals at the feed bunk n/day (**B**), attendance at the feed bunk min/day (**C**), number of lying bouts n/day (**D**), and time lying min/day (**E**) for of sick bulls (n = 33) *vs.* matched paired healthy bulls (n = 99) from 10 days before to 10 days after the first treatment event. Means within day differ (*; $p < 0.05$) or tended to differ (†; $0.05 < p < 0.10$).

Differences between healthy and sick bulls started to be evident from at least 10 day before the first treatment event took place. Sick bulls did in average 15% fewer steps (days: −10, −8, −7, −6, −5, −4, −3, −2, −1, 0, +1, +2, +5, +6, +7, +8, +9, and +10; $p < 0.05$; −9 and 4; $p < 0.10$), 22% less lying bouts (from days −10 to +10 except for day +3; $p < 0.05$; day +3; $p < 0.10$), and spent less time lying (days: −9, −8, −5, −4, −2, +1, and +3; $p < 0.05$; −10, −6, −1, 0, +2, and +4; $p < 0.10$) compared with healthy bulls. Bulls attended the feed bunk 15% fewer times (days: −7, −6, −5, −4, −3, −2, −1, 0, +1, +2, +3, +4, +5, and +7; $p < 0.05$; −10, −9 and +6; $p < 0.10$), and spent 18% less time at the feed bunk (days: from −10 to +10; $p < 0.05$) than healthy bulls. Table 1 provides the probability level for the effect of health status, days of sickness, season, age, and the interaction between health status and days of sickness on all behavioral indexes.

Table 1. The probability level for the effect of health status, days before sickness, season, and the interaction between health status and days of sickness on the daily steps counts (n/day), frequency of meals at the feed bunk (n/day), attendance at the feed bunk (min/day), number of lying bouts (n/day), and lying time (min/day) for sick bulls (n = 71) *vs.* matched paired healthy control bulls (n = 213).

Predictive Variables	Steps Counts	Frequency of Meals	Attendance to the Feed Bunk	Lying Bouts	Lying Time
	p-Value	*p*-Value	*p*-Value	*p*-Value	*p*-Value
Season	<0.05	<0.10	0.12	>0.05	<0.05
Age	<0.05	<0.05	<0.05	>0.05	>0.05
Days	<0.05	<0.05	<0.05	<0.05	<0.05
Health status	<0.05	<0.05	<0.05	<0.05	<0.05
Days × health status	>0.05	>0.05	<0.05	<0.10	>0.05

3.3. Predictive Models and Validation

The match-pair design is a useful tool to assign healthy bulls to control for environmental and site-specific factors affecting behavior [14]. All prediction models for the days before the first treatment event had an AUC > 0.75. Table 2 shows the outcomes of the diagnostic test characteristic resulting from all the prediction models of the training database from the days before the diagnostic of sick bulls. The best model with the highest AUC value (0.88) was found for day −9. This model at the cut-off point chosen from the highest combination of Se (79%) and Sp (81%) had 81%, 47%, and 6% accuracy, FPR, and FNR, respectively. The predictive model of day −9 included attendance at the feed bunk, lying bouts, and lying time as behavior indexes remaining significant after the backward stepwise procedure. The predictive logistic regression model obtained on day −9 was used in the validation dataset to measure its performance and resulted in a sensitivity, specificity, and accuracy of 92%, 42%, and 82 %, respectively. The FPR and FNR were 50% and 12.5%, respectively. Table 3 summarizes the result of the analysis of maximum likelihood estimates for the parameters of the model for day −9.

Table 2. Outcomes of the diagnostic test characteristic resulting from the prediction models of the training database from days before the treatment event of sick bulls.

Days [1]	AUC [2]	Accuracy, %	Se [3], %	Sp [4], %	FPR [5], %	FNR [6], %
−10	0.86	80	84	78	42	7
−9	0.88	81	79	81	47	6
−8	0.79	75	72	76	57	9
−7	0.81	71	74	71	61	9
−6	0.83	70	80	67	62	7
−5	0.80	66	69	66	66	11
−4	0.76	70	69	71	63	10
−3	0.86	79	82	78	50	6
−2	0.87	76	83	75	55	6
−1	0.84	75	76	75	56	8

[1] Days before the sick bull diagnostic. [2] Area under the curve. [3] Sensitivity. [4] Specificity. [5] False positive rate. [6] False negative rate.

Table 3. The analysis of maximum likelihood estimates for the parameters of the prediction model for d −9.

Parameter	Estimate	Standard Error	p-Value
Intercept	8.512	3.1704	< 0.05
Age at entry, days	0.017	0.0090	> 0.05
Attendance to the feed bunk, min/day	−0.036	0.0112	< 0.05
Lying bouts, n/day	−0.127	0.0429	< 0.05
Lying time, min/day	−0.006	0.0030	< 0.05

4. Discussion

4.1. Normal Behavior

One of the objectives of the present study was to describe the bull's normal daily behavior. A good understanding of bull's normal behavior is necessary to establish references from which we can distinguish bulls at risk of becoming sick. There are few reports where all activities have been measured and reported at the same time. Most previous studies have monitored only some activities separately and will serve as reference for the discussion of the normal behavior of healthy bulls. In general, the results reported herein agree with previous reports. For example, bulls in our study did, on average, 2422 ± 128 steps/day, and agree with results reported by Devant et al. [15] for healthy bulls before castration (2544 ± 120 steps/day). Pillen et al. [16] observed a lower value of daily steps (1472 steps/day). However, the value was the average of bulls and steers, and considering that steers have 56% lower activity compared with bulls [15], the estimated value for bulls was close to 2000 steps/day. The lying bouts have not been as well studied as the rest of behavioral indexes. We found only three studies reporting results that varied widely. In our study, bulls did, on average, 27.8 ± 0.76 lying bouts/day. Rouha-Muelleder et al. [17] reported a wide variation of lying bouts in bulls depending on the type of flooring and ranged from 9.1 to 28.3 lying bouts/day. In contrast, Pillen et al. [16] and Ball et al. [18] reported that bulls did, on average, from 11.4 to 15 bouts/day. Regarding total lying time, bulls in our study spent 889 ± 13 min/day lying and agrees with other reports where healthy bulls spent almost 60% of their daily time lying [19–21]. For feeding behavior, most previous reports also support our findings. Bulls in our study attended the feed bunk 8 ± 0.15 times/day and for a total of 95 ± 8 min/d. Similar studies also found that bulls attended the feed bunk 7.8 to 10.5 times [22] and 97 min/day [19]. While we monitored the attendance at only the concentrate feed bunk, other reports monitored access to the concentrate and straw feed bunk together. However, because the diets offered in all studies cited previously were composed of almost 90% concentrate, the comparison was considered valid.

4.2. Differences in Behavior Between Healthy vs. Sick Bulls

To our knowledge, the present research is the first study that compared five different daily activities at the same time from days −10 to +10 relative to the diagnostic of the disease between sick and healthy bulls. Most studies focused predominantly on feeding behavior, but not on other activities, for the early prediction of diseases in bulls [9,10,22].

Activity and behavior have been long considered indicators of pain and illness [23]. Sick bulls react to the illness reducing their activity, and they could be easily distinguished from healthy bulls. Hanzlicek et al. [24] reported that sick heifers reduced steps counts after inoculation with *Mannheimia haemolytica*. Similarly, White et al. [25] inoculated calves with *Mycoplasma bovis* and observed that steps counts were negatively associated with the appearance of clinical signs of the diseases. In our study, the difference between healthy and sick bulls in steps counts was already evident 10 days before the first treatment event took place. Marchesini et al. [11] observed that bulls suffering from bovine respiratory syndrome (BRD) had lower activity and rumination 3 to 6 days before the onset of visible signs of the diseases. Similarly, Pillen et al. [16] in newly received feedlot cattle reported that calves had a lower activity 6 days before BRD diagnosis, and this reduction was more pronounced the day before the diagnosis. Therefore, activity may be useful as an early predictor of health disorders.

For most of the activities monitored, the largest difference compared with healthy bulls occurred the day when farm personnel identified the animal as potentially sick (Figure 2). This provides evidence of the reliability of the protocol followed by farm personnel in identifying sick bulls. Sick bulls herein had lower lying bouts from day −10 until day +10 relative to the first treatment. Swartz et al. [14] observed that lying bouts in young calves suffering from BRD began to decrease 2 days before having any sign of sickness, and continued until 3 days after treatment. Pillen et al. [16] also found that lying bouts of sick bulls decreased from 14.5 to 11.4 compared with healthy bulls. Sutherland et al. [26] observed that the number of lying bouts in sick calves with neonatal diarrhea tended to decrease 5 days before the clinical diagnostic of the disease. These previous results are in agreement with our results, demonstrating that the lying bouts are affected before and after the first treatment event. Sick bulls spent less time lying than healthy bulls, and this reduction was more pronounced before the appearance of clinical signs of sickness than after. There is no general agreement on the effect of sickness on lying time in bulls. Sutherland et al. [26] reported that calves before having neonatal diarrheas spent more time lying 2 days before clinical signs but less time lying the day of the diseases appearance. In contrast, Theurer et al. [27] observed an increase in lying time on calves after inoculation with *Mannheimia haemolytica* compared with before infection. In spite of the lack of agreement in the literature on the effect of diseases on lying time, in our study, lying bouts and lying time remained in the prediction model after a backward stepwise selection of variables, as discussed later. Our results also demonstrate that feeding behavior was affected before and after the disease diagnostic, where the frequency of attendance and the total time spent at the feed bunk was reduced in sick bulls. Several studies agree with our findings. For example, Sowel et al. [28] found that healthy steers spent 30% more time at the feed bunk compared with morbid steers. Sowel et al. [22] also reported in a follow-up study that sick steers attended the feed bunk less frequently than healthy steers. Buhman et al. [29] observed that the frequency and the time of attendance at the feed bunk were lower in sick calves compared with healthy calves. Quimby et al. [9] found that the feeding behavior was able to identify sick animals 4.1 days earlier than the diagnosis by the farm personnel. Wolfger et al. [10] reported that steers with BRD had a lower daily frequency of meals (12 *vs.* 9.7) and shorter time (9.7 *vs.* 7.6 min) per meal 7 days before feedlot staff noticed any clinical sign.

Overall, sick bulls showed changes in daily activities already at 10 days before the diagnostic of the disease. We monitored bulls behavior from 10 days before the sickness based on previous studies that observed changes in behavior 2 to 6 days before the observation of clinical signs [9,11,14,16,26]. However, results suggest that these changes may start occurring even earlier, and future studies should monitor activities for periods longer than 10 days.

4.3. Predictive Models and Validation

To our knowledge, our study is the first to develop a model to predict diseases in bulls with a formal validation using an independent dataset. Because we considered it important to select the earliest date for an early treatment, the analysis was conducted on individual days. According to our results, the prediction model developed using the training database on day −9 had a Se and an Sp of 79% and 81%, respectively. The Se and the Sp were similar to the results found in previous studies predicting different diseases. For example, Marchesini et al. [11] reported that Se and Sp of the prediction model from days 1 to 3 before the clinical diagnostic for the BRD and lameness in beef cattle were 81% and 95%, respectively. Quimby et al. [9] used feeding behavior to predict BRD in newly received calves and found a Se of 78% and an Sp of 79% of the model at day 6 before the visual detection of the diseases. Wolfger et al. [10] also used feeding behavior to predict BRD and reported a Se of 82% and a Sp of 78% on day 5 before the observation of clinical signs. The prediction model included time of attendance to the feed bunk, lying bouts, and lying time as behavioral predictors.

Surprisingly, measures of activity (step counts), in spite of the clear differences between healthy and sick bulls (Figure 2), did not provide additional information to the model.

The application of the prediction model at day −9 in the independent dataset (validation data) resulted in an acceptable overall accuracy (82%). However, the low specificity (42%) resulted in a high FPR (50%). The FPR represents the percentage of animals that would be treated without any need. However, the high FPR should be interpreted in the context of current preventive practices. In many farms, preventive treatments are conducted in all animals upon arrival. In the current experiment, the incidence of diseases was around 10%. A 50% FPR implies that twice as many animals (20%) would be treated. However, when preventive treatments are commonly provided to all animals [1], the strategy proposed will reduce by 80% the unnecessary preventive treatment and, therefore, will reduce the use of antibiotics. Furthermore, early detection may also improve the effectiveness of treatments and the consequences of the disease, reducing the use of antibiotics and the negative economic impact of the disease, and improving the wellbeing of bulls. On the other hand, the FNR (12.5%), that represents the percentage of animals that would not be treated when they actually need treatment, while acceptable, implies that periodic surveillance of animals to catch those that are not identified by the prediction model is still required.

5. Conclusions

Activity monitoring devices may be useful tools for the early identification of bulls at risk of becoming sick. The most reliable prediction model was able to identify these bulls 9 days before the visual detection of clinical signs by farm personnel. However, the high FPR found could affect the reliability of this prediction, which deserves further refinement.

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Chapter IV

Annex (Transition Cows)

INTERPRETATIVE SUMMARY:

Behavior changes in dry Holstein cows at risk for periparturient health disorders. Belaid. We examined if the prepartum behavior of cows was affected by the occurrence of postpartum diseases. From a total of 456 cows enrolled in the experiment, 115 (25%) were diagnosed with one or more postpartum disorders. The comparison of healthy against sick cows showed differences in prepartum behavior, but differences were clearer when only one health disorder was considered. A prediction model was developed for metritis. This model had a sensitivity of 73% and specificity 86% and may be useful for the early diagnostic of cows at risk of metritis.

RUNNING TITLE: PREPARTUM BEHAVIOR OF POSTPARTUM SICK COWS

Behavior Changes in Dry Holstein Cow at Risk of Periparturient Diseases.

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ABSTRACT

The objective of this study was to determine if prepartum behavior can be an early predictor of postpartum diseases in cows. Holstein dry cows (n = 456) were monitored with accelerometers from d –21 to the day of calving (d 0). Accelerometers measured steps counts, daily attendance at the feed bunk, frequency of meals, number of lying bouts and lying time. Cows postpartum health status was monitored daily from 0 to 30 DIM and all incidences of diseases and treatments were recorded. For normal behavior in the prepartum period, univariate analysis (ANOVA) was performed. To compare sick and healthy cows, a multivariate linear mixed model was built from d –21 to the day of calving (d 0) in order to describe differences for each behavioral index between sick and healthy cows. A multivariate logistic regression model was developed to predict metritis using prepartum behavioral indexes. On average, over the entire prepartum period, healthy cows (n = 341) did 1,627 ± 56 steps, spent 184 ± 10.6 min at the feed bunk, did 8.5 ± 0.3 meals, did 10 ± 0.5 lying bouts and spent 743 ± 18.4 min lying per day. Sick cows (n = 115) did 1,644 ± 89 steps, spent 183 ± 10 min at the feed bunk, did 8 ± 0.4 meals, did 11 ± 0.6 lying bouts and spent 740 ± 40 min lying per day. Differences in behavior between sick and healthy cows were more pronounced when considering specific postpartum disease separately. When compared with healthy cows, cows with metritis did more steps (+4%), more lying bouts (+12%) and attended more to the feed bunk (+8%); cows with mastitis did fewer steps (–5%), less frequent meals (–6%) and attended more to the feed bunk (+10%); cows with retained placenta did less frequent meals (–7%) and more lying bouts (+4%); cows with displaced abomasum did less frequency of meals (–20%) and spent less time at the feed bunk (–20%); and cows with ketosis did less meals (–16%) and spent less time at the feed bunk (–31%). A prediction model was developed for cows with metritis. The prediction model with the best outcomes was found when combining all prepartum days. This model included lactation number, attendance at the feed bunk at d –10, –7 and –2, steps counts at d –2, lying bouts at d –9 and lying time at d –9, –4 and –2. Using the cut point chosen from the highest sensitivity (73%) and specificity (86%), this model had 83.7% accuracy, 48.4% false discovery rate and 6.1% false omission rate. Results indicate that the occurrence of metritis can be predicted in advance and preventive treatment can be applied only to animals at risk.

Keywords: behavior, diseases prediction, accelerometers, metritis.

INTRODUCTION

The transition from late gestation to early lactation is the most critical period in the lactation cycle of dairy cows. During this period dairy cows are exposed to multiple stressors which can lead to a high susceptibility to postpartum disorders (Grummer, 1995; Mulligan and Doherty, 2008). During the first 3 week after calving, 50% to 75% of cows have at least one disorder event (Ferguson, 2001; LeBlanc et al., 2006). Economic and welfare implications of postpartum disorders in dairy cows are of high relevance (von Keyserlingk et al., 2009). Reducing postpartum incidence can enhance the profitability of dairy herds and cows welfare through the reduction of its negative impact on production efficiency, treatment cost and the duration and severity of cows pain (Gröhn et al., 2003; Yildiz, 2018). Therefore, the prevention of postpartum diseases is important to ensure animal welfare and farm profitability.

Farmers often use health control protocols with subjective criteria to identify sick cows. Hence, a large proportion of cows at risk of postpartum disorders can easily escape diagnosis (Heuwieser et al., 2010; Espadamala et al., 2016). Moreover, the intensification of the production systems in many dairy farms has resulted in a decrease in the interaction between humans and animals, making the identification of sick cows even more complicated.

The use of technologies to continuously monitor animal activity could provide an alternative to the subjective observation for the assessment of health status of transition cows (Proudfoot et al., 2012; Weary et al., 2009). Cows subsequently diagnosed with postpartum metritis spent less time feeding and consumed less feed compared with healthy cows beginning 2 weeks before the observation of clinical signs of infection (Huzzey et al., 2007). Cows with ketosis postpartum spent and frequented less the feed bunk the week before calving, compared with their healthy counterparts (Goldhawk et al., 2009). Cows subsequently diagnosed with subclinical hypocalcemia had higher DMI during weeks –2 and –1 before calving than the healthy control cows (Jawor et al., 2012). Cows with metabolic and digestive disorders at the early postpartum period had less activity and rumination time compared with their healthy counterparts (Stangaferro et al., 2016a). These findings provide evidence that monitoring transition cows behavior can be useful to detect cows at risk of postpartum health disorders. Such an early warning system could reduce the time needed to diagnose postpartum diseases and, thus, could allow the implementation of a preventive targeted therapy to cows at risk.

We hypothesized that prepartum behavior is a useful predictor of postpartum health disorders. The aim of the current study was (1) to see if there are differences in the prepartum behavior of subsequently healthy or sick cows during the first 30 days following calving; and (2) to develop prediction models able to anticipate their occurrences.

MATERIAL AND METHODS

Housing, Management, and Diets

The present study was conducted in a commercial Holstein dairy farm located in the province of Lleida (Spain). The farm had a capacity of 1,200 milking cows and the average 305-d milk yield of the herd was of 10,675 L/cow. Cows were selected based on their expected date of calving. In total, 456 cows were monitored from 21 days prepartum to 30 days postpartum.

Prepartum cows were housed in two identical 1,820 m^2 compost bedded pens that were aerated twice a day. Along the year, the stoking rate of prepartum cows ranged from 70 to 90 cows/pen, determining a ratio of 20 to 26 m^2/cow. Cows were fed a TMR ad libitum distributed twice daily at approximately 0600 and 1600 h. Water was provided ad libitum in four linear water troughs of 2 m each located in each pen. Cows were kept in the prepartum pen until calving and then moved, within the first 24 h, to the postpartum pen (1,820 m^2). The postpartum pen was also a compost bedded barn with 80 headlocks and four linear water troughs of 2 m each providing water continuously. Postpartum cows were milked three times a day at 0500, 1300 and 2100 h and were fed a TMR ad libitum distributed twice daily at 0500 and 1500 h. The TMR was pushed up 4 to 5 times/d and orts were removed from the feed bunk before each new TMR delivery.

Prepartum and postpartum diets were formulated according to NRC (2001) guidelines. The prepartum diet consisted (DM basis) of 63.5% hay, 18.0% rapeseed meal, 11.5 % ground corn grain, and 7.0% brewers grains. The postpartum diet was formulated to meet requirement of Holstein cows producing 38 kg/d and consisted (DM basis) of 17.0% corn silage, 16.0% alfalfa hay, 6.0% hay, 35.0% ground corn grain, 12.0% rapeseed meal, 12.0% brewers grains and 2.0% minerals and vitamins.

Activity Monitoring System and Behavior Recording

An electronic activity monitoring system (Fedometer [FEDO] system; ENGS, Rosh Pina, Israel) validated by Wolfger et al. (2015) was used to monitor the prepartum cows behavior from d –21 to the day of calving (d 0). The system consists of an accelerometer (FEDO data logger), an activator connected to a cable emitting an electromagnetic field to detect cows at the feed bunk and a receiver transmitting the information to a PC with the software Ecoherd (Eco-herd-software; ENGS).

Accelerometers were fitted at the front right leg to cows with more than 21 d from their expected calving date as described by de Passillé et al. (2010). The identification number of each accelerometer was associated with the identification number of the cows in the Ecoherd software. Data collected by accelerometers was transmitted wirelessly to the system to be summarized into hourly duration of attendance at the feed bunk (min/h), frequency of meals (n/h), steps counts (n/h), number of lying bouts (n/h), and lying time (min/h). The system was checked periodically for proper functioning through team viewer (Team Viewer® 12, Germany) installed on the farm computer.

Health Records and Diseases Definition

From the day of calving until 30 DIM, all cows were examined daily for postpartum diseases by the two veterinarians responsible of the herd health control. All information about health status was logged daily on the farm computer to be collected after for further analysis.

Cows were considered healthy when no disease events were declared from calving until 30 DIM. Otherwise, cows were considered sick and were diagnosed with a specific disease under the following criteria: retained placenta (**RP**), when fetal membranes were retained for more than 24 h postpartum; metritis, when they had watery pink or brown, fetid uterine discharge, accompanied or not by anorexia and fever (> 39.5 °C); milk fever (**MF**), when they were down within the first 72 h after calving, had nervous symptoms, staggering, varying degrees of unconsciousness, and good responsiveness to intravenous administration of calcium; displaced abomasum (**DA**), when they had the characteristic ping on simultaneous auscultation and percussion, and exclusion of other causes of left- or right-side pings; ketosis, subclinical or clinical, when their beta-hydroxybutyrate blood concentration was ≥ 1200 µmol/L (FreeStyle Optium®, FSO, Abbott, Burgos, Spain); clinical mastitis, when they had abnormal milk or inflammation in one or more quarters; and other diseases when they had symptoms different from those of the aforementioned diseases.

Statistical Analyses

Behavioral data were first summarized by cow and day to obtain the daily total number of steps, time of attendance at the feed bunk and frequency of meals, the number of lying bouts and the lying time. For the normal behavior of healthy cows, descriptive statistics was conducted for the prepartum period and bivariate analysis (ANOVA) was performed to determine differences among days for each behavioral index. For the comparison of healthy *vs*. all sick cows or cows with a specific disease, the PROC MIXED was used for each behavioral index to describe differences in the prepartum period from day –21 to 0 relative to calving. The linear mixed models included postpartum cows health status (healthy, sick), lactation number, prepartum days (d –21 to 0) and the interaction between days and health status as fixed effects; and the cow as a random effect. When an interaction was significant, the SLICE option was used for the evaluation. Significance and tendencies were declared at $P < 0.05$ and $0.05 < P < 0.10$, respectively.

To develop a prediction model for postpartum diseases or specific postpartum diseases, a logistic regression model was conducted using the PROC LOGISTIC for each prepartum day (d –21 to –1). The model included the fixed effects of the number of lactation and all the behavioral indexes to identify variables that were associated with the health status. To generate the prediction model, those predictors with $P < 0.20$ were selected using a backward stepwise selection process of variables until all remaining predictors had a $P < 0.10$. All models with an area under the curve (**AUC**) greater than 0.70 were chosen for the final prediction models. For each model, the sensitivity (**Se**) and the specificity (**Sp**) were calculated for each possible cut point as described by Dohoo et al. (2003), and the cut point that yielded the highest combination of Se and Sp was selected. Diagnostic test characteristics included the false discovery rate (**FDR**), the false omission rate (**FOR**) and accuracy. The FDR was defined as the proportion of cows that were diagnosed incorrectly sick in the postpartum period. The FOR was defined as the proportion of cows that were diagnosed incorrectly healthy in the postpartum period. The accuracy was defined as the proportion of healthy and sick cows diagnosed correctly in the postpartum period.

After developing prediction models for each prepartum day, a prediction model using all days of the prepartum period (from d -21 to d -1) was developed in order to enhance accuracy. This model included the lactation number of cows and all the behavioral indexes from days –21 to d –1. The same statistical procedure used to obtain the prediction models per prepartum days was performed and the model was evaluated with Se, Sp, accuracy, FDR, and FOR. All statistical analyses were performed with SAS (v.9.4; SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Normal Behavior

From a total of 456 cows enrolled in the study, 341 cows were healthy. Over the entire prepartum period, on average (mean ± ES), healthy cows attended the feed bunk 8.5 ± 0.2 times per day where they spent 185 ± 6.5 min/d. They did 1,623 ± 41.2 steps, 10 ± 0.3 lying bouts and spent a total of 745 ± 116 min/d lying. Moreover, behavior was not constant along the 21 d prepartum period (Figure 1). Behavior of the calving day was different from previous prepartum days. Several studies evaluating the behavior associated with calving reported similar results on the day before parturition. Cows on the last 24h increased their activity (Jensen, 2012) and lying bouts (Huzzey et al., 2005), and decreased their frequency of meals (Huzzey et al., 2005, Proudfoot et al., 2009), time of attendance at the feed bunk (Schirmann et al., 2013) and lying time (Huzzey et al., 2005). These changes in behavioral indexes observed in the last 24 h are used now by many available technologies to predict the calving event (Titler et al., 2015; Borchers et al., 2016).

Comparison of Healthy vs. Sick Cows

From the total of cows enrolled in the study (n= 456), 115 cows were diagnosed sick in the first 30 DIM, representing an incidence of 25%. The comparison between these sick cows, independent of the specific disease diagnosed, and healthy cows (n = 341) from d –21 until d 0 in steps counts, frequency of meals, feed bunk attendance, lying bouts and lying time are presented in Figure 1. In general, steps counts and frequency of meals were the behavioral indexes most affected by cows health status. Sick cows during the prepartum period did, in average, 10% more steps than healthy cows. Differences were significant on d –18 and tended to be on d –16 and 0. Sick cows also reduced their frequency of meals by almost 15% the last ten days preceding calving in comparison with healthy cows. This difference was significant on d –9, –4, –3 and 0, and showed a tendency on d –1. Sick and healthy cows had almost the same values for time of attendance at the feed bunk, lying bouts and lying time. Differences were found on d 0, when sick cows, in comparison with healthy cows, visited less the feed bunk (45 ± 10.7 min/d *vs*. 67 ± 0.5 min/d, respectively), did more lying bouts (14 ± 0.3 n/d *vs*. 16.6 ± 0.57 n/d, respectively) and spent more time lying (698 ± 21 min/d *vs*. 641 ± 12 min/d, respectively). To the best of our knowledge, this is the first study that compared healthy cows versus sick cows, presenting one or more of the seven selected postpartum diseases, from 21 d prepartum to 30 DIM. There are only two previous studies where prepartum behavior of sick cows was investigated, but without specifying the type of postpartum diseases (Luchterhand et al., 2016; Braun et al., 2017). Moreover, the experimental design, data analysis methodology and other characteristics of those studies were different from ours, making comparisons difficult. Our results provided limited evidence for using postpartum behavior as an early predictor of periparturient sick cows because differences in most behavioral indexes were only clear the day of calving. Therefore, the time to implement preventive treatments is likely too short. Nevertheless, a preliminary analysis of the prepartum behavior indexes showed large differences among individual diseases which may have contributed to hide relevant differences when analyzed together. For example, the activity of cows with mastitis was higher than the activity of healthy cows, while the activity of cows with ketosis was lower than the activity of healthy cows, thus, mixing both diseases together diluted these differences. Therefore, the comparison of sick cows with a specific postpartum disease versus healthy cows would be more appropriate.

Comparison of Healthy vs. Cows with Specific Diseases

From the total of cows diagnosed sick in the first 30 DIM (n = 115), metritis was the postpartum diseases with the highest number of cases (n = 43; average incidence = 9.4%) followed by mastitis (n = 27; average incidence = 6%), RP (n = 26; average incidence = 5.7%), DA (n = 19; average incidence = 4%), clinical or subclinical ketosis (n = 15; average incidence = 3%), milk fever (n = 7; average incidence = 1.5%) and other diseases (n = 13; average incidence = 2.8%). The average incidence of these diseases was within the normal range (Le Blanc, 2010; Suthar et al., 2012; Vergara et al., 2014). The comparison of healthy cows versus cows with each specific diseases was investigated in except for milk fever, because of the small number of cases (n = 7).

Healthy vs. Metritis. The comparison between healthy cows (n = 341) and cows with metritis (n = 43) from d –21 until d 0 in steps counts, frequency of meals, feed bunk attendance, lying bouts and lying time are presented in Figure 2. The average DIM (± SE) on the day of diagnosis for metritis was 6 ± 0.5. No differences were found between healthy cows and cows with metritis during the prepartum period in steps counts nor in frequency of meals except on d –14, when cows with metritis tended to do more steps than healthy cow (1,766 ± 106.7 *vs.* 1,557 ± 40.9 n/d, respectively) and on d –3, when cows with metritis visited fewer times the feed bunk compared with healthy cows (8.2 ± 0.5 *vs*. 9.4 ± 0.2 n/d, respectively). The week before calving, cows with metritis spent on average 11% more time at the feed bunk compared with healthy cows. The difference was significant on d –4 and tended to be on d –7, –6 and –2. Cows with metritis also did, on average, 10% more lying bouts during the prepartum period than healthy cows. That difference was significant on d –15, –14 and 0 and with a tendency on d –11, –10, –9 and –6. No differences were found between cows with metritis and healthy cows in lying time except on d –18 and d 0 when a tendency was observed. Although previous reports evaluated feeding behavior (Urton et al., 2005; Huzzey et al., 2007) and animal activity (Stangaferro et al., 2016c; Barragan et al., 2018) related to metritis, none used five different activity or feeding prepartum behavior indexes together to predict metritis in dairy cows. Our results showed small differences in activity between healthy cows and cows with metritis. Cows with metritis tended to have fewer meal frequency but spent more time at the feed bunk compared with their healthy counterparts. This means that the average time in each visit was longer in cows with metritis than cows without metritis, but results are contradictory. Urton et al. (2005) reported that only cows with acute metritis reduced prepartum feeding time by 22 min/d, on average, compared with non-metritis cows. Similar result was also reported by Huzzey et al. (2007). Patbandha et al. (2012) reported that cows with metritis reduced feeding time and frequency of meals during weeks –2 and –1 compared with the healthy cows. In contrast, Neave et al. (2018) observed no differences during the weeks –2 and –1 between healthy cows and cows diagnosed later with metritis in feed intake, time at the feed bunk and frequency of meals. Zamet et al. (1979) also observed no differences in feed intake in the prepartum period between healthy cows and cows with metritis. Lying behavior is also controversial. In the current study the lying bouts tended to be higher in cows with metritis at week –2, but no differences were observed in lying time. Patbandha et al. (2012) observed no differences between healthy cows and cows with metritis in both lying bouts and lying time in the two weeks prior to calving. In contrast, Neave et al. (2018) reported that cows with metritis did fewer lying bouts and spent less time lying in weeks –2 and –1 than their healthy counterparts. Differences found among studies could be the result of the different types of housing system, because cows in the study of Neave et al. (2018) were housed in a freestall barn, while in our study and that of Patbandha et al. (2012) were housed in compost bedded and loose housing systems, respectively.

Healthy vs. Mastitis. The comparison between healthy cows (n = 341) and cows with mastitis (n = 27) from d –21 until d 0 in steps counts, frequency of meals, feed bunk attendance, lying bouts and lying time are presented in Figure 3. The average DIM (± SE) on the day of diagnosis for mastitis was 14 ± 1.7. The prepartum behavior of cows with mastitis was almost identical to those of healthy cows. The only differences were found at d 0, when cows with mastitis did fewer steps than healthy cows (1,875 ± 126 and 2,100 ± 40 n/d respectively); at d –20 and –4, when cows with mastitis visited fewer times the feed bunk compared with healthy cows (7 ± 0.8 n/d and 9 ± 0.2, respectively); at d –11, when cows with mastitis spent more time at the feed bunk compared with healthy cows (254 ± 24 *vs*. 194 ± 6 min/d, respectively); and at d –3, when cows with mastitis spent more time lying compared with healthy cows (793 ± 40 *vs*. 724 ± 113 min/d, respectively). Our results showed no differences in most prepartum behavior indexes that can be used to predict mastitis incidence. Many studies have investigated the behavioral changes related to mastitis incidence (Medrano-Galarza et al., 2012; Fogsgaard et al., 2015; Sepúlveda-Varas et al., 2016), but none focused in the prepartum period. Fogsgaard et al. (2015) observed a reduction in feed intake 10 d before clinical appearance of mastitis compared with healthy cows. Sepúlveda-Varas et al. (2016) reported that cows with mastitis decreased their feed intake and frequency of meals over the 5 d before their diagnostic in comparison with healthy cows. Stangaferro et al. (2016b) found that the combination of reduction in rumination time and physical activity was able to predict cows with mastitis only one day before clinical appearance of the disease. The lack of changes in prepartum behavior may be attributed to the fact that in our study mastitis occurred at 14 ± 1.7 DIM and the changes in behavior, according to the previous studies, started from 5 to 10 days before the diagnostic of mastitis.

Healthy vs. Retained Placenta. The comparison between healthy cows (n = 341) and RP (n = 26) from d –21 until d 0 in steps counts, frequency of meals, feed bunk attendance, lying bouts and lying time are presented in Figure 4. The average DIM (± SE) on the day of diagnosis for RP was 1 ± 0.3. The difference in behavior started to be evident in some indexes the week prior to calving. Cows with RP frequented 20% less times the feed bunk in d –7, –6, –5 and d –3, and did 30% more lying bouts in d –2, –1 and 0 compared with healthy cows. We found only one report that investigated the association between prepartum behavior and RP (Luchterhand et al., 2016), who reported that only primiparous cows with RP had a 10% reduction in their feeding time compared with their healthy counterparts. During the last two weeks before calving our results showed that, independently of the parity number, the frequency of meals together with lying bouts can be used as early indicators of RP during the postpartum period.

Healthy vs. Displaced Abomasum. The comparison between healthy cows (n = 341) and cows diagnosed later with displaced abomasum (n = 19) from d –21 until d 0 in steps counts, frequency of meals, feed bunk attendance, lying bouts and lying time are presented in Figure 5. The average DIM (± SE) on the day of diagnosis for DA was 8 ± 1.5. Differences in the prepartum behavior between healthy cows and cows with subsequent DA were more pronounced in the frequency of meals and in the time of attendance to the feed bunk than in the rest of behavioral indexes. Cows with DA over the last two weeks before calving reduced the number of meals by almost 25%, being significant in d –11, –8, –7, –5, –4,–3, –2, and –1 or with a trend in d – 9; and the time spent at the feed bunk by almost 20% in comparison with healthy cows, being significant in d – 3 and tented to be in d – 4 and – 2. There were no differences in the rest of behavioral indexes except in d 0, where cows with DA did fewer steps than healthy cows (17,579 ± 210.1 vs. 2,100 ± 39.7 n/d, respectively); in d –20 and –1, when cows with DA had less lying bouts than healthy cows (8 ± 1.9 vs. 11 ± 0.3 n/d, respectively); and in d –18 and –11, when cows with DA spent less time lying compared with healthy cows (633 ± 56 vs. 742 ± 118 min/d, respectively). Edwards and Tozer (2004) reported that cows diagnosed later with DA had higher activity than healthy cows during all the first 30 DIM except d 2. And Stangaferro et al. (2016a) observed that the combination of rumination and activity was able to predict DA cows 3 d earlier than its clinical appearance. However, a direct comparison of our results, where we monitored behavior prepartum, with these previous studies, where behavior was monitored postpartum, is not possible. However, there seems to be evidence that, at some time, there are changes in behavior occurring prior to the clinical diagnosis of DA.

Healthy vs. Ketosis. The comparison between healthy cows (n = 341) and cows with ketosis (n = 15) from d –21 until d 0 in steps counts, frequency of meals, feed bunk attendance, lying bouts and lying time are presented in Figure 6. The average DIM (± SE) on the day of diagnosis for ketosis was 6 ± 0.5. Cows with ketosis reduced the frequency of meals by almost 16% and the time of attendance to the feed bunk by 31% compared with healthy cows. Differences were significant in days –18, –8, –7, – 6, –4, –3 and 0 for the frequency of meals, and in days –21, –13, –12, –11, –10, –9, –8, –7, –6, –5, –4, –3, –1 and 0 for the time of attendance to the feed bunk. No differences were observed in the rest of behavioral indexes except in d –19, when cows with ketosis tended to spend more time lying than healthy cows

(894 ± 69 vs. 774 ± 126 min/d, respectively). Results agree with previous reports where cows with clinical ketosis reduced feeding time and frequency of meals, or ate less the week prior to calving (González et al., 2008; Goldhawk et al., 2009; Rodriguez-Jimenez et al., 2018). In contrast, changes in activity are contradictory. While we did not find major changes in prepartum activity in cows diagnosed with ketosis, Itle et al. (2015) reported an increase in standing time and Rodriguez-Jimenez et al. (2018) a reduction in standing time the week before calving.

Our results suggest that changes in the prepartum behavior of dairy cows can be used as indicators of their risk to have postpartum health disorders. Early detection of these diseases would allow early treatment which may reduce the negative effects in milk yield (Rajala and Gröhn, 1998), time of conception (Fourichon et al., 2000), and culling rate (Gröhn et al., 2003), as well as improving animal welfare (Stojkov et al., 2015).

Prediction Models

All predictor models developed for healthy vs. sick cows between d –21 and 0 had AUC values ranging from 0.58 to 0.64. Therefore, none of these models met the established criteria and were not further developed. For the prediction models for specific diseases, metritis was the only disease with enough cases (n = 43) to develop a prediction model. Two different prediction models for metritis were finally developed. A prediction model based on individual prepartum days and another based on all prepartum days. The outcomes of the diagnostic test characteristics resulting from these models are presented in Table 1. For the prediction using individual prepartum days, the only model that had an AUC > 0.70 was found for d –4. This model included the attendance at the feed bunk, frequency of meals, lying bouts and lying time. The application of this model at the highest point of Se (37%) and Sp (90%) resulted in an accuracy of 84%, a FDR of 69% and a FOR of 8%. The FOR, representing the number of cows incorrectly diagnosed healthy, is small, while the FDR, presenting the number of cows incorrectly diagnosed sick, is high. Therefore, the use of this prediction model could increase unnecessary preventive treatment. The prediction model developed considering all prepartum days together had an AUC value of 0.93. At the highest Se (73%) and Sp (86%), this model had 84% accuracy, 48% FDR and 6% FOR. Remaining predictors from the stepwise process were lactation number, attendance at the feed bunk of d –10, –7 and –2, steps counts of d –2, lying bouts of d –9 and lying time of d –9, –4 and –2. Table 2 presents the analysis of maximum likelihood estimates for the prediction models on d –4 and all prepartum days. Several studies investigated the differences in prepartum behavior between subsequently healthy and sick cows (Huzzey et al., 2007; González et al., 2008). Metritis, due to its high incidence, has centered the interest of many of them (Urton et al., 2005; Huzzey et al., 2007; Stangaferro et al. 2016c). However, only few studies developed models to predict its occurrence in the postpartum period. Urton et al. (2005) reported that feeding behavior in the day of calving predicted acute metritis with a Se of 89% and Sp of 62%. More recently, Stangaferro et al. (2016c) used rumination and activity to predict metritis from d –5 to d 2 around its clinical diagnostic. They reported that the changes in rumination and activity were able to identify cows with metritis approximately 1 d earlier than with traditional health-monitoring programs. The Se and Sp of their prediction were 59% and 98%, respectively. Results of our study reveal the possibility to predict metritis two days before calving and 8 days before clinical signs. This model can lead to an earlier identification of those cows at a higher risk and could be useful to design early treatments to reduce metritis incidence or its impact on animal health or performance.

CONCLUSIONS

Results from the current study demonstrated differences in behavior during the prepartum period between healthy cows and cows with a specific postpartum disease. The prediction model developed for metritis, including all prepartum days, was able to identify cows with metritis 2 d prior to calving with a Se of 73% and Sp of 86%. The model is able of predicting cows at risk for metritis allowing the application of a targeted preventive treatment. However, the FDR is high and further refinement to minimize unnecessary treatment may be required.

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Table 1. Diagnostic test outcomes for metritis prediction resulting from final models of day –4 and all prepartum days.

Time	AUC[1]	Accuracy, %	Se[2], %	Sp[3], %	FDR[4], %	FOR[5], %
Day –4	0.71	84	37	90	69	8
All prepartum days	0.93	84	73	86	48	6

[1]AUC: area under the curve.

[2]Se: sensitivity.

[3]Sp: specificity.

[4]FDR: false discovery rate.

[5]FOR: false omission rate.

Table 2. The analysis of maximum likelihood estimates for the prediction models on d –4 and all prepartum days.

Models variables	Estimate	SEM[1]	P–value
Prediction model of day –4			
Intercept	–0.155	1.2722	> 0.1
Attendance at the feed bunk	0.003	0.0017	< 0.1
Frequency of meals to the feed bunk	–0.100	0.0604	< 0.1
Lying bouts	0.082	0.0414	< 0.05
Lying time	–0.004	0.0013	< 0.05
Prediction model of all prepartum days			
Intercept	8.341	5.0295	< 0.1
Lactation number	–1.484	0.4733	< 0.05
Attendance at the feed bunk d –10	–0.017	0.0080	< 0.05
Lying bouts d –9	0.302	0.1113	< 0.05
Lying time d –9	0.018	0.0059	< 0.05
Attendance at the feed bunk d –7	0.014	0.0072	< 0.05
Lying time d –4	–0.020	0.0058	< 0.05
Steps counts d –2	–0.0029	0.0012	< 0.05
Attendance at the feed bunk d –2	0.0176	0.0067	< 0.05
Lying time d –2	–0.0094	0.0047	< 0.05

[1]SEM: standard error of the mean.

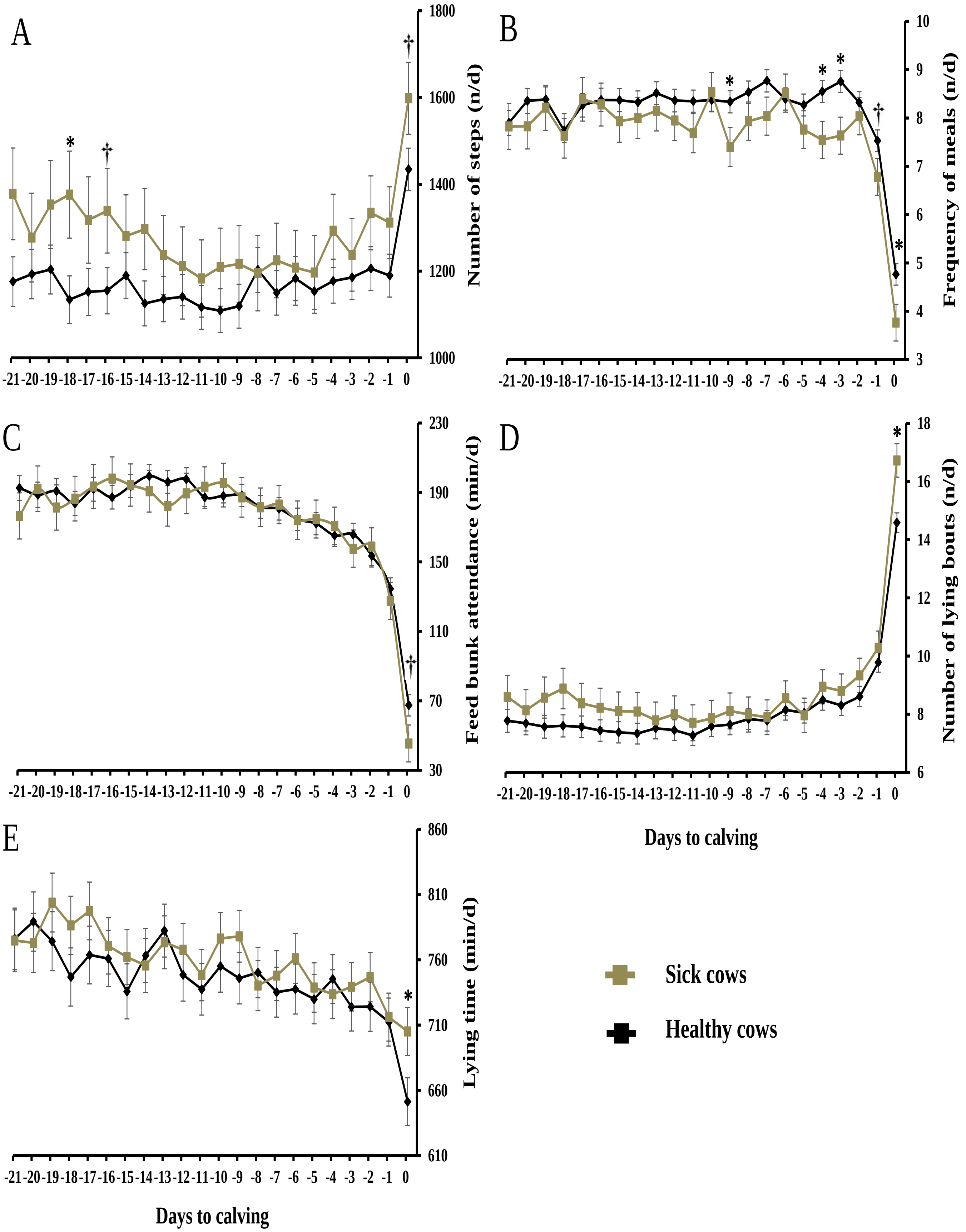

Figure 1. Belaid

Figure 1. Daily steps counts (A; n/d), frequency of meals (B; n/d), feed bunk attendance (C; min/d), number of lying bouts (D; n/d) and lying time (E; min/d) of healthy cows (n = 341) *vs.* sick cows (n = 115) from d –21 to d 0 relative to calving. Results are presented as LSM ± SEM; (*) within the same day differ at $P < 0.05$; (†) within the same day tended to differ ($0.05 < P < 0.10$).

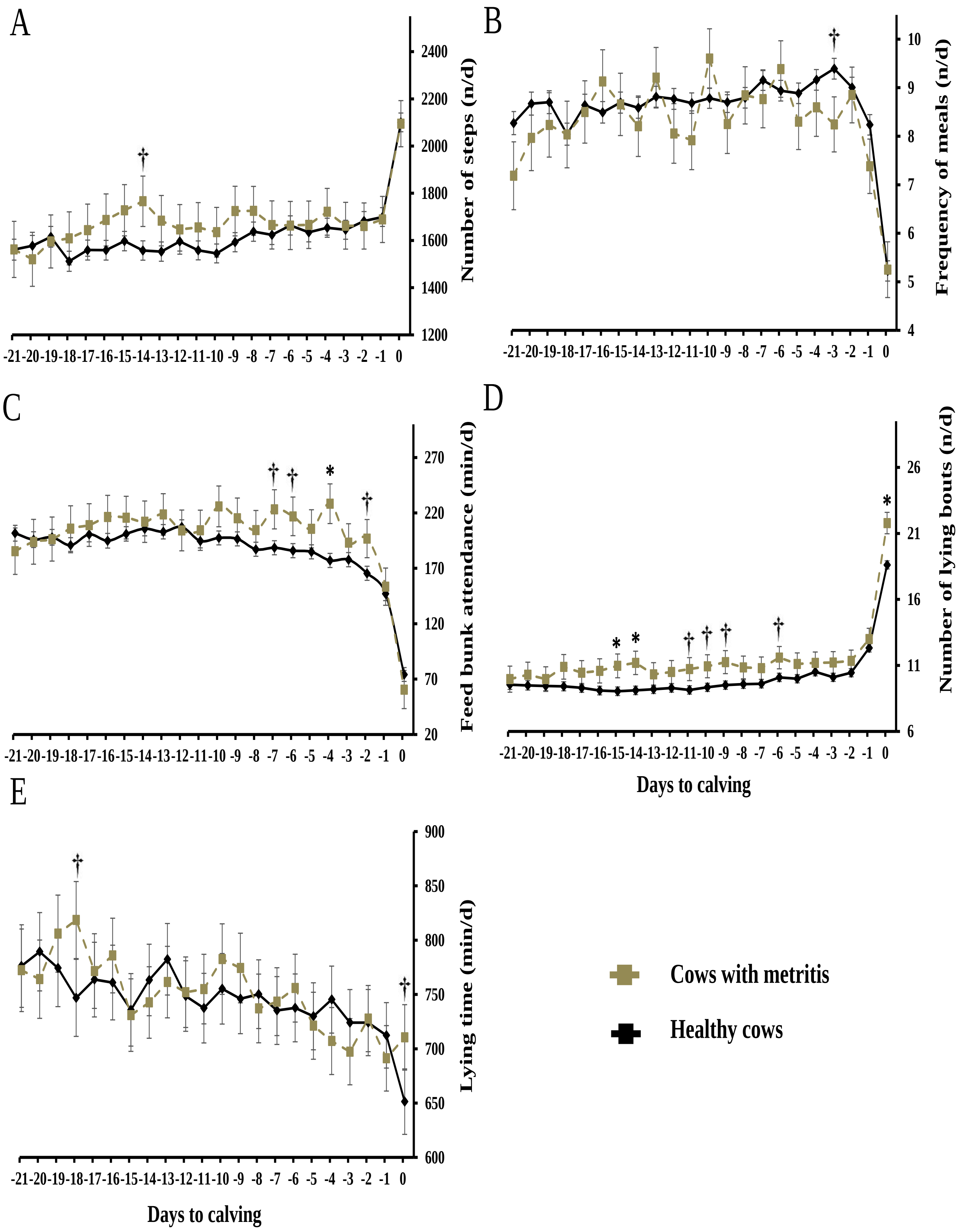

Figure 2. Belaid.

Figure 2. Daily steps counts (A; n/d), frequency of meals (B; n/d), feed bunk attendance (C; min/d), number of lying bouts (D; n/d) and lying time (E; min/d) of healthy cows (n = 341) *vs.* cows with metritis (n = 43) from d –21 to d 0 relative to calving. Results are presented as LSM ± SEM; (*) within the same day differ at $P < 0.05$; (†) within the same day tended to differ ($0.05 < P < 0.10$).

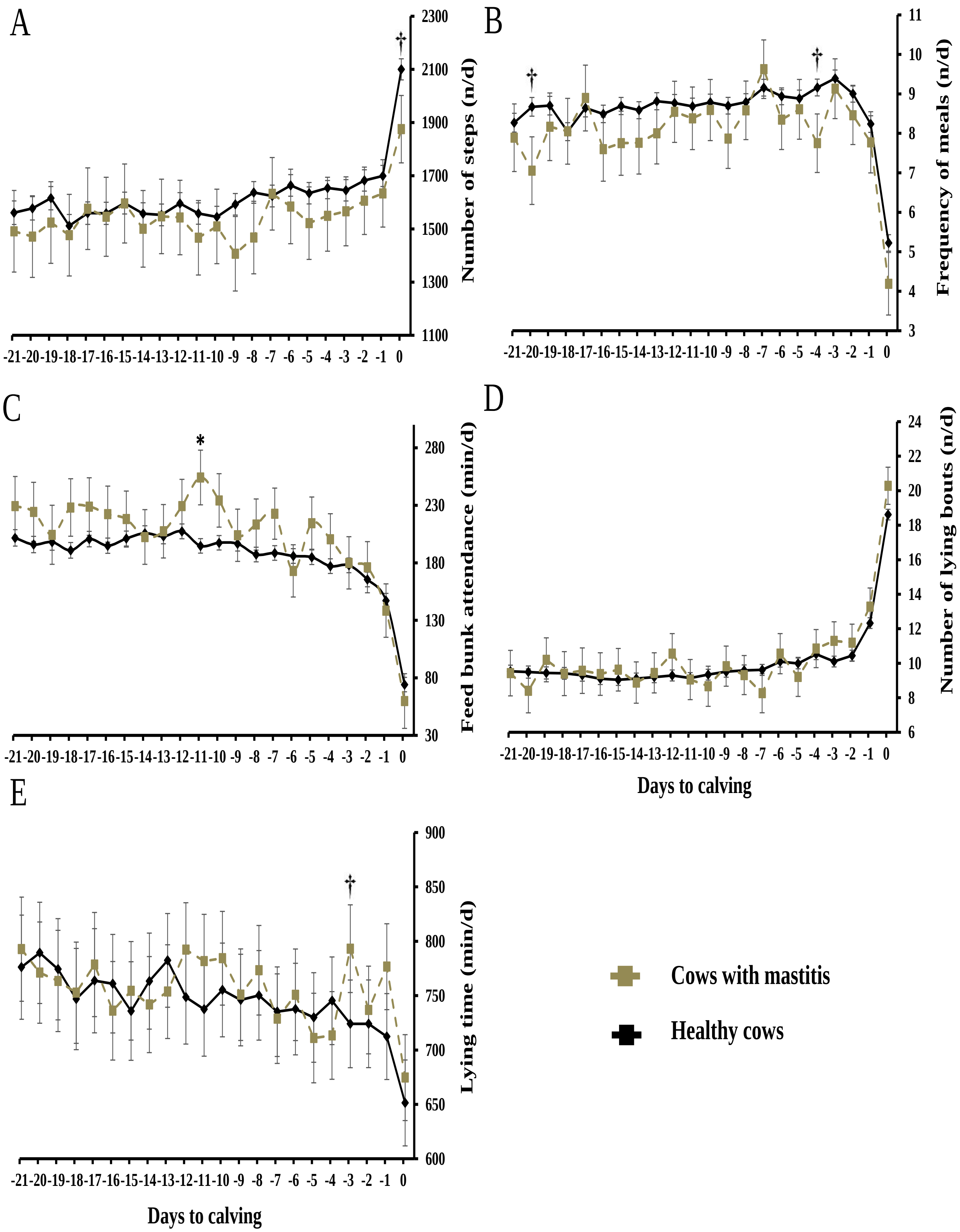

Figure 3. Belaid.

Figure 3. Daily steps counts (A; n/d), frequency of meals (B; n/d), feed bunk attendance (C; min/d), number of lying bouts (D; n/d) and lying time (E; min/d) of healthy cows (n = 341) *vs.* cows with mastitis (n = 27) from d –21 to d 0 relative to calving. Results are presented as LSM ± SEM; (*) within the same day differ at $P < 0.05$; (†) within the same day tended to differ ($0.05 < P < 0.10$).

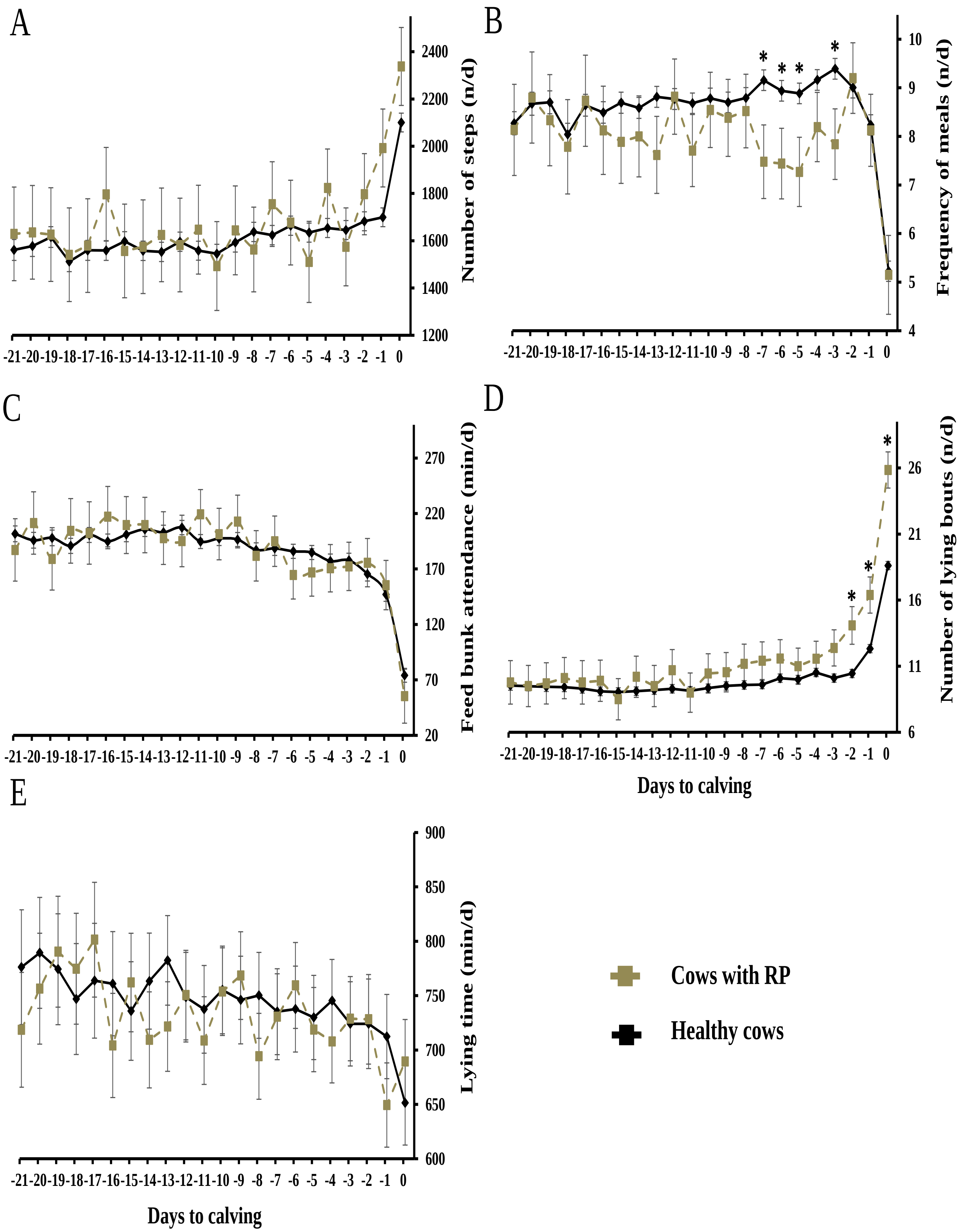

Figure 4. Belaid.

Figure 4. Daily steps counts (A; n/d), frequency of meals (B; n/d), feed bunk attendance (C; min/d), number of lying bouts (D; n/d) and lying time (E; min/d) of healthy cows (n = 341) *vs.* cows with RP (n = 26) from d –21 to d 0 relative to calving. Results are presented as LSM ± SEM; (*) within the same day differ at $P < 0.05$; (†) within the same day tended to differ ($0.05 < P < 0.10$).

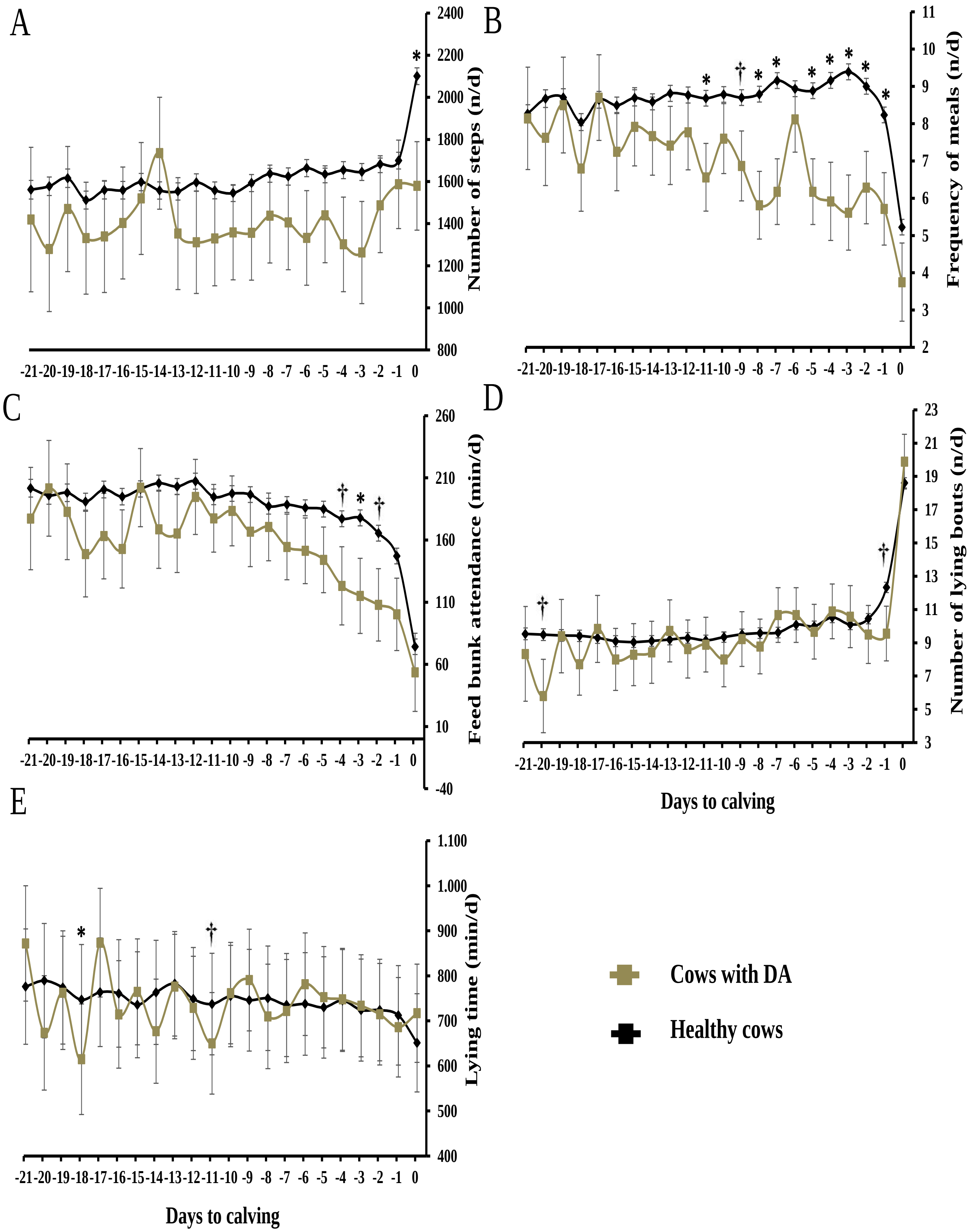

Figure 5. Belaid.

Figure 5. Daily steps counts (A; n/d), frequency of meals (B; n/d), feed bunk attendance (C; min/d), number of lying bouts (D; n/d) and lying time (E; min/d) of healthy cows (n = 341) *vs*. cows with DA (n = 19) from d –21 to d 0 relative to calving. Results are presented as LSM ± SEM; (*) within the same day differ at P < 0.05; (†) within the same day tended to differ (0.05 < P < 0.10).

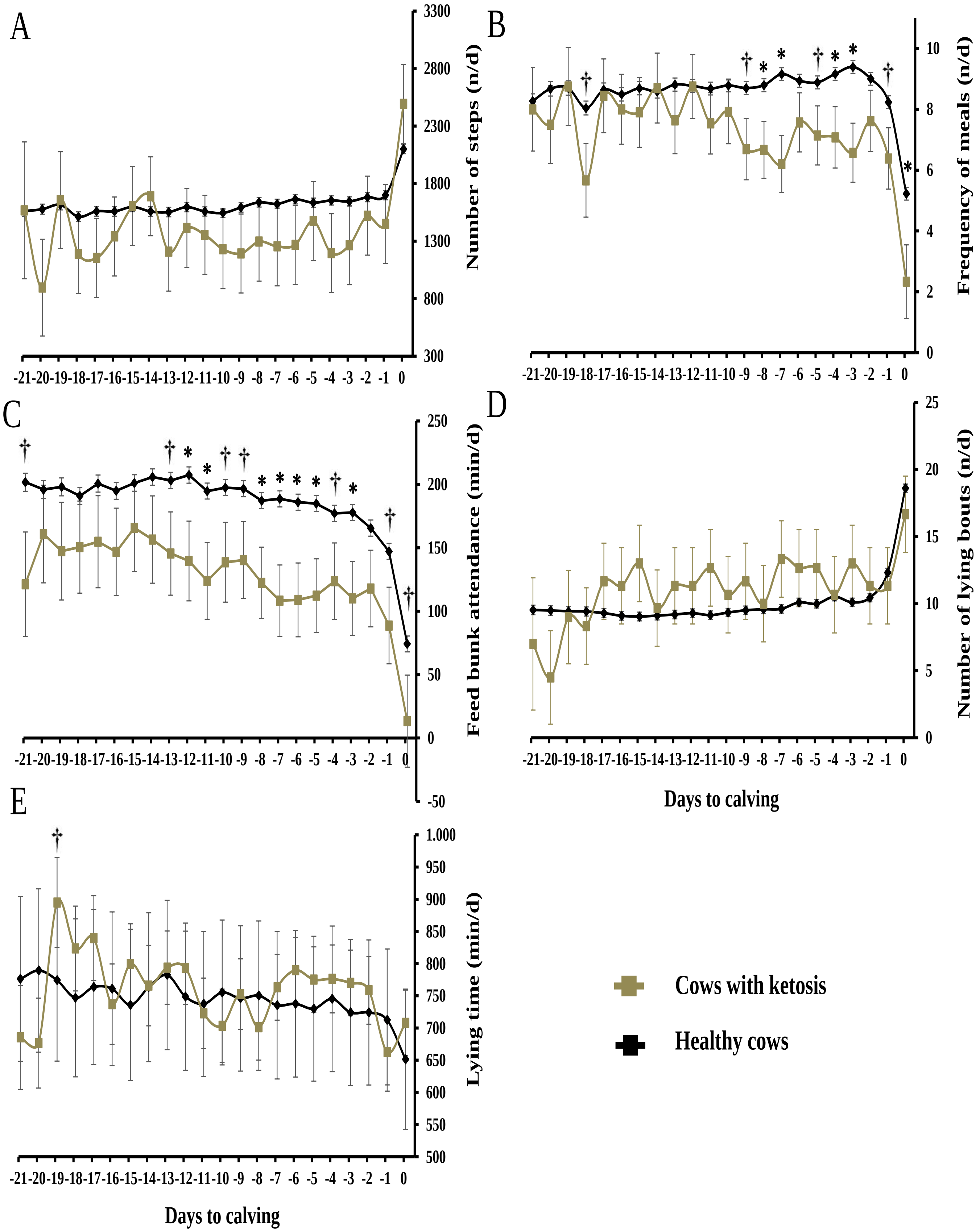

Figure 6. Belaid.

Figure 6. Daily steps counts (A; n/d), frequency of meals (B; n/d), feed bunk attendance (C; min/d), number of lying bouts (D; n/d) and lying time (E; min/d) of healthy cows (n = 341) *vs.* cows with ketosis (n = 15) from d –21 to d 0 relative to calving. Results are presented as LSM ± SEM; (*) within the same day differ at $P < 0.05$; (†) within the same day tended to differ ($0.05 < P < 0.10$).

Chapter V

Economic Analysis

Economic Analysis of the Use of a Pedometers System to Implement Targeted Preventive Treatments

Our results suggest that calves, young bulls, and transition cows change their behavior before having any clinical sign of disease. We have used these behavioral changes to develop models able to predict diseases at day –10 and –9 before the diagnostic of the disease, in calves and young bulls, respectively, and metritis 2 days before parturition and 8 days before its clinical appearance in transition cows. Therefore, there is enough time to take advantage of the prediction models developed to implement targeted preventive treatments for diseases in feedlot cattle and metritis in dairy cattle. However, the false discovery rate of the predictions, which refers to the percentage of animals incorrectly diagnosed sick, was high. Treating healthy animals without any need may increase the cost of targeted preventive treatment and limit its use. However, the targeted preventive treatment might still be beneficial compared with systematic preventive treatment even when the methodology is imprecise. For example, if we apply a targeted preventive treatment using a model with a 50% false discovery rate in a farm with an average incidence of diseases of 10%, we will treat 20% of the animals, instead of treating all animals in systematic preventive treatments. This will reduce the use of antibiotics and early treatment will likely minimize the impact of the diseases. In contrast, to monitor behavior to identify animals at risk of disease requires the implementation of a pedometers system which requires an investment. The targeted preventive treatment would be economically justified when its benefits cover, at least, the cost of the monitoring system and the systematic use of the preventive treatments.

The objective of this analysis is to see if the use of a pedometer system to identify animals at risk of becoming sick and the implementation of a targeted preventive treatment is economically beneficial in beef and dairy farms.

The economic analysis is divided in three parts. In the first part, the cost of diseases, the cost of the different factors involved in conventional preventive treatment (treatment and labor), the cost of targeted preventive treatment (treatment and labor) and the cost of a pedometer system (equipment, implementation and labor) were estimated for feedlot and dairy cattle. In the second part, the economic profit of using a pedometers system to implement targeted preventive treatments was calculated for the 3 farms types studied: calves, young bulls, and transition cows. And in the third part, a discussion on the outcomes and the possible limitations of the results are reported.

1. Estimation of Costs

1.1. Feedlot Cattle

1.1.1. Diseases

There are many estimates of costs associated with diseases in feedlot cattle in the literature, although the costs reported vary widely depending on the factors considered for its calculation, apart from the pharmaceutical cost of the treatment itself. McNeill et al. (1996) reported that more than 60% of disease costs are associated with non-pharmaceutical costs. Therefore, it is important to define which factors are included in the losses before reporting the cost of diseases.

Typically, many performance indexes are affected by cattle health status. Sick cattle eat less feed and have lower average daily gain and feed efficiency, compared with healthy cattle (Morck et al., 1993; Schneider et al., 2009). Consequently, cattle that suffer any disease during fattening usually remain for a longer time in the farm, which means more days on feed to achieve the same weight as healthy cattle (Waggoner et al., 2007). Moreover, those animals are sold at lower prices than healthy cattle because of their reduced body weight, carcass characteristics and marbling scores (Johnsen and Pendell, 2017). For example, Fulton (2009) estimated that the cost per case of bovine respiratory diseases was about $40 in the first, $58.35 in the second, and $291.93 in the third treatment. However, in that study, only the pharmaceutical cost of the treatment was considered while other costs derived from reduced growth rates or lower feed efficiencies were not considered. Similarly, Waggoner et al. (2007) reported that healthy cattle averaged $95.25 more net return per head than did sick cattle, but didn't evaluate the differences in feed costs. Thus, we did not take into account these studies. The only study that included all factors in the calculation of disease cost is that of McNeill (2001). In this study, healthy cattle had $151.18 more profit per head than sick cattle. This difference in profit was due to treatment costs ($44.55), and reduced efficiency, lower gain and reduced sale value ($106.63).

1.1.2. Preventive Treatment

Feedlot cattle almost always receive preventive treatments at their arrival to the farm, which should be included in the budget of on-farm health programs. By definition, a preventive treatment is administrated systematically to a group of animals to protect them against possible risk of diseases (ECDC/EFSA/EMA, 2015; EMA, 2016). These treatments are highly recommended, above all, when the incidence of diseases is high and could have a big impact on farm profitability (Edwards, 2010; Regev-Shoshani et al., 2015; Step et al., 2007). Preventive treatments include vaccines, non-steroidal anti-inflammatory drugs, oral and injectable antibiotics, vitamins, anti-inflammatory drugs, anthelmintics, probiotic pastes, antihistamines, oral electrolyte fluids or drenches, corticosteroids, etc. The average cost per animal of using these products is $11.70, ranging from $7.87 when only a single product is used, to $15.57 for six or more products combined (Gardner et al., 1998; USDA APHIS, 2001; Schneider et al., 2009). In addition, the labor needed to administer the preventive treatment represents $1.00 per animal treated, estimating the time necessary to perform the treatment at 6 min and considering a labor cost of $10.80 per one hour (USDA ERS, 2014a). Thus, the average cost of applying a preventive treatment is $12.72 per animal.

1.1.3. Targeted Preventive Treatment

The targeted preventive treatment is a preventive treatment aimed to be applied only to those animals with a high probability of sickness. Its use could decrease the cost of preventive treatment by not treating animals with low or no risk of becoming sick and improve treatment effectiveness by treating sick animals at an early stage of the disease (Schoening et al., 2005). Its administration could reduce the losses related to the disease and this reduction should be taken into consideration when calculating the economic profit. For example, if the cost of a diseases is $151.18/case and the targeted preventive treatment has an efficacy of 50%, the losses due to diseases after the targeted preventive treatment will be reduced by half, resulting in $75.59. In feedlot cattle, we considered a targeted preventive treatment cost of $12.72 per animal treated. Regarding the effectiveness of the targeted preventive treatment, morbidity is reduced by 50% (Schumann et al., 1990; Morck et al., 1993; Encinias et al., 2006; Benton et al., 2008). Therefore, the cost of the disease of treated animals will be ($75.59).

1.1.4. Pedometers and Labor

The price of a pedometer system varies depending on its quality and the number of parameters measured, ranging from $60 to up to $150. In our study, we have used pedometers able to measure five behavioral parameters which are steps counts, frequency of meals, time spent at the feed bunk, number of lying bouts, and lying time. Their price was $100 per pedometer, including the installation of the system in the farm. In calves and young bulls, pedometers were fitted at the beginning of the growth cycle, adjusted two times during the monitoring cycle and removed at the end. The pedometer adjustment was necessary due to animal growth. The time necessary to carry out all these actions was estimated at 40 min per animal and cycle, which, considering $7.00 of labor cost per hour, means $5.00 of labor cost per animal an cycle.

1.2. Dairy Cattle

1.2.1. Metritis

Metritis is a costly disease that affects postpartum dairy cows (Sheldon et al., 2009; Liang et al., 2017). Its economic impact on farm profitability is not only the result of the treatment but also losses associated with the decrease in milk production (Rajala and Gröhn, 1998; Dubuc et al., 2011; Wittrock et al., 2011); the milk discarded due to the antibiotic treatment (Liang et al., 2017); the increase in days open due to the delayed recovery of postpartum reproductive function (Mahnani et al., 2015); the consequent early elimination of some animal from the herd if they are not treated on time (Østergaard and Gröhn, 1999; Bewley et al., 2010); or the eventual death of sick animals (Dubuc et al., 2011; Wittrock et al., 2011; Giuliodori et al., 2013). Many studies have been conducted to estimate the economic losses of metritis (Drillich et al., 2001; Overton and Fetrow, 2002; Guard, 2008; Mahnani et al., 2015; Lima et al., 2019). The average total cost reported in these studies was in the range of $162 to $386 per case. These variations in the cost could be explained by the differences in the cost of treatment itself, which ranges from $15 to $101.5; differences between the prediction models used to estimate losses in future performance; the number of primiparous and multiparous cows present in each study (Wittrock et al., 2011); and the different diagnostic criteria used to detect metritis because of its inconsistent definition (Kelton et al., 1998; Sannmann et al., 2012; Espadamala et al., 2016). Herein, to report the cost of metritis and its treatment, we have used the median of these previous studies instead of the mean. Thus, we used is $353.5 and $66 for the cost of metritis and its treatment, respectively.

1.2.2. Preventive Treatment

There are many strategies that can be implemented to prevent the appearance of metritis. These strategies can be direct, targeted to the cause of the metritis appearance, or indirect, targeted to metritis predisposing factors. Direct strategies are based on the use of antimicrobials such as ceftiofur, oxytetracycline or ampicillin to prevent the multiplication of metritis associated bacteria (Smith et al., 1998; Chenault et al., 2004). Indirect strategies include the administration of vitamin E or selenium to enhance the immune system function, which is compromised around parturition (Hoeben et al., 2000); the use of dietary cation-anion difference (DCAD) to prevent milk fever and hence, retained placenta, which is the largest risk factor for metritis (Erb et al., 1985; Sandals et al., 1979; Markusfeld, 1984; Gröhn et al., 1990); and the maximization of prepartum intake, since lower feed intake is strongly associated with subsequent development of metritis (Huzzey et al., 2007); among others. The cost of using these preventive treatments varies widely depending on many factors such as the strategy used, or the number of measures implemented. In the dairy farm where our experiment was conducted, dry cows received DCAD salts in the diet during the last 21 days before the expected calving date. The cost of formulating a diet DCAD in that farm was estimated at $7.00 per dry cow. Therefore, in our analysis, we set a cost of 7.00 $/cow for the metritis systematic preventive treatment.

1.2.3. Targeted Preventive Treatment

As an example, the targeted preventive treatment applied to animals at risk is the antimicrobial Ceftiofur. Ceftiofur is the antimicrobial of reference because of its efficacy against metritis (Haimerl et al., 2017). Its cost is around $22 per animal in one treatment episode (Drillich et al., 2001; Lima et al., 2019), plus $1.00 per animal, considering labor costs of $10.80 per hour (USDA ERS, 2014a). According to Risco and Hernandez (2003), the administration of ceftiofur hydrochloride before the clinical appearance of metritis has an effectiveness of 69%.

1.2.4. Pedometers and Labor

In dairy farms, as pedometers are already implemented to detect estrus in cows, we estimated an additional cost of $40 per animal, which is the result of the difference between the cost of the pedometer used in our study ($100) and those normally used at farms for heat detection ($60).

2. Calculation of the Economic Profit

The calculation of the economic profit of using a pedometers system to implement a targeted preventive strategy in the three types of farms studied (calves farm, young bulls farm, and dairy cows farm) is performed in steps: 1) we first estimated the cost that farmers are currently paying in animals health related issues (losses due to diseases and the preventive treatment); 2) we calculate the cost of implementing a targeted preventive strategy (treatment of all positive animals and their effectiveness, losses due to the false negatives animals not treated and cost of labor needed to fit animals with pedometers). Once both are determined, we performed their comparison to estimate the benefit of using a targeted preventive treatment. The benefit, in this case, is calculated in one production cycle and should be estimated for one year to compare it with the cost that farmers pay for the pedometer system in one year.

It is important to understand the interpretation of results of prediction models. Prediction models vary in their precision and accuracy. The false discovery rates (FDR) is the percentage of animals incorrectly diagnosed sick from the total of true positive and false positive animals predicted by the model. The false omission rates (FOR) is the percentage of animals incorrectly diagnosed healthy from the total of true negative and false negative animals predicted by the model.

Table 3 presents the sensitivity, specificity, FDR, and FOR of the prediction models of diseases in feedlot cattle and metritis in dairy cattle.

Table 3. Sensitivity, specificity, false discovery rates and false omission rates of the prediction models of diseases in feedlot cattle and metritis in dairy cattle.

	Se [1] %	Sp [2] %	FDR [3] %	FOR [4] %
Calves	66.7	66.7	60	14
Young bulls	79	81	47	6
Transition cows	73	86	48	6

[1] Se: Sensitivity; [2] Sp: Specificity; [3] FDR: False discovery rates; [4] FOR: False omission rates.

2.1. Calve's Farm

The total of calves enrolled in this study was 325, from which 33 were diagnosed sick. To calculate the profitability of implementing a targeted preventive treatment, we will start by calculating the cost that farmers are already paying for the health program. We estimate the total cost of a health program in a feedlot cattle as the sum of the losses due to diseases ($151.18/case) multiplied by the number of sick animals (33 calves) and the cost of the preventive treatment and the labor involved ($12.72/treatment) multiplied by the number of animals present at the farm (325). Therefore, the cost of the health program already implemented in the farm is of $9,123 per productive cycle.

The cost of implementing a targeted preventive requires to consider the numbers of false positive and false negative. Table 4 presents the true positive, false positive, true negative, and false negative identified by the pedometer system.

Table 4. True positive, false positive, true negative and false negative identified by the pedometer system to predict diseases in calves.

		Observed		
		Sick	Healthy	Total
Predicted	Sick	22	97	119
	Healthy	11	195	206
	Total	33	292	325

In this case, the cost of treatments in the targeted preventive strategy ($12.72/treatment) is multiplied by the number of animals identifies by the system sick (119). Thus, $12.72 × 119 = $1,514. Because the targeted preventive treatment has an effectiveness of 50%, the real losses due to diseases are 50%. Thus, losses per sick animal treated: 50 × (22 × $151.18)/100 = $1,663. Then, the losses due to sick animals which were not predicted sick and, thereby, not treated, should also be considered. This is the number of sick animals no treated (11) multiplied by the cost of diseases ($151.18/case) but without counting the cost treatment ($44.5/case), thus 11 × $106.63 = $1,173. Finally, we should add the labor cost needed to fit all calves with pedometers, which is $5.00 multiplied by the number of calves at the farm (325) = $1,625. Then, the total cost of implementing a targeted preventive treatment will be the sum of the targeted treatment ($1,514), losses due to targeted preventive treatment ($1,663), losses due to sick animals no treated ($1,173), and the cost of labor needed to fit animals with pedometers

($1,625). Thus, the result will be $5,975 per productive cycle. Therefore, applying the targeted preventive treatment instead of the systematic preventive treatment allows to save $3,148 ($9,123 - $5,975) for one productive cycle of 2 months, and $18,888 in one year.

The cost of the pedometers in the farm is calculated by multiplying the cost of one pedometer ($100) by the number of calves present at the farm (325) divided by the number of years to pay-off (6), thus, $5,417. Then, the profitability of implementing a targeted preventive treatment to predict diseases in calves per year is $13,471 ($18,888 - $5,417).

2.2. Young Bull's Farm

From 770 young bulls raised in this farm, 71 where diagnosed sick. The profitability of implementing a targeted preventive treatment using a pedometers system in bulls are also calculated following the same steps aforementioned in calve's farm. The cost of the health program already implemented at the farm is the sum of the cost of diseases ($151.18/case) multiplied by the number of sick bulls (71), and the cost of preventive treatment ($12.72/treatment) multiplied by the number of bulls present at the farm (770). Thus, $20,528.

To calculate the cost of targeted preventive treatment we should know the number of FDR and FOR. Table 5 presents the true positive, false positive, true negative, and false negative identified by the pedometer system to predict diseases in young bulls.

Table 5. True positive, false positive, true negative and false negative identified by the pedometer system to predict diseases in young bulls.

		Observed		
		Sick	Healthy	Total
Predicted	Sick	56	133	189
	Healthy	15	566	581
	Total	71	699	770

Once both FDR and FOR are known, the cost of treatment in the targeted preventive strategy ($12.7/treatment) is multiplied by the number of bulls predicted as sick by the model (213). Thus, $12.72 × 189 = $2,404. Since a targeted preventive treatment has an effectiveness of a 50%, the losses per sick bulls treated is: 50 × (56 × $151.18)/100 = $4,233. Then, the losses due to sick bulls which were not predicted sick and not treated: 15 × ($151.18 - $44.5) = $1,600. Finally, the labor cost needed to fit all bulls with pedometers, which is $5.00, multiplied by the number of bulls at the farm (770) = $3,850. Thus, the total cost of implementing a targeted preventive treatment is of $12,087 per productive cycle. And comparing this last ($12,087) to the cost of the systematic preventive treatment already implemented in the farm ($20,528), the benefits is $8,441 for one productive cycle of 3 months and $33,764 in one year.

On the other hand the cost of pedometers ($100) is multiplied by the number of bulls present at the farm (770) divided by the number of year to pay-off (6), thus, $12,833. Therefore, the profitability of implementing a targeted preventive treatment to predict diseases in bulls per year is $20,931 ($33,764 - $12,833).

2.3. Transition Cows Farm

From a total of 456 cows enrolled in the study, 43 were diagnosed with metritis. The cost of the current health program for prepartum cows is the sum of the number of cows with metritis (43) multiplied by the cost of metritis ($353.5) plus the cost of the preventive treatment ($7.00) multiplied by the number of dairy cows present at the farm (456). Thus, the cost is of $18,395.

To calculate the cost of implementing a targeted preventive treatment, it is important to know the numbers of false positive and false negative cows with metritis predicted by the pedometer system. Table 6 presents the true positive, false positive, true negative, and false negative of metritis cows resulting from the pedometer system.

Table 6. True positive, false positive, true negative and false negative of metritis cows resulting from the pedometer system.

		Observed		
		Sick	Healthy	Total
Predicted	Sick	31	58	89
	Healthy	12	355	367
	Total	43	413	456

The cost of the targeted preventive strategy is: the cost of the treatment ($23/case) multiplied by the number of cows predicted sick by the model (89) = $2,047, plus the losses per sick cows treated: 31 × (31 × $353.5)/100 = $3,397, plus the losses due to sick cows with metritis that were not predicted sick and not treated: 12 × ($353.5 - $66) = $3,450. Thus, the total cost of implementing a targeted preventive treatment is $8,894.

Therefore, calculating the difference between the costs of health program already implemented in the farm ($18,395) and the cost of implementing the targeted preventive treatment ($8,894), results in saving of $9,501 for one annual lactation cycle.

The cost of pedometers is calculated by multiplying the additional cost of pedometer ($40.0) by the number of cows present at the farm (456) divided by the number of year to pay-off (6), thus, $3,040. Therefore, comparing this last ($3,040) to the economic profit of implementing the targeted preventive treatment in one annual lactation cycle ($9,501), the profitability of implementing a targeted preventive treatment to predict metritis in cows per year is $6,461.

3. Possible Limitation of Results

In the current economic analysis, we tried to calculate whether the use of pedometers system to implement a targeted preventive treatment is profitable in feedlot and dairy cattle. Results demonstrated that treating animals at high risk of diseases by the targeted preventive treatment even though the high false discovery rates found are more profitable than systematic preventive treatment. The economic profit found per year in calves, young bulls, and dairy cows, were $13,473, $20,931, and $6,461, respectively. However, these findings should be interpreted carefully. When calculating the profitability of using a targeted preventive strategy in feedlot farm, we assumed that the incidence of diseases doesn't change without preventive treatment. However, the absence of a preventive treatment could increase the incidence of diseases. Therefore, the profitability reported previously in beef cattle is likely an overestimation to the real benefit of the targeted preventive strategy. On the other hand, in dairy cattle, we reported only the economic benefit of using a targeted preventive strategy to prevent metritis. However, the pedometer system may also be useful in identifying animals at risk of other postpartum diseases that we have not considered. Thus, the economic profit reported in dairy cattle could be underestimated.

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Chapter VI

General conclusions

This PhD thesis was developed with the objective to investigate if the use of an activity monitoring system could be useful in the early prediction of diseases in cattle. The three studies conducted in feedlot and dairy cattle allowed to conclude:

1. Animals before having any clinical signs of diseases modified their behavior when compared with their healthy counterpart.
2. These changes in behavioral pattern in animal at risk of sickness allowed to develop prediction models able to identify diseases at day –10 and –9 before the diagnostic of the disease, in calves and young bulls, respectively; and metritis 8 days before its clinical appearance in transition cows.
3. The prediction models developed may allow to implement targeted preventive treatments only to animals at risk of sickness. This may reduce unnecessary treatments in healthy animals usually seen in systematic preventive treatment and likely increase the treatment effectiveness by treating animals at the early stage of the disease.
4. The percentage of animals incorrectly diagnosed sick by models was high which affects the reliability of the prediction. However, the use of the prediction models to implement a targeted preventive treatment may still be more profitable than systematic preventive treatment.

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Annex

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