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Automatic registration of dairy cows grazing behaviour on pasture

Automatisk registrering av mjölkkors betningsbeteende

av

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Institutionen för husdjurens utfodring och vård

Examensarbete 332
30 hp E-nivå

Swedish University of Agricultural Sciences
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Sammanfattning

Information om kors betningsbeteende kan vara av stort intresse för mjölkproducenter, då den kan avslöja hur väl anpassat betet är för korna. Födointag på bete kan dock vara utmanande att mäta. Automatiska system för att studera mjölkkors beteende har blivit viktigare och relativt vanligt förekommande.

Syftet med denna studie var att utvärdera en aktivitetsmätare (HOBO® G Logger Pendant Data Logger, USA), en treaxlad accelerometer som registrerar kors huvudposition då de betar, för att se om kors betningsbeteende kan urskiljas från andra beteenden. Ytterliggare en treaxlad accelerometer (IceTag3D™, IceRobotics Ltd, Scotland) inkluderades och registrerade om korna stod upp eller låg ner. Valideringen utfördes genom att jämföra data från beteendeobservationer med information om huvud- och benposition. 20 kor studerades kontinuerligt i 30 min, i totalt 5 timmar var.

Vid uppskattning av betningsbeteende hade HOBO® loggern en säkerhet på 83,6%. När information från IceTag™ loggern inkluderades var säkerheten 75,6%. Då även andra beteenden inkluderades var den uppskattade säkerheten för HOBO® loggern 81,4%, vilket var lägre jämfört med då IceTag™ loggern inkluderades (84,2%). HOBO® loggern överskattade betningsbeteende med 5,1%, medan IceTag™ loggern underskattade betningsbeteende med 4,3%.

Denna studie visade att HOBO® loggern med en relativt hög säkerhet kan bestämma kors betesbeteende. För att säkerställa resultatet bör dock en vidare validering under en längre period med större variation i beteenden utföras. För att kunna bestämma födointag krävs ytterliggare utveckling av loggern.

Abstract

Information regarding cows grazing behaviour and time spent grazing can be of great interest to dairy farmers, since this information can indicate how well suited the pasture is to the cows. Feed intake at pasture is however challenging to measure. Automated systems for monitoring the behaviour of cows within dairy production have become increasingly important and relatively common.

The aim of this study was to validate an activity measuring device (HOBO® G Logger Pendant Data Logger, USA), a triaxial accelerometer that registers the cow's head positions during grazing, in order to see if cows' grazing behaviour on pasture could be distinguished from their non grazing behaviour. Another three axis accelerometer (IceTag3D™, IceRobotics Ltd, Scotland) was included and registered if the cows were in a standing or lying position. The validation was performed by comparing data from behavioural observations to information about head- and leg positions. By continuous sampling, the behaviour of 20 cows was studied during 5 hours each, divided into periods of 30 min.

Discriminant analysis showed that the HOBO® logger had an accuracy of 83.6% when estimating grazing behaviour. With addidtion of the IceTag™ logger the accuracy was 75.6%. When also non grazing behaviour was included the estimated accuracy for the HOBO® logger alone was 81.4%, which was lower compared to when the IceTag™ logger was included (84.2%). The HOBO® logger overestimated grazing behaviour with 5.1%, while the IceTag™ logger underestimated grazing behaviour with 4.3%.

The present study showed that the HOBO® logger is a relatively accurate and useful tool to automatically determine cows' grazing behaviour at pasture. To ensure the result, further validation for a longer period of time, with a larger variation in behaviours is needed. In order to know how large the actual feed intake is, additional development of the logger is required.

Introduction

The dairy cows in Sweden are, in accordance to the Swedish legislation, let outside to graze on pastures during two to four months every summer (DF 10§, SJVFS 2010:15 25-26 §§). Grazing has advantages for the cows as well as for the dairy farmers. Grazed grass, which is the very central part of the cows' diet in summertime, is the most inexpensive feed available to the producers (O'Kiely, 1994). To consume palatable grass and express natural foraging behaviour can improve the welfare of the cows (Phillips, 2002). The nutritional requirements of lactating dairy cows are high (Gibb *et al*., 1998; Phillips, 2002) and grazing cows may have an even larger energy requirement compared to confined cows, due to energy costs through an increased activity at pasture (Aharoni *et al*., 2009). When housed inside during most of the year, the feed intake of the cows is relatively well governed. Feed intake at pasture is challenging to measure, which can cause dairy farmers to become concerned that their cows are not appropriatly fed (Holmes and Wilson, 1984).

Information regarding cows grazing behaviour and time spent grazing can be of great interest to the dairy farmer, since this information can indicate how well suited the pasture is to the cows. Cattle graze around nine hours per day (Phillips, 2002) and a change in grazing time and grazing behaviour can reflect the quality of the pasture (Fraser, 1983). As the grazing season progresses and the quality of the pasture declines, cows can change their grazing behaviour (Albright and Avare, 1997), such as extending the time spent grazing and increasing their bite rate (O'Driscoll *et al*., 2010). If the quality of the grass is inadequate, supplementary feeding may be necessary to avoid decreases in body condition and milk production.

To visually observe grazing behaviour is time consuming and hardly an option in the modern production. Estimates based on automatic recordings would therefore be an advantage (Nielsen *et al*., 2010). The technology ought to be high in accuracy and cost efficient to be beneficial to the milk producer.

Automated systems for monitoring the behaviour of cows within dairy production have become increasingly important and relatively common. Development in technology means new openings in behaviour monitoring (de Passillé, 2010). Today there are a number of activity meters that can measure lying, standing (O'Driscoll *et al*., 2008; Aharoni *et al*., 2009; Darr and Epperson, 2009;

Bewley *et al*., 2010; Ledgerwood *et al*., 2010) and walking behaviour (Martiskainen *et al*., 2009; Moreau *et al*., 2009; Pastell *et al*., 2009; de Passillé *et al*., 2010). There is also some equipment available for studying grazing behaviour such as legswitch movement, jaw movement (Umemura *et al*., 2009) and biting and chewing sounds (Laca and WallisDeVries, 2000), together with bite mass and intake rate (Rutter *et al*., 1997; Gibb *et al*., 1998; O'Driscoll *et al*., 2010). Cows that graze have a slower and more irregular walking pattern than non grazing cows that walk. The head position of the cows differs as well (Shinoda *et al*., 2009. Abstr).

The aim of this study is to validate an activity measuring device (HOBO® G Logger Pendant Data Logger, USA) that registers the cow's head positions during grazing, in order to see if cows' grazing behaviour on pasture can be distinguished from their non grazing behaviour. This will be achieved by comparing registrations from the HOBO® logger to behavioural observations and data from another activity logger (IceTag3D™) that registers leg movement and standing/lying behaviour.

Literature review

Walking behaviour

During forward locomotion, like walking, the centre of gravity is moved towards the front limb by the thrust of the hind limb, and the front limb is then forced to lift and move forward in order for the cow to sustain the balance. During walking the cow is supported by three limbs at any time and each hoof is on the ground for at least half of the stride. The gait is cyclical and is divided into four different phases; lifting, swinging, supporting and thrusting, where the first two can be grouped into a hanging limb period, and the two later as a supporting limb period. Flexion and extension of the limbs in the different phases are carried out by using mostly hip, knee, hock and digital flexor- and extensor muscles (Phillips, 2002).

Cows have a walking speed of 1.33 to 1.47 m/s (4.8 km/h, respective 5.3 km/h) (Chapinal *et al*., 2009). To accelerate, both length and frequency of the strides are increased (Shipley *et al*., 1996). As the pace increases, the thrust phase is reduced (Phillips, 2002), as well as the time needed for swinging the limb forward. The velocity is partly depending on leg morphology and body size (Shipley *et al*., 1996).

A sound cow has a symmetrical gait where all legs equally bear the weight (Chapinal *et al*., 2009) at an even pace (Callaghan *et al*., 2003). The cow walks with a flat back posture (Sprecher *et al*., 1996; Callaghan *et al*., 2003; Chapinal *et al*., 2009; O'Driscoll *et al*., 2009) where the hind feet almost exactly land on or in front of the fore foot prints (Callaghan *et al*., 2003; Chapinal *et al*., 2009; O'Driscoll *et al*., 2009). The head is held steady while walking and there are no, or little, abduction or adduction of the hind legs (Chapinal *et al*., 2009; O'Driscoll *et al*., 2009). Abduction and adduction do exist, and increases with age and poor breeding (Phillips, 2002).

A cow can change her walking behaviour by shortening her stride and slowing down her pace if she is insecure, if the pasture is slippery or has insufficient lighting (Phillips and Morris, 2000; Phillips, 2002).

Foraging behaviour

Time budget

Cattle are primarily diurnal feeders, beginning at dawn and ending at dusk. They have about five grazing bouts per day, each bout lasts on average for 1 hour and 50 minutes (Phillips, 2002). Grazing time can be defined in several ways. O'Driscoll *et al*. (2010) consider a grazing bout being the period when the cow is performing eating jaw movements, including pauses between eating bouts in up to 7 minutes, when the cow is neither actively biting nor chewing forage. Gibb *et al*. (1998) suggest a 5 minutes limit of inactivity between eating bouts. Within a bout there can be a great number of pauses (Gibb *et al*., 1998). Number and length of bouts are not fixed. Generally they graze for about nine hours per day (Phillips, 2002), between eight and ten hours is common (McDonald *et al*., 2002), and as much as 12 hours can occur. They try to spread out their feed intake over the daylight hours, but if day length gets shorter or if intake requirements get higher, feeding at night time can take place (Phillips, 2002). The start of the grazing bouts is well synchronised among the cows in the same group (Gibb *et al*., 1998). The first meal generally starts shortly after sunrise, and is followed by three to four meals, where the last one ends around sunset (Phillips, 2002). The last bout is the longest and most intensive in order to have enough food to digest during night, when little grazing occurs (Gibb *et al*., 1998; Phillips, 2002). Cows' grazing behaviour is controlled by both external and internal factors. Access to an appropriate pasture is an external stimulus. Metabolic requirements and the hunger-satiety system are internal factors that affect the grazing behaviour (O'Driscoll *et al*., 2010).

Cows' diets consist of voluminous, high-fiber food, in large quantaties (Sjaastad *et al*., 2003). They consume coarse grass that are relatively low in digestibility, and therefore demand great amounts of mastication before they can be fully digested. Grazing cattle have developed an advantageous foraging strategy. They consume grass with relatively low selectivity as quickly as possible, and thereafter masticate it for a longer period, in somewhat safety (Phillips, 2002). A great part of the foraging time is spent chewing. While chewing they cannot graze efficiently, but they can start looking for the next food item (Laca *et al*., 1994). If they find the next bite while still chewing the former bite, the remaining mastication time could be spent in vigilance for predators (Phillips, 2002; Fortin *et al*., 2004), avoid competitors or interact with the herd, without reducing the intake rate (Fortin *et al*., 2004). Cows have a high foraging velocity (Shipley *et al*., 1996). However, with an increased velocity, the detection of the next tuft of grass will be more difficult (Getty and Pulliam, 1991). The grazing cow must alternating accelerate, and slow down and stop in order to capture her feed. Since that is energy- and time consuming, the cow often choose to take several bites in the same spot before moving on (Shipley *et al*., 1996). Fiber content of the forage (Shipley and Spalinger, 1992), together with bite size (Shipley and Spalinger, 1995) and number of bites that are ingested in the mouth before chewing (Laca *et al*., 1994), regulates how long the cow chew the previous bite before moving on. The walking speed during grazing is according to Shinoda *et al*. (2009. Abstr) between 0.25 km/h and 0.6 km/h, which is much slower than the estimated normal walking speed.

Anatomy, grazing behaviour and mastication

Cows' anatomy has evolved and adapted to the available types of plants and is well suited for grazing (Sjaastad *et al*., 2003; Shipley, 2007). Characteristic features are their wide muzzle and lips along with a broad dental arcade of flattened lower incisors (Phillips, 2002; Shipley, 2007). The wider lips facilitates the consumption of long grass (Sjaastad *et al*., 2003), while they inhibit the fine selectivty of individual plant items (Phillips, 2002). The lips are uncleft and not very mobile while the tongue is long and flexible (Sjaastad *et al*., 2003). Lips, teeth as well as tongue are all used to grab and transport the forage into the mouth (Phillips, 2002; Sjaastad *et al*., 2003). The tongue is wired around the grass, which is transferred into the mouth, where it is compressed between the incisors in the lower jaw and the upper palate. The grass is ripped off the sward by jaw movements and by shaking the head upwards (Phillips, 2002; Sjaastad *et al*., 2003). As the cows are grazing they move their head from side to side, in a characteristic sweeping action. Once in the mouth, the herbage is cut by the incisors and grinded by the molars, through up- and inward movements of the lower jaw (Phillips, 2002). The joint in the lower jaw allows great sideway movements, which enhances the grinding effect. Since the upper jaw is wider than the lower jaw, mastication can only be performed on one side at a time. The mastication side is changed about every 50th chewing motion (Sjaastad *et al*., 2003). Through intense chewing, with an additional contribution of saliva, a bolus is created and later on swallowed. After swallowing, the grazing cycle starts over again. During mastication the head is held horizontally, or in a somewhat lowered position (Phillips, 2002).

Feed intake

Feed intake is regulated by three different factors; bite size, bite rate (bites per minute) and total grazing time. A typical 600 kg dairy cow has a bite size of 0.85 g DM, but up to 3.24 g DM can occur, depending on grass type (Forbes, 1988). 30-70 bites per minute is common, which adds up to 30-40 000 bites per day, but as many as 50 000 bites per day do occur. The bite rate is generally held constant during the main part of a meal but varies over the day, and increases as the day progresses (Phillips, 2002). When calculating feed intake, Gibb *et al*. (1998) considered intake rate (bite mass and bite rate) and total eating time, with an exclusion of all periods of jaw inactivity longer than 3 seconds. Feed intake is not constant, individual differences in such as lactation stage, hierarchy, size and age occur. According to the optimal theory of grazing, the cows themselves optimize their input and output, by fulfilling their energy- and nutrient requirements at the lowest cost in energy and time spent grazing (Phillips, 2002).

Cattle prefer in general to graze pastures that are tall and thick. A tall sward eases the grasping of the grass and increases the bite size (Phillips, 2002; Shipley, 2007). McDonald *et al*. (2002) propose a relatively short sward (12-15 cm) to maximize bite size. Combined with a high denseness, a greater bite mass can be achieved, and they can faster secure their energy requirements (Shipley, 2007). A dark green pasture indicates a higher content of nitrogen, which is also preferred (Phillips, 1993).

Accelerometer technique

The HOBO® logger and the IceTag3D™ logger are two tri-axial accelerometers. They measure acceleration in three different axis, or channels; horizontally, vertically and laterally (Martiskainen *et al*., 2009). The sensors record acceleration and inclination simultaneously by the registration of an analogue signal in each axis (x, y, z). The three signals are converted into gravity units; -3 g to +3 g, which in Sweden means a measurement range of about 29.46 m/s^2 (1 g ≈ 9.82 m/s^2).

The three signals are summarised into one signal, which can graphically be shown in the raw data. The signal is proportional to the acceleration the cow exposes the accelerometer to. The accelerometer registers the position as a function of time (Huikai *et* al., 2008). By observing the graph, differences between behaviours can be seen, and comparisons can be made. The position of the acceleration channels in the graph depends on the logger's position on the cow related to the direction of gravity. When the cow is lying, the full force of gravity is recorded on the y-axis, with a response close to 1 g. The x-axis is in an almost neutral position with a response close to 0 g. When the cow is standing, the readings are reversed (Robert *et al*., 2009).

The acceleration is not measured continously by an accelerometer, point measurements are instead taken at a given rate; the sampling rate (de Passillé *et al*., 2010). The frequency of the sampling rate is measured in Hertz (Hz), which is number of samplings or events per second.

Activity measuring devices

Activity studies in animal production can according to Moreau *et al*. (2009) be divided into groups with three different purposes; firstly, in order to improve animal performance, such as lactation and reproduction. Secondly, to work as a health indicator, such as within lameness, and finally, to better understand the cows' utilisation of pasture, for instance by studying grazing behaviour.

Regarding the firstly and secondly mentioned purposes, it is well known that cows show an increased level of actvity during oestrus (Kiddy, 1977; Pennington *et al*., 1986; Roelofs *et al*., 2005) and that their activity level can decrease during lameness (O'Callaghan *et al*., 2003; Edward and Tozer, 2004; Mazrier *et al*., 2006). Since missed detection of oestrus (Britt, 1985; Plaizier *et al*., 1997; De Vries, 2006) and lameness (Clarkson *et al*., 1996; Green *et al*., 2002; Rajkondawar *et al*., 2002) can cause the farmer large financial drawbacks, the motivation for developing automatic detection devices has been high, and within these areas commercial activity devices are relatively well known (Firk *et al*., 2002; Roelofs *et al*., 2005).

When it comes to automatically measuring grazing behaviour of dairy cows, data loggers has become increasingly common, and the techology is developing. There are a number of sensors that are able to register activity and behavioural patterns within animal production. The HOBO® logger and the IceTag3D™ logger are two examples of activity measuring devices built on accelerometer technique.

HOBO®

Ledgerwood *et al*. (2010) has with satisfying results validated the HOBO® logger on dairy cattles' lying and standing behaviour, including lying time, number of lying bouts and laterality. The loggers were fitted on either the lateral or the medial side of 24 dairy cows. The logger was tested at different sampling intervals; 6, 30, 60 and 300 s. Lying and standing were to >99%

accurately estimated when using the 6- and 30 s sampling intervals. Ledgerwood *et al.* (2010) concluded that less frequent sampling, such as 300 s is useful for estimating lying time, but inadequate when measuring number of lying bouts. When the 300 s interval was used shorter standing and lying bouts were missed out.

de Passillé *et al.* (2010) used the HOBO® logger in order to study differences in acceleration of different gait types (walking, trotting, and galloping) in dairy calves. The logger was attached to one hind leg, measured in three axes, and set to a sampling rate of 33 Hz. By studying raw data, and calculation of the vector sum of the forward and vertical axes, all three behaviours could with a high accuracy be discriminated from each other.

Moreau *et al.* (2009) also used the HOBO® logger in order to distinguish goats grazing activity at pasture. Resting, walking and eating are behaviours that were looked upon. The latter was subdivided into browsing (head up) and grazing (head down). Three different mounting alternatives were tested; on a chest belt, on a dog's harness (placed on the wither) and on a neck collar (placed just behind the ears). The sensor could accurately recognise eating with 87% to 93%, resting with 68% to 90% and walking with 20% to 92%. To separate walking from eating, and eating from resting, the neck collar placement was the most effective, followed by the dog harness. Most accurate to distinguish between head up and head down when eating, was when the logger was attached to the dog harness. Grazing could correctly be recognised in 61% to 71% of the cases, browsing in 75% to 82%.

IceTag3D™

Nielsen *et al.* (2010) validated the IceTag3D™ sensor based on registrations from ten cows, all equipped with a sensor on both hind legs. The registrations were compared to video recordings. They concluded that the IceTag3D™ can estimate number of steps taken, and the frequency and duration of standing and walking with a fairly high accuracy. The highest accuracy rate they obtained was 90%, and that was when they excluded walking periods shorter than 5 s. Nielsen *et al.* (2010) also valdidated the IceTagAnalyzer software, how well it predicted lying or standing behaviour. The prediction was based on 177 recordings. Three out of the 177 recordings (1.7%) were misclassified. In two cases the sensor showed that the cows were standing, but they were in fact lying down. In one case the sensor incorrectly estimated the cow to be lying, when she in fact was standing.

Aharoni *et al.* (2009) used the IceTag™ logger together with a GPS and a heart rate monitor to study energy cost and grazing activity in cows on pasture. The IceTag™ logger contributed with information concerning position status and activity. Bewley *et al.* (2010) used the IceTag™ logger to give information about the time budget of milking cows.

Other accelerometers

Pastell *et al.* (2009) used a three dimensional accelerometer to distinguish lame cows from sound. A sensor, measuring 25 Hz, was fitted to each leg on 11 cows, 5 sound and 6 lame. The gait of the cows was filmed, and compared to measured data. They could see differences in acceleration in all phases of the gait. Acceleration differences in the gait of sound and lame cows could not clearly be seen in the raw data, but differences in symmetry between the legs were immediatly detected. The promising result is in a high grade due to that they used not only one, but four accelerometers per cow.

Robert *et al*. (2009) used a triaxial accelerometer in their behavioural study on calves, and could distinguish lying and standing from other behaviours with an accuracy of 99.2% and 98.0% respectively. Walking was classified with a 67.8% accuracy. The sampling rate was as high as 100 Hz, and three different logging intervals were tested; 3, 5 and 10 seconds. The two shorter intervals were in highly accordance with the true observations. However, if a behaviour last longer than the logging interval, there are risks of misclassifications (Aminian *et al*., 1999). Moreau *et al*. (2009) refer to cows' relatively slow movements and claim that a logging interval of less than 5 seconds is not necessary.

Müller and Schrader (2003) mounted an accelerometer to the hind leg of dairy cows. By sampling at 32 Hz, with a logging interval of 1 minute they managed to distinguish low activity (lying) from high activity (locomotion) relatively well. Behaviours that gave rise to different levels of activity could be identified from raw data of acceleration measurements. Depending on how sensitive the device is, disturbances can arise. An example of that is the small movements which the cow performes, while she is lying down and thus being inactive.

Martiskainen *et al*. (2009) attached a tri-axial accelerometer, sampling 10 Hz, to the neck collar of 30 dairy cows. Periods of activity and inactivity were easily distinguished from each other using raw data only. To acctually separate the different behaviours from one another, further processing of the raw data, through advanced classification methods was needed. After processing, using a Support Vector Machine, a statistical learning method, reasonable agreements were achieved. Ruminating, lying, and eating were all correctly classified by at least 80% (86%, 83% and 81% respectively). Walking, lame walking and standing were correct classified in less than 80% of the cases (79%, 66% and 65% respectively). Lying down and standing up were poorly classified with 0% and 29% respectively. Movements performed when the cows were lying down were often misread.

Other activity measuring techniques

Umemura *et al*. (2009) used a bite counter, attached to the collar, in order to register jaw movements in five dairy cows, and further be able to estimate their feed intake. The counter consisted of an advanced pendulum. The device managed to register jaw movements when the cow's head was tilted downwards, with the counter thus in contact with the jaw. It did however not manage to distinguish between prehensile bites and mastication. Results were to some part affected by walking. Recordings were compared to manual observations.

Laca and WallisDeVries (2000) used video recordings and a wireless microphone to distinguish biting and chewing sounds in order to estimate forage intake. The microphone was taped to the forhead of four steers, with a transmitter attached to the halter, and managed to accurately classify 954 biting and chewing registrations with 94% accuracy. The microphone showed more information about intake rate and were more accurate when distinguishing chewing motions compared to biting motions. Laca and WallisDeVries (2000) mention that different structures of the forage probably change the sound spectrum, and that different individuals produce different sounds. Teeth structure as well as size and shape of the head can have impact of the differences.

O'Driscoll *et al*. (2008) used a data logger including a mercury tilt switch which, attached to a hind leg, could sense if the cow was in a lying or standing position. The logger gave incorrectly some short lying registrations, which indicates that the logger registered some leg movements while standing. Other than that, the logger seems as a very good alternative to manual observations, since the indices of concordance were 96.9% and 93.7% respectively for standing and lying. Champion *et al*. (1997) also used the mercury tilt swith and achieved about the same results in lying and standing behaviour as O'Driscoll *et al*. (2008).

Gibb *et al*. (1998) and O'Driscoll *et al*. (2010) included the IGER grazing behaviour recorders in their studies in order to record grazing behaviour, such as grazing time per day, number of eating bouts and the duration of these. Bites per minute were also looked upon. The results had relatively large variations in significance. The IGER recorder is a microcomputer based system that registrates jaw movements digitally, and was first described by Rutter *et al*. (1997). It can distinguish jaw activity during grazing from jaw activity during rumination. The precursor to IGER was a simple stretchable noseband that produced electrical signals in proportion to jaw movements (Penning, 1983).

Material and methods

The study was performed at the Swedish University of Agricultural Science's research centre Kungsängen in Uppsala, during ten days at the beginning of June 2010. Data was collected through behavioural observations and registrations from two different activity monitoring devices. It was approved by the Uppsala Local Committee of Ethics in Animal Testing (Ref.no. C74-10) in agreement with the Swedish animal welfare regulations.

Animals

A total of 20 lactating dairy cows of the breed Swedish Red from the experimental herd of Kungsängen participated in the trial. Mean body weight at the beginning of the period was 622 kg (range 550-742 kg). The cows were both primiparous (n=4) and multiparous (n=16) within a lactation number varying from 1 to 5 (mean=3.0) with a mean of 130.8 days in milk (range 33-335 DIM). Average milk yield of the 20 cows was 33.7 litres/day (range 19.7-48.9 litres/day). The cows included in the study had no clinical symptoms of lameness.

The 20 cows were randomly organised into two groups with ten cows in each. Lactation stage and numbers of lactations were however taken into consideration when groups were formed. All cows were grazing a heterogeneous grass sward of *e.g.* timothy, meadow fescue and white clover. A large paddock was divided into four equally sized paddocks (ABCD) of 0.625 ha where group 1 (Cow 1-10) and group 2 (Cow 11-20) were grazing AB and CD respectively. The paddocks were separated with electric fences. Group 1 was circulating between paddock A and B, and group 2 was circulating between C and D to always ensure a satisfactory pasture. Due to another project, group 1 had access to shade through a 78.5 m^2 tent in their paddock. Each cow had access to 625 m^2 of pasture. Both groups were held on pasture day and night. Cows were however removed twice daily from pasture, from around 06.00 to 08.00 and from around 15.30 to 18.00 respectively when they were manually milked in a tied up barn. At milking the cows received a small feed sample with silage (3 to 4 kg DM) and concentrate. The cows had to do about ten minutes of walking to get to the barn, and the same amount on the way back to the pasture.

Behavioural observations

The behavioural observations were registered using personal digital assistants (PSION Workabout, Psion Teklogix, Canada) and were conducted during 5 hours a day for ten days, 2.5 hours in the morning (≈9.30-12.00) and 2.5 hours in the evening (≈18.00-20.30). The observations were performed by two persons, the author and a colleague. Each person observed one cow continuously for 30 minutes and ten cows per day. All 20 cows were observed during one day. Each cow was in total observed for 30 minutes per day and five hours during the whole observation period. The observers were stationed in an empty paddock (B or C), with full vision of all cows. The cows got quickly accustomed to the presence of the observers. To easier recognise and locate the observed cows, each cow was marked on their side with an individual number (1-20), in a luminescent colour. The behaviours which were registered using continuous sampling are presented in table 1.

Table 1. Ethogram with discriptions of the registred behaviours

Behaviour	Description of behaviour
Standing	All four feet on the ground
Walking	Moving forward, at least two feet on the ground
Grazing while standing	Standing with muzzle ≤ 15 cm from the ground
Grazing while walking	Walking with muzzle ≤ 15 cm from the ground
Getting down	Action performed between standing and lying
Lying	Trunk in full contact with the ground, with no weight support of the legs
Getting up	Action performed between lying and standing
Drinking	Muzzle in contact with water
Social behaviour	Interaction between at least two individuals
Other behaviour	Behaviour that does not fit into the above categories

Technical equipment

The cows were fitted with activity sensors, one on their head and the other on their leg. They were habituated to wearing the sensors one day prior to the start of recordings.

HOBO®

Each cow had a sensor (HOBO® Pendant G Acceleration Data Logger, USA) attached to their halter, in order to record the head positions during the registered behaviours. The sensor was positioned such that the x-axis was parallel to the jawline, pointing towards the muzzle, and the y-axis was peripendicular to the jawline, in the direction towards the eye (see figure 1). The unit was waterproof and made out of plastic, measured 58×33×23 mm and weighed 18 g. Plastic cable straps were used to fix the logger to the halter (see figure 1).

The HOBO® logger is a three-channel logger, but number of channels is selectable and we chose acceleration measurements in two axes; x and y, meaning measurements in 2g. The logging interval was set to every fifth second, which means that the acceleration of the cow and the changes in inclination of the head is measured every fifth second. The capacity of the loggers' memory depended on logging interval as well as number of logged channels. We chose to reduce the load of the memory by reducing the number of axis. The exclusion of the third channel would not impact the quality of the grazing activity measurements (de Passillé, *et al*., 2010; Ledgerwood *et al*., 2010).

The loggers were launched on a laptop in the barn by a coupler and base station with USB interface. HOBOware® software was used to visually see the measurings. Behaviours were recorded and stored in the logger until downloaded to the laptop the following day, during afternoon milking. When data had been successfully downloaded, the loggers were once again fixed to the halters and reactivated. This was a daily routine during the ten days of recording.

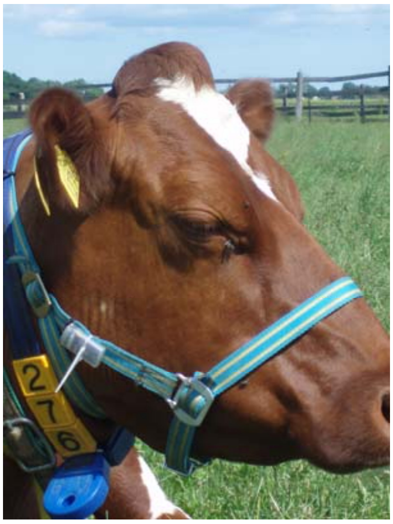

Figure 1. Placement of head logger attached to the halter.

Figure 2. Placement of logger attached to the leg (Photo: IceRobotics).

IceTag3D™

Another three axis accelerometer (IceTag3D™, IceRobotics Ltd, Scotland) registered if the cow was lying or standing. The device was waterproof, made out of plastic, measured 96×81×31 mm and weighed 130 g. It was attached to the cow's right hind leg, between the hock and the fetlock (see figure 2), with a 360 mm long and 40 mm wide belt of Velcro tape. The x-axis was parallel to the ground in the direction of the cow's head, while the y-axis was vertical to the ground in the direction of the cow's back. The z-axis was parallel to the ground but with direction to the median plane of the cow. When the logger, and consequently the leg of the cow, deviate 45° from the vertical plane the cow is registered as lying down. Since cows often fold their front legs underneath them when lying down, the sensor was attached around the hind leg, meaning fewer disturbances to the cow (Gustafsson *et al.*, 2007). The right leg was chosen since studies have shown that pregnant cows, particularly in late gestation, prefer to lie on their left side, due to discomfort associated with the growth of the foetus into the right abdominal cavity (Arave and Walters, 1980; Forsberg *et al.*, 2008). Grant *et al.* (1990) claim that rumination is more effective when the cow lies on her left side, due to the position of the rumen.

The IceTag3D™ sensor measured the cow's activity at 16 Hz in three dimensions. The data was stored in the device until transferred wirelessly to a laptop in the barn, using the USB connected IceReader® download station. The IceTag3D™ sensor had a large memory so data was only downloaded and reactivated when needed, about two times during the data collection period. After downloading, the registered data could be viewed in tabular and graphical form using IceTagAnalyser® software. The data was summarised in intervals of every second, to better match the HOBO® logger.

Statistical analysis

All gathered data from the personal digital assistants and HOBO®- and IceTag3D™ loggers were transferred to a PC and converted into text files. The files were examined visually, filtered and corrected if inaccurate before imported to SAS (Statistical Analysis System, version 9.2, SAS Institute Inc., 2008). The time settings of laptop and PC were synchronised. Data from every fifth second from the three devices were merged into one large data set. All data from each cow during all ten days was identified, which summed up to 69 881 registrations and 20 individual sets of data (Cow 1 to 20).

The data from the behavioural observations was compared to the information about head- and leg positions, in order to decide if the cows were grazing or not. When a cow is grazing and she has her muzzle in contact to the ground, thus the inclination of her head changes, the x- and y axis of the HOBO® logger show different values compared to when she is not grazing. Threshold values for grazing were manually set to a span between $x > 0.5$ and $y > -0.7$. However, to find the optimal values a linear discriminant model was practiced, using the DISCRIM procedure in SAS (Version 9.2, SAS Institute Inc., 2008). The discriminant criterion in the model classifies the observations into either grazing or non grazing behaviour. To be able to predict how accurately the model would be in practice, cross validation was performed. The data was divided into two subsets; one training set and one validation set. In the first set an analysis was performed, the model was trained and the fit optimised. In the other set the analysis, and consequently the loggers' accuracy was validated. Four random cows out of the 20 were included in the training set (14 040 registrations), and the remaining 16 cows were included in the validation set (55 841 registrations). The procedure gave estimated classification rates between observed grazing behaviour and grazing behaviour registered by the activity devices. Non grazing behaviour was also estimated.

The validation of the HOBO® logger was divided into two parts:
- Including the IceTag3D™ logger
- Excluding the IceTag3D™ logger

Results

The validation of the HOBO® logger was divided into two parts; one including and the other excluding the information from the IceTag™ logger. The total number of registrations in the validation set were 55 841, with 23 090 grazing registrations (41.3%) and 32 751 non grazing registrations (58.7%), see table 2.

Table 2. Number of grazing/non grazing registrations and percentage of total registrations

	Obs.	**%**	**HOBO®**	**%**	**HOBO® +IceTag™**	**%**
Grazing behaviour	23 090	41.3	25 895	46.4	20 677	37.0
Non grazing behaviour	32 751	58.7	29 946	53.6	35 164	63.0
Total	55 841	100.0	55 841	100.0	55 841	100.0

To classify the registrations into either grazing or non grazing behaviour the optimal function obtained from the linear discriminant analysis was used:

$$y - 0.738775 + 1.603250x > 0 = \text{Grazing}$$
$$y - 0.738775 + 1.603250x < 0 = \text{Not grazing}$$

The comparison between the recorded data from the activity loggers and the observations of the 16 cows is displayed in table 3. The HOBO® logger showed an overall accuracy in grazing- and non grazing behaviour of 81.4%. When the IceTag™ logger was included, the accuracy was 2.7% higher. When solely estimating grazing behaviour the HOBO® logger alone had a higher accuracy rate (83.6%) compared to when information from the IceTag™ logger was included (75.6%). The HOBO® logger overestimated grazing behaviour with 5.1%, while the IceTag™ logger underestimated grazing behaviour with 4.3% (see table 2). Notable is when estimating non grazing behaviour with the inclusion of the IceTag™ logger, the accuracy was as high as 90.2%, compared to 79.9% for the HOBO® logger alone.

Table 3. The predicted classification rates of grazing and non grazing behaviour for HOBO® logger including/excluding the IceTag™ logger

Behaviour	Logger	Correct class. (%)	Error rate (%)
Total	HOBO® HOBO®+IceTag™	81.4 84.2	18.6 15.8
Grazing	HOBO® HOBO®+IceTag™	83.6 75.6	16.4 24.4
Non grazing	HOBO® HOBO®+IceTag™	79.9 90.2	20.1 9.8

The HOBO® logger managed to correctly classify the behaviours with a relatively high accuracy rate, but with large differences between individual cows. Figure 4a shows a plotted graph with the overall results of the estimated classiffications for the 16 cows. Figure 4b shows the results with addition of leg position (lying or standing).

The graphs consist of estimated registrations of grazing- and non grazing behaviours, expressed as symbols in four different colours. Each symbol/colour has a different significance.

○ Black/Circle	Observed as Non grazing	Registered as Non grazing	Correct
● Red/Filled circle	Obs. Non grazing	Reg. Grazing	Incorrect
■ Green/Filled square	Obs. Grazing	Reg. Non grazing	Incorrect
□ Blue/Square	Obs. Grazing	Reg. Grazing	Correct

In order to avoid overwriting and to clearer visualise the trend, only every 100th registration is shown in figure 4a and figure 4b, and every 25th registration in figure 5a and figure 5b. The discriminant (y – 0.738775 + 1.603250x), the optimal threshold between grazing and non grazing of the HOBO® logger is displayed in the graph, as well as the initial discriminant. An optimal result would be exclusionary black and blue symbols.

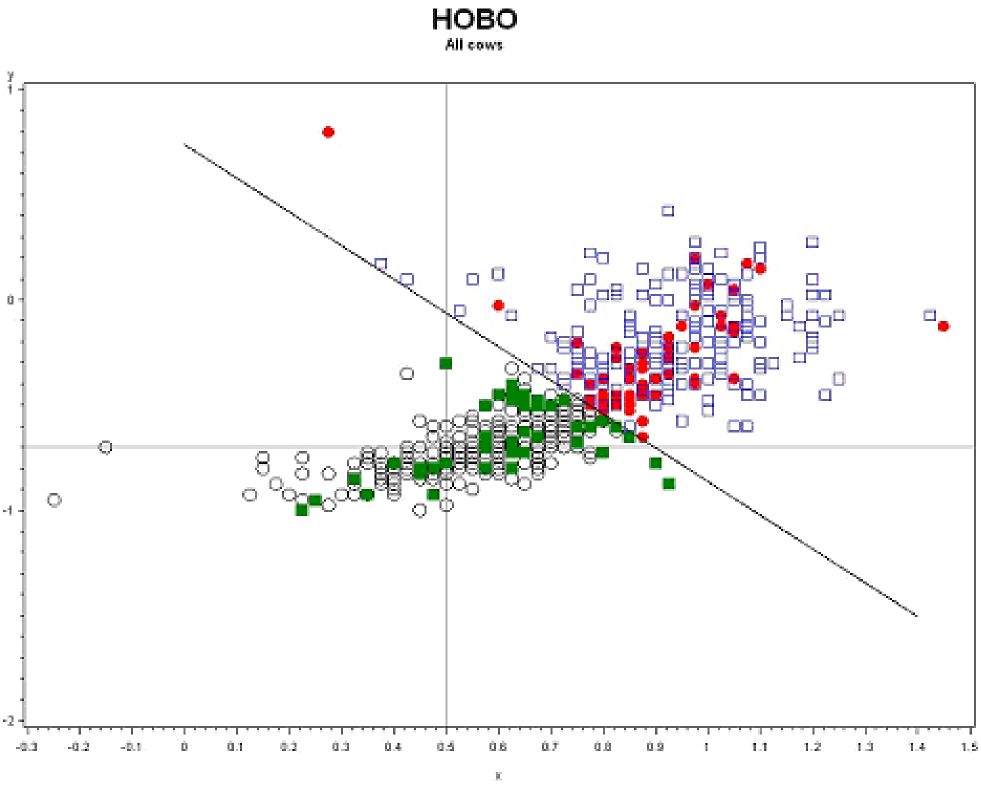

Figure 4a. Estimated behaviour classifications of all 16 cows, excluding information from leg logger. Blue squares are correctly estimated grazing registrations, black circles are correctly estimated non grazing registrations. Green squares and red circles are incorrect estimations. Every 100th registration is shown in the graph.

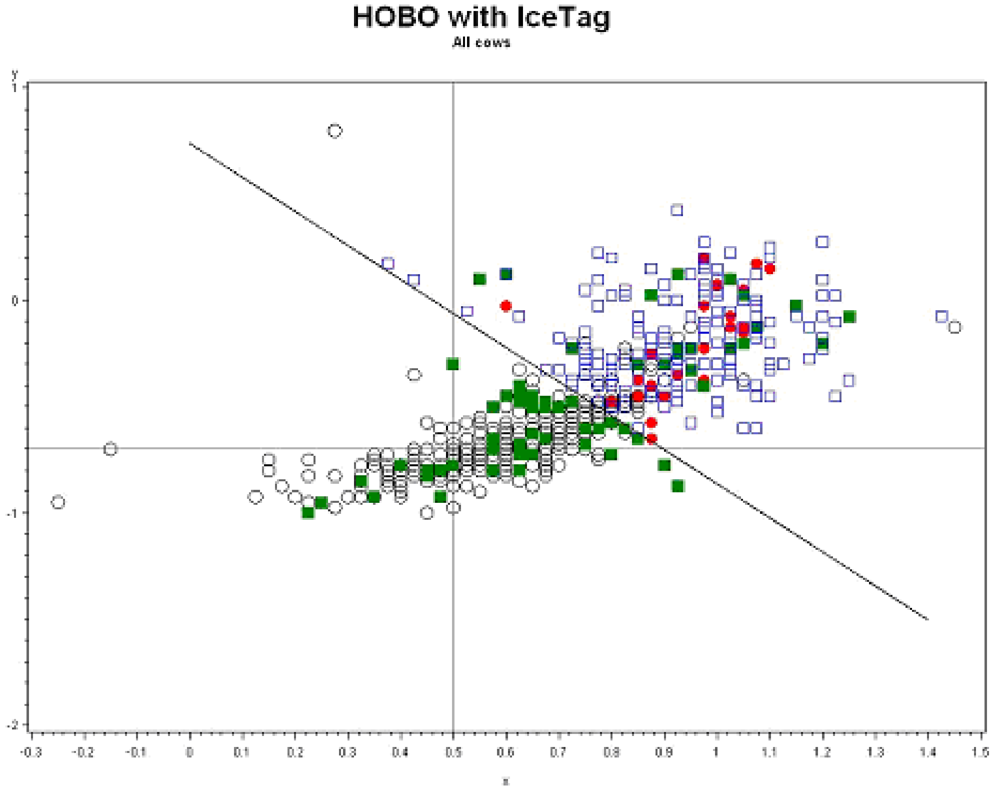

Figure 4b. Estimated behaviour classifications of all 16 cows, including information from leg logger. Blue squares are correctly estimated grazing registrations, black circles are correctly estimated non grazing registrations. Green squares and red circles are incorrect estimations. Values have a tendency to change whether leg logger is included or not. Every 100th registration is shown in the graph.

Some cows were correctly classified to a very high rate (high proportion of blue and black symbols), while other cows had a high rate of misclassification (high proportion of red and green symbols). Figure 5a and figure 5b show graphs with the registrations plotted of cow number 20, which displayed a relatively high rate of agreement between observed grazing behaviour and with the loggers predicted grazing behaviour, as well as a low number of errors.

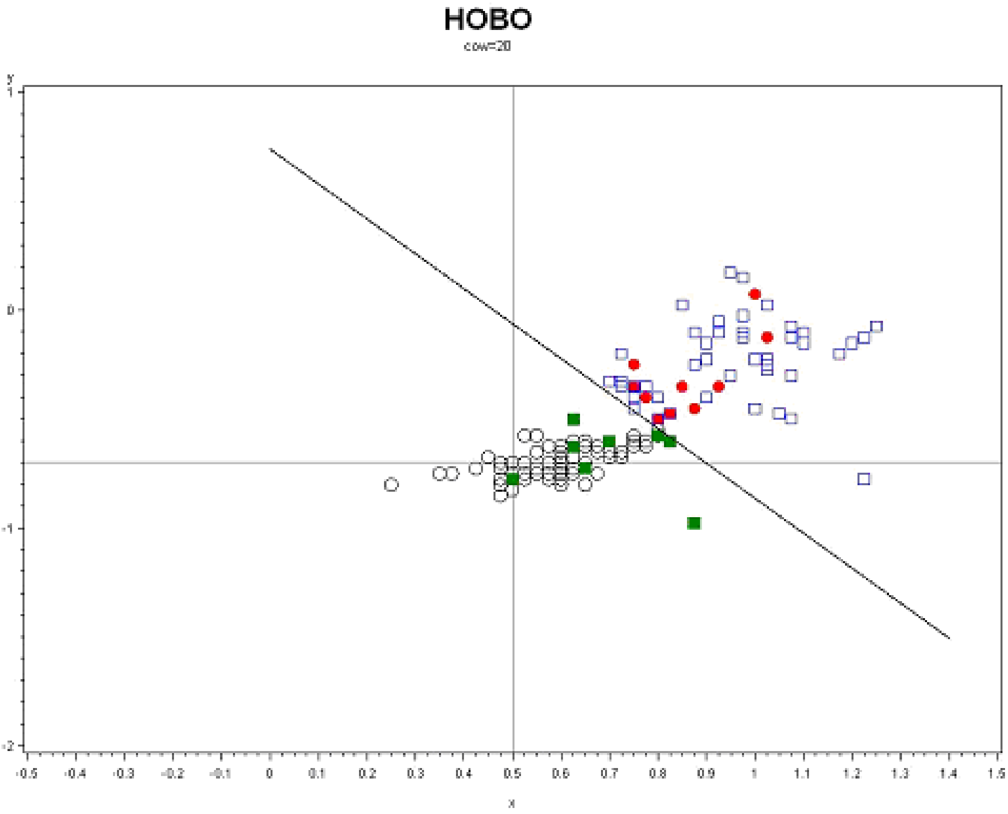

Figure 5a. Estimated behaviour classifications of cow number 20, excluding information from leg logger. Blue squares are correctly estimated grazing registrations, black circles are correctly estimated non grazing registrations. Green squares and red circles are incorrect estimations. Values have a tendency to change whether leg logger is included or not. Cow number 20 has a relatively high rate of agreement between observed grazing behviour and with the logger estimated grazing behaviour, as well as a low number of errors. Every 25th registration is shown in the graph.

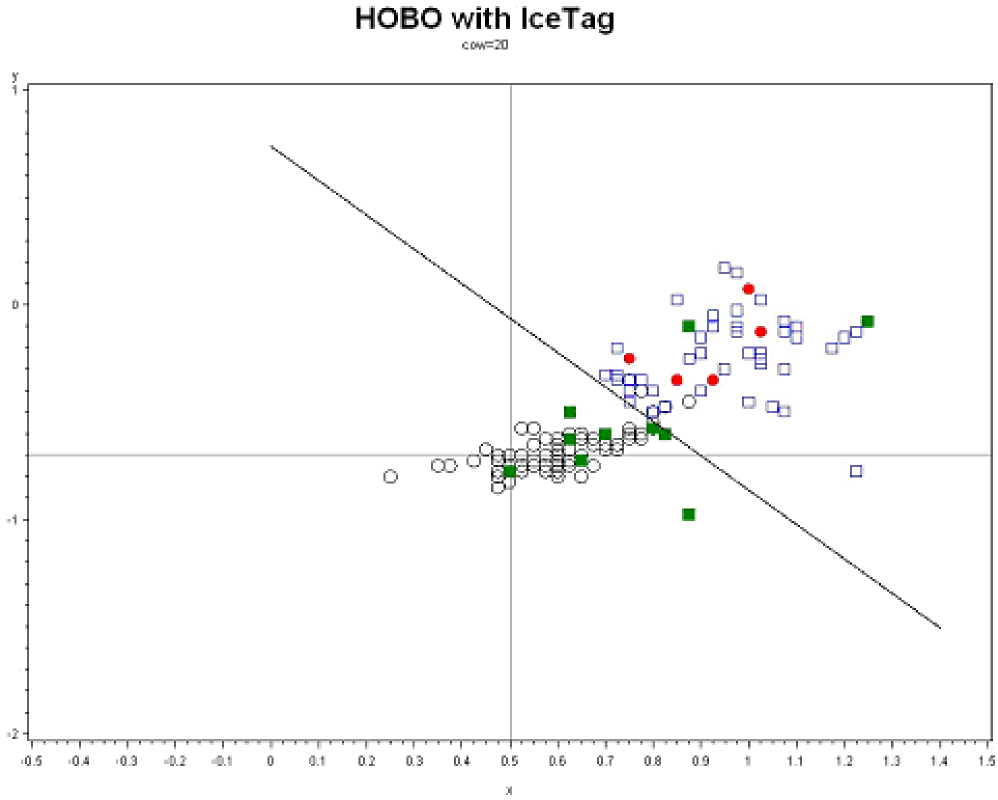

Figure 5b. Estimated behaviour classifications of cow number 20, including information from leg logger. Blue squares are correctly estimated grazing registations, black circles are correctly estimated non grazing registrations. Green squares and red circles are incorrect estimations. Values have a tendency to change whether leg logger is included or not. Cow number 20 has a relatively high rate of agreement between observed grazing behviour and with the logger estimated grazing behaviour, as well as a low number of errors. Every 25th registration is shown in the graph.

Figure 5a shows the behavioural estimations of the HOBO® logger exclusively. The IceTag™ logger gives in figure 5b the additional information if the cow is standing up or lying down, which therefore can change the appearence of the graph. If the HOBO® logger accurately estimate that the cow is grazing, but the leg logger has estimated that the cow is lying down (and therefore presumed not grazing), the overall estimation would be that she is not grazing, which is inaccurate. When included, the accuracy of the IceTag™ logger is crucial in order to make the correct estimations. In figure 5a there are some blue symbols that in figure 5b has turned green, which indicate that the IceTag™ logger has overestimated non grazing behaviour (lying).

Discussion

The validation of the HOBO® logger was divided into two parts. In the first part the accuracy of the HOBO® logger itself was evaluated, in the second part the IceTag™ logger was included, to see if information about the leg position would increase the accuracy. The IceTag™ logger was believed to give some extra support to distinguish what behaviour the cows were performing, *e.g.* if the inclination of the head logger says that the cow is grazing, that could be backed up if the leg logger says that she is actually standing. The loggers correctly classified the behaviours with a relatively high rate of accuracy, but with large differences between individuals. Differences in between the loggers could be seen; with an accuracy of estimated grazing behaviour of 83.6% for the HOBO® logger and 75.6% when including the IceTag™ logger. When also non grazing behaviour was included the estimated accuracy for the HOBO® logger alone was 81.4%, which was lower compared to when the IceTag™ logger was included (84.2%).

The differences in the results of estimations between the loggers (seen between figure 4a and figure 4b, and between figure 5a and figure 5b) can be explained. When blue dots in figure 4a and figure 5a, have turned green in figure 4b and figure 5b, it means that grazing behaviour which was correctly estimated by the HOBO® logger, has been incorrectly estimated by the IceTag™ logger, *i.e.* the leg logger says that the cow is lying down, and thereby not grazing. When red dots in figure 4a and figure 5a, have turned black in figure 4b and figure 5b, it indicates that the HOBO® logger missclassified the observed non grazing behaviour, but the IceTag™ logger states that the cow is lying down, and thereby not grazing.

In this study, the behaviours of the cows were studied through direct observations, using personal digital assistants. This method is highly subjective, and registrations of behaviours can be delayed due to human error. If, as in this case, two observers are involved, it may result in additional differences (Müller and Schrader, 2003). Using video recordings, subjective judgements such as when the behaviour starts and ends can be discussed and standardised afterwards. This approach, however, is very time consuming (Moreau *et al*., 2009; Ledgerwood *et al*., 2010). In both methods, it is important that all equipment is synchronised, since also a minor time deviation can have a large impact on the interpretation of the data.

Where on the cow the activity devices are fixed is important (Moreau *et al*., 2009). Also a proper attachment is crucial, since they are supposed to register the movements of the cow, and not the movements of the halter or the leg band itself. In order to avoid incorrect registrations the sensor should be mounted so that deviation from its initial position is impossible (Martiskainen *et al*., 2009). In this study all leg loggers were fixed in a similar way of all 20 cows. The head loggers' position may however have differed more between cows, due to different shapes and sizes of their heads. This required some adjustment to some halters, in order to fit. Once the halters' size had been adjusted, the prerequisites for the inclination of the logger may have changed. It is also of great importance that the devices do not interfere with the cows' ability to move (Müller and Schrader, 2003). Cuthill (1991) state that the weight of the sensor should not exceed 5% of the body weight of the cow. In our case that would mean that the sensors could not exceed 27.5 kg for the lightest cow, and 37.1 kg for the heaviest cow, which they did not, by far.

Nielsen *et al*. (2010) mention the issue with inaccurate estimation of activity measurement, attached to a leg. Cows can walk in such a low speed that the sensor is not registrating any activity for some time. If only one leg is equipped with a sensor, the risk for missed out walking behaviour is larger, since the cow can move the legs that are not provided with sensors. Another risk for misprediction can be that the cow is standing still with her body, but lifting her legs, and thus incorrectly registrating walking behaviour. Incorrect registrations can also be made by the logger attached to the head. A more slippery surface can change the gait of the cow (Phillips and Morris, 2000; Phillips, 2002), and thus also the inclination of the head, and its logger. Other factors that may change the gait pattern, and thus head position, or differ between individuals are lameness (Sprecher *et al*., 1996; Callaghan *et al*., 2003), size, length of legs and thus strides, age, gestation, udder size, udder fill, breeding (Phillips, 2002), adduction or abduction (Chapinal *et al*., 2009; O'Driscoll *et al*., 2009). The results in this study may have been affected by these factors. All cows are individuals, which can explain the large spread in accuracy between cows.

During the observations of the cows' behaviour at pasture, grazing behaviour was defined as standing or walking with the muzzle ≤ 15 cm from the ground, eating or not. As soon as the muzzle was > 15 cm from the ground they were assumed as being standing or walking, chewing or not. This resulted in many registrations such as: grazing, walking, grazing, walking, etc. Other studies may have defined that as grazing (Gibb *et al*., 1998; O'Driscoll *et al*., 2010). In combination with the delays due to human errors there may have been som incorrectly estimated registrations.

The HOBO® logger has been validated in order to distiguish behaviours, such as lying and standing (Ledgerwood *et al*., 2010) and locomotion, such as walking, trotting and galloping (de Passillé *et al*., 2010) with highly accurate results. In these studies the loggers were attached to the legs of the animals. Even more interesting for this study is Moreau *et al*. (2009) who in their study could some what discriminate grazing from walking in goats, when the logger was placed on a neck collar. The estimation of grazing behaviour had an accuracy of 61%-71%, which is lower than in this study.

The IceTag™ logger did not work at its optimum in this study, but there are several studies that show more accurate estimations. Nielsen *et al*. (2010) could estimate number of steps taken, and the frequency and duration of standing and walking with a 90% accuracy. Bewley *et al*. (2010) achieved valuble information about the time budget of dairy cows, and Aharoni *et al*. (2009) got information about pasture position status and activity by using the IceTag™ logger.

The HOBO® logger was attached to the cow's halter, which can be valuble when measuring grazing behaviour. A light and flexible sensor attached to the halter seems more beneficial than a larger and bolder one attached to the leg. Umemura *et al*. (2009) think that a device attached to a halter is not pratical in the dairy production and suggest a device around the already existing collar instead. The different positions of the head are much involved in grazing, which argue for a head attachment. The very same degree of inclination may however exist during lying as during grazing, but for grazing distinctive jerking head movements are relatively unusual during lying. An IceTag™ logger for neck attachment has been launched in early 2011, which would be interesting to se results upon.

To be able to have an idea of how much the cows are actually grazing some kind of automatic measuring device is needed. The HOBO® logger in this study has proved to be a relatively useful tool to automatically determine cows' grazing behaviour at pasture, but further validation for a longer period of time, with a larger variation in behaviours is desirable. In order to know how large the actual feed intake is, additional measurements are needed. Preferable would be to intergrate another device to the activity logger. A microphone that can distinguish biting sounds from masticating sounds may be an idea.

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