VALIDATION AND IMPLEMENTATION OF A REMOTE THREE-DIMENSIONAL ACCELEROMETER MONITORING SYSTEM FOR EVALUATING BEHAVIOR PATTERNS IN CATTLE

by

BRADLEY DUANE ROBÉRT

B.S., Kansas State University, 2007

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Clinical Science
College of Veterinary Medicine

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2010

Approved by:

Co-Major Professor
Dr. B.J. White

Co-Major Professor
Dr. R.L. Larson

Abstract

We performed research that investigated the ability of three dimensional accelerometers to classify cattle behavior and also describe the circadian patterns within that behavior. The first of three studies (validation study) tested a decision tree classification system and its ability to describe behaviors of lying, standing, and walking. Classification accuracies for lying, standing, and walking behaviors were 99.2%, 98.0%, and 67.8% respectively, with walking behavior having significantly lower accuracy (P<0.01). This study also tested the accuracy of classifying the above behaviors using different device reporting intervals, or epochs. Reporting intervals of 3, 5, and 10 seconds (s) were evaluated in their ability to describe cattle behaviors of lying, standing, and walking. Classification accuracies for the 3s, 5s, and 10s reporting interval were 98.1%, 97.7%, and 85.4% respectively, with no difference in classification accuracy of the 3s and 5s epochs (P=0.73) while the 10s epoch exhibited significantly lower overall accuracy (P<0.01). This validated accelerometer monitoring system was then implemented in two studies (Winter 2007 and Spring 2008) where the devices were used to describe behavior patterns of beef calves in a drylot production setting. Lying behavior of the cattle was analyzed and found to be significantly associated (P<0.001) with hour of the day. Calves in these studies spent most (> 55%) of the nighttime hours (2000 to 0400) involved in lying behavior and spent the least percentage of time lying (<30%) during periods of time where feed was presented at the bunk (0700 and 1700). Mean lying time was also associated with trial day (P<0.01) and most trial days (67.5%) calves spending between 45% and 55% of time lying. Variation of lying behavior was found between individuals (range 29% to 66%); however, consistency in lying behavior was found within individual calves across study periods. The accelerometer monitoring system studies presented here provide evidence these devices have utility in recording behaviors (lying, standing, and walking) of individual beef calves raised in typical production settings.

Table of Contents

List of Figures

List of Tables

Acknowledgements

It is an honor to thank those who have helped me throughout my Master's experience. Firstly, I would like to thank my advisory committee members Dr. Brad White, Dr. David Renter, and Dr. Robert Larson. The knowledge shared and time spent helping me during my studies was immeasurable. By challenging my thinking, research, and writing skills on a daily basis they helped me to become a successful graduate student and researcher. As arduous and time-consuming that a graduate degree can be, I must admit that I truly had one of the best times of my life. These three along with my fellow graduate students helped me realize my true potential as both a student and person. Speaking of fellow students, I couldn't have worked with a better group of people. A special thanks to my office mates Gregg Hanzlicek and Abram Babcock who were there every time I needed help; whether it was explaining statistics or if I just needed an extra set of hands while working cattle. I was also fortunate to work with Dr. David Anderson and Dr. Hans Coetzee on several exciting research projects; and I must say there was never a dull moment.

I would also like to thank Jason Nickell, Craig Pauly, Brandon Reinbold, Brian Lubbers, Ben Wileman and Lindsey Kelly for all of the advice and help given. I hope you know how much I truly appreciate all of the guidance and support you've given me; and it was an absolute pleasure getting to know all of you. Finally, I would like to thank my friends and family for being there for me whenever I needed a lift. Mom and Dad especially; you lead by example and have always told me to never give up, and that things happen for a reason. I love you both more than you will ever know and I will never forget the encouragement and advice you have given me; without you I wouldn't be where I am today.

CHAPTER 1 - Thesis Introduction

For research and animal health purposes it has become important for livestock producers and animal health care providers to evaluate the behavior of their cattle. In the past, simple subjective evaluations have been used for describing cattle behavior; however, new thoughts about the implications of animal husbandry, treatment protocols, and surgical procedures on cattle behavior have aroused interest in behavioral analysis. Not only do researchers want to describe the behavior of cattle, they wish to quantify the different activities that compose the animal's behavioral repertoire as well have an objective method for making comparisons; something that is impossible with subjective evaluations. In order to accomplish these tasks novel devices such as video-analysis, pedometers, Global Positioning Systems (GPS) and accelerometers have been used to provide a remote, objective, and consistent method for evaluating cattle behavior.

The implementation of remote electronic monitoring schemes in today's cattle production settings can prove to be a difficult task. Most livestock production settings house animals outdoors, an environment that is very hostile for the application of electronic monitoring devices due to the potential for mud, feces, water, and physical damage to interfere with the devices' monitoring capabilities. Also, management and housing of cattle are often done on a group basis, sometimes having up to several hundred individuals per group, making the behavioral monitoring of individual animals even more difficult to achieve.

Cattle involved in these were similar in type and were managed according to standard U.S. practices in order to present relevant information to what is typically done in the cattle industry. This thesis presents the logical steps involved with the development, validation, and implementation of a remote three-dimensional accelerometer monitoring system for use in cattle. The validation study (Chapter 3) tested the ability of a decision tree classification system to accurately describe lying, standing, and walking behavior in cattle using video analysis as the "gold standard." This study also evaluated the ability of different accelerometer recording settings as to their accuracy in classifying data into the above behaviors. This validated system was then implemented in two studies (Chapter 4) where the monitoring system was used to describe the behavior patterns of growing beef cattle. Accelerometers recorded data remotely and applied at the individual animal level; differences and patterns in cattle behavior that we found may have implications for future studies involving behavior as a study outcome. This thesis provides evidence of the merit of accelerometers for monitoring cattle behavior in typical production settings.

CHAPTER 2 - Review of Literature

Introduction

The assessment of free-moving individuals in an open environment presents difficulties when trying to describe their physical activity or behavior. Quantifying normal behavior patterns of cattle can provide researchers and animal health providers with activity information that would be useful for determining the effects of various environmental and procedural stimuli on health-related, physiologic, and production aspects of behavior. Previous research (Berger, Scheibe et al. 2003) has shown that biological rhythms can be used to define periods of abnormal behavior caused by adaption, sickness, and social interaction, as well as stress-inducing conditions. Commercial production and experimental research settings routinely house cattle together in large groups making monitoring individual calf behavior difficult. Behavioral data needs to be repeatable, natural or undisturbed, and free from bias due to the observer or observational method. These requirements can be achieved by using remote monitoring systems directly implemented on the animal in the production setting environment.

Several researchers have argued that new, technologically advanced, and objective monitoring systems may become reliable behavioral assays if validated.(Geers 1994; Frost, Schofield et al. 1997; Duff and Galyean 2007; Weary, Huzzey et al. 2009) Several systems have been used to monitor cattle behavior and each methodology has potential benefits and caveats when employed to evaluate cattle activity in the field. Environmentally mounted systems may utilize video cameras to give basic behavioral information regarding environment interaction, locomotion, and overall activity (Chapinal, de Passille et al. 2009; Mitlohner, Morrow-Tesch et al. 2001; Huzzey, Veira et al. 2007). Animal location monitoring systems such as Global Positioning Systems (GPS) can be used to describe grazing patterns and spatial orientation (Turner, Udal et al. 2000; Ungar, Henkin et al. 2005; Guo, Poulton et al. 2009). Transponders have also been developed to provide information about the latency, duration, and bout number of feeding and watering behavior in animals housed in typical production settings (Schwartzkopf-Genswein, Atwood et al. 2002; DeVries, von Keyserlingk et al. 2003; Sowell et al. 1999). Pedometers have evolved from step-count only devices into accelerometers capable of describing postural activities (lying, standing, ruminating) as well as ambulatory activities (grazing, walking) allowing researchers to distinguish behavior pattern changes associated with reproduction and health. These unique monitoring systems allow the observer to obtain a more accurate assessment of animal well-being without influencing behavior with human presence.

An objective method to monitor cattle behavior is critical for generating data necessary to evaluate potential activity changes due to the implementation of new health, management, or production procedures. The objective of this review is to describe the challenges associated with behavioral measurement in cattle and the potential benefits and limitations of several behavioral measurement technologies including: visual observation, video analysis, positional tracking, radio frequency transponders, pedometers, and accelerometers. This work should provide the basic information necessary to assist future researchers in selecting the most appropriate behavioral measurement technology for the specific situation and desired measured outcomes.

Challenges with cattle behavioral observation

Evaluation of natural cattle behavior patterns is difficult due to the animal's response to human interaction as well as animal interaction with other environmental factors. The human-animal interaction and the impact of the production systems influence inferences about the effect of different treatments and environments regarding behavior. Cattle behavior can be impacted by the frequency and method of animal handling, the presence of humans, and additional environmental factors.

Many common cattle production procedures do not inflict significant pain responses; however, the psychological fear of humans may initiate behavioral changes when the animal is handled (Grandin 1997). Human-animal interactions routinely occur and are essential to livestock production; however, frequent and unnecessary interactions can result in increased animal fearfulness leading to stress that potentially can limit the productivity and welfare of the animal (Hemsworth 2003). Grandin (1993) evaluated the persistence of behavioral agitation in cattle and found abnormal behaviors upon entering a squeeze chute were consistent within individuals. These individuals showing abnormal behaviors in the chute were indistinguishable among a pen of their peers after exiting the chute, implicating that handling was associated with the altered behavior. Observing cattle undisturbed in the pen was not adequate to identify animals that showed severe aversive behavior in the processing facility (Grandin 1993). Gupta et al. (2008) evaluated the effect that repeated regrouping and relocation (R&R) had on 14 month old Holstein-Fresian steers. Compared to a control group whose composition and location was never altered, they found the R&R group spent a greater percentage of time (P<0.05) standing, eating, and drinking than control steers for the two days subsequent to each relocation and regrouping (Gupta, Earley et al. 2008). A study testing the effect of different handling procedures (good, minimal, poor) found that receiving poor handling (noisy, abusive, deprived of food and water) during cattle receiving negatively impacted liveweight gain of cattle (Petherick, Doogan et al. 2009). These studies demonstrate how the presence of a human or an actual human-animal interaction can impact cattle behavior. This altered behavior due to human presence negatively impacts our ability as observers to accurately describe true behavior, but observational methods utilizing remote or indirect tactics could prove useful in alleviating this effect.

A study involving Angus heifers (Ishiwata, Kilgour et al. 2007) tested conditions immediately following restraint in a squeeze chute. When given the choice of entering a pen containing a human observer or novel object, animals more frequently chose the pen not containing a human (P < .01). They concluded that stress could be moderated immediately following restraint if the animals were returned to a group of peers and not approached needlessly. A similar study using 10 month old Saler and Limousine calves performed docility tests during situations where human presence and contact was tested along with presence of the calves' peers (Grignard, Boissy et al. 2000). This study found calves that maintained visual contact with their peers spent more time (P < 0.001) motionless than when isolated and calves were significantly less still when the human was present than when the human was absent (P <0.001) (Grignard, Boissy et al. 2000). Merely having a person present to observe cattle behavior may influence animal activity; therefore, direct observation by a person in visual contact with the cattle may result in behavioral data inadvertently altered by the presence of a person.

Not only is domesticated animal behavior affected by human presence, the presence of wild predator species (wolves, mountain lions) can cause adverse behavioral changes in these animals because they are prey animals. A study of cattle vigilance or scanning behavior found individuals in small groups ($n<6$) exhibited increased vigilance rates when compared to animals in larger groups (Kluever, Breck et al. 2008). A subsequent study (Kluever, Howery et al. 2009) was able to modify cattle behavior with the presence of olfactory and visual cues from predatory (wolf) and heterospecific (mule deer) animals; finding those cues affected foraging rates, vigilance, and use of high quality foraging areas. Areas where natural predators prey on cattle probably comprise a very small percentage of all livestock production systems; however, the fact that cattle still display prey-like behavior may influence how they view humans and their actions.

From these data we know that human presence and environmental changes during direct observation periods potentially alters behavior, decreasing our ability to identify true behavioral changes. There is a need for more indirect and individually-based monitoring systems for describing behavior if we wish to accurately and efficiently evaluate behavioral changes based on production or management interventions.

Subjective Behavioral Monitoring Techniques

Visual Observation

Animal researchers are challenged by the inability of subjective monitoring indices to provide an accurate description of behavior or productive performance. Although observational methods using study participant reporting cannot be used in the monitoring of animals, subjectively assigned values such as disposition score (Voisinet, Grandin et al. 1997; Petherick, Holroyd et al. 2003; Reinhardt, Busby et al. 2009), flight speed (Muller and von Keyserlingk 2006; Petherick, Doogan et al. 2009), lameness score (O'Callaghan, Cripps et al. 2003; Whay, Main et al. 2003), and clinical illness score (Perino and Apley 1998; Buhman, Perino et al. 2000; O'Connor, Martin et al. 2001) are still used to describe the activity, attitudes and behavior of these animals.

These visual evaluations performed by a human observer can be beneficial for describing general behavior and activity of cattle but can be limited in their relevance to actual physiological characteristics of the animal (Hanzlicek, White et al. 2009). These measurements are often taken at periodic time intervals when it is convenient for the observer to view the animals, which may present biased information as human presence and housing environment can affect the animals' expressed behavior (Grignard, Boissy et al. 2000; Gupta, Earley et al. 2008). Additionally, because these are one-time observations and not continuously recorded, it may be difficult to describe behavioral changes in the animal over time.

Objective Behavioral Monitoring Techniques

Video Analysis

Video analysis for recording animal behavior is a widely used tool due to the ease of acquiring the technology and the fact that video can continuously monitor individuals or groups of animals. Because of the accessibility of the technology, researchers (Morrow-Tesch, Dailey et al. 1998; Hanninen and Pastell 2009) have developed software directly aimed at analyzing and classifying video data. Drawbacks to video analysis include increased time and labor in analyzing data, potential introduction of subjectivity when classifying behavior, and ability to record video only during certain times of the day and certain areas of the production environment. Despite the challenges, video analysis of behavior can be implemented in a wide variety of instances including but not limited to: creating time budgets, describing circadian patterns, monitoring indices of welfare, evaluating production practices, and determining treatment efficacies. This method of observation is routinely used as a "gold standard" to compare the accuracy of new behavioral monitoring indices and devices.

Mitlohner, Morrow-Tesch et al. 2001 performed studied methods to analyze continuous video in order to describe the behaviors of standing, lying, feeding, drinking, and walking in feedlot cattle. Methods evaluated included focal animal sampling (single animal behavior represents pen behavior), time sampling (portion of total behavior observation used to represent longer time period), and scan sampling (behavior of individual or pen are described at fixed time intervals). Shorter frequency scan and focal animal sampling in this trial were capable of describing feedlot cattle behavior with no difference in accuracy when compared to continuous video. Procedures described above (Mitlohner, Morrow-Tesch et al. 2001) were used for another study (Mitlohner, Morrow et al. 2001) aimed at evaluating the effect of different housing scenarios (shading, misting, negative control) on the performance and behavior of feedlot heifers. Video analyses of data gathered during daylight hours were able to find behavioral differences in management procedures aimed at alleviating heat-stress in feedlot cattle. Feeding behaviors in dairy cattle have also been observed using video analysis in order to identify behaviors that may aid animal health care providers in predicting animals at-risk for disease (Vasilatos and Wangsness 1980; Huzzey, Veira et al. 2007).

Studies in dairy production often analyze video data to evaluate how different housing and pen-floor environments are associated with indices of cow-comfort typically evaluating lying behavior as this posture is indicative of increased animal well-being (Overton, Sischo et al. 2002; Overton, Moore et al. 2003; Cook, Bennett et al. 2005; Drissler, Gaworski et al. 2005). Lameness in dairy cows is another instance where video analysis has been used to provide researchers a tool to assess locomotion (Leroy, Bahr et al. 2008; Chapinal, de Passille et al. 2009). These studies have shown the utility of video analysis as a behavioral index; however, the time and labor involved with analyzing the video, and the inability to monitor all animals during all times of the day are disadvantages of this observational system.

Positional Tracking

Certain production practices such as grazing present instances where animals are not housed in a confined environment, making it difficult to observe or monitor behavior because of their physical location. The landscape itself may make directly observing the animals impossible with weather and lighting factors adding to the difficulty. The animals' aversive reaction to human presence may also disable the observer to get within eyesight of animals. Global Positioning System (GPS) data have been used to remotely monitor animals for means of evaluating forage usage, grazing patterns, animal spatial tendencies, and behavior patterns.

Pepin et al. (2006) and Berger et al. (2003) used an automatic telemetry system to remotely monitor the position and behavior of red deer and mouflon respectively (Berger, Scheibe et al. 2003; Pepin, Renaud et al. 2006). The systems were equipped with both a GPS sensor and an acceleration sensor that denoted the position of the animals' head (up or down) allowing the researchers to describe grazing behavior. Both studies were able to describe the grazing and activity patterns of the different species in different times of year as the studies were carried out over several years. Forage utilization and landscape preference of cattle have also been evaluated by quantifying location occupancy-patterns in the different forage areas as well as the surrounding environment conditions (Turner, Udal et al. 2000; Ungar, Henkin et al. 2005; Guo, Poulton et al. 2009). Other studies have used GPS data to create time budgets for animals during different seasons (Schlecht, Hulsebusch et al. 2004). The utility in these devices stems from their ability to monitor animals not housed in confined situations but rather in larger more open environments. This is especially true of wild animals as relevant behavioral monitoring needs to take place in a natural-undisturbed setting. Unfortunately devices are expensive, preventing researchers from mounting the devices on larger groups of animals. Also, like other remote monitoring technologies; limited battery life and memory storage become important factors when trying to monitor animals not housed in confined environments.

Radio Frequency Tags

Similar to GPS location monitoring systems, radio frequency technology can be used to determine animal proximity to specific areas of interest including feed and water sources. Common systems consist of a transponder placed on the animal and readers or sensors placed at strategic places within the production system; most commonly at feed and water sources. This technology has been used to evaluate general behavior patterns as well as potential changes in behavior that may be associated with animal wellness.

Many studies have used radio frequency transponders to evaluate feeding and drinking behavior because of the important association these behaviors have on the well-being and productivity of the animal (Gibb, McAllister et al. 1998; Schwartzkopf-Genswein, Huisma et al. 1999; Schwartzkopf-Genswein, Atwood et al. 2002; DeVries, von Keyserlingk et al. 2003; Bach, Iglesias et al. 2004; Wang, Nkrumah et al. 2006; Chapinal, Veira et al. 2007) in dairy and feedlot cattle. These devices have been validated using video surveillance as a gold standard of behavior and were found to be a reliable means for monitoring individual feeding and drinking behavior of group-housed cattle

One important use of behavioral monitoring systems in cattle is the potential for early identification of diseased animals. Sowell et al. (1999) suggested that studying the number of feeding bouts by feedlot steers enabled them to identify animals that would later be identified as morbid because sick steers spent 30% less time at the feed bunk when compared to healthy steers (Sowell, Bowman et al. 1998; Sowell, Branine et al. 1999). Sick calves also exhibit a greater frequency and duration of drinking behavior 4 to 5 days after arrival to the feedlot than healthy animals; indicating that drinking behavior may be a valid indicator of animals suffering from BRD (Buhman, Perino et al. 2000).

These radio frequency monitoring systems are beneficial for monitoring cattle as they provide information about duration and frequency of behaviors shown to have direct relationships with biological characteristics of the animal. Also, these devices are implemented at the individual animal level which allows the researcher to more thoroughly describe behavior as compared to use of group norms. However, radio frequency devices are limited in their use by the need to place tag readers at only certain areas of the production setting. A more versatile radio frequency system that allows for monitoring in all areas of the production environment may be more useful for evaluating and describing cattle behavior.

Pedometers

Pedometer technology has been used in many different scenarios to quantify behavior by measuring step count, distance traveled, and overall increased activity. A major utilization of pedometers in cattle has been identifying increased activity associated with the onset of estrus (Kiddy 1976; Redden, Kennedy et al. 1993; Roelofs, van Eerdenburg et al. 2005). Devices can be placed on cows and routinely checked in order to identify animals with changing activity levels. This practice helps the producer to more efficiently predict ovulation of cows; in turn improving artificial insemination procedures.

Adewuyi et al. (2006) tested the association between walking behavior and level of non-esterified fatty acids in cows post-partum, showing that increased walking activity was associated with depleted fat reserves of the animal in turn causing high levels of these acids which can impair physiological processes. Several studies tested the accuracy of pedometers to measure distance traveled in grazing situations (Anderson and Kothmann 1977; Walker, Heitschmidt et al. 1985). Both studies found no significant differences between pedometer-calculated and actual traveled distance with the later study (Walker, Heitschmidt et al. 1985) suggesting that distance traveled to find sufficient forage can affect energy expenditure of the animal. Distance traveled or steps taken were intermediate outcomes of interest with the end goal of pedometer monitoring being the quantification of the energy expenditure associated with walking behavior.

Pedometers also have been used to identify lameness in dairy cows (O'Callaghan, Cripps et al. 2003) as well as quantify pain or behavior changes due to castration in calves (Currah, Hendrick et al. 2009). These devices have been used in a disease challenge study to evaluate changes in behavior of calves with induced pneumonia (Hanzlicek, White et al. 2010). Pedometers in this study were capable of showing that calves spent less time ($P < 0.01$) walking after versus before pathogen inoculation. These devices have multiple capabilities which add to their utility; however, they are limited by their ability to only evaluate behaviors related to ambulation of the animal.

Accelerometers

Accelerometers are devices capable of distinguishing between periods of non-ambulation and periods of dynamic activity because of their ability to measure the force of gravity as well as accelerations due to movement (Aminian 2004). This ability allows the monitoring of multiple species (Robert, White et al. 2009; Watanabe, Sakanoue et al. 2008; Hansen, Lascelles et al. 2007) as well as multiple behaviors (Robert, White et al. 2009; Moreau, Siebert et al. 2009). These behaviors can include gross overall behavior (Muller and Schrader 2003) or be as specific as grazing behavior (Watanabe, Sakanoue et al. 2008). Static activities are determined from the orientation of accelerometer attached to the test subject in relation to the direction of gravitational acceleration (Aminian, Robert et al. 1999). Human studies utilizing uni-axial accelerometers (Veltink, Bussmann et al. 1996; Bussmann, Tulen et al. 1998; Aminian, Robert et al. 1999) placed multiple devices on various body segments including the sternum, thigh and waist and found the devices were capable of describing both dynamic and static activities.

Many other behavior monitoring systems are limited in their capability to evaluate multiple types of behaviors at the same time; while accelerometers can describe multiple behaviors and postures concurrently. There are numerous devices available that provide objective activity data, but no single model is best suited for every situation as several considerations should be addressed. Type and number of accelerometers per individual, device position on the individual, and duration of the monitoring period are important variables to consider before study commencement. In addition miscellaneous materials required for collecting data in the field including software, user interface, and mounting apparatuses must be considered (Trost, Mciver et al. 2005).

Accelerometer data-capture settings are an important component to consider when implementing the devices to monitor activity. Recording interval, or epoch, is the period of time over which accelerometer data samples are averaged. An optimal epoch would comprise the exact amount of time in which the activity of interest occurs. If the epoch were longer than the length of a dynamic activity for example, the epoch could consist of more resting periods adjacent to the activity period, causing a decreased resolution in the data by mimicking a period of rest (Chen and Bassett 2005). If an epoch is shorter than the length the activity, the classification system would realize more false positive classifications for activity during a resting period due to shifting or minor activities (Aminian, Robert et al. 1999; Mathie, Lovell et al. 2002; Mathie, Coster et al. 2003). Sampling frequency, the number of samples taken per second, is another issue important to the overall success of an accelerometer monitoring system (Robert, White et al. 2009). Common telemetry-based monitors sample with a frequency between 1 and 64 Hz (Chen and Bassett 2005) and satisfy the Nyquist criterion which states that the sampling frequency must be at least twice that of the highest frequency activity being classified (Oppenheim, Willsky et al. 1983).

The raw output of these accelerometers is usually given as a value that has no direct correlation to activity or behavior; however, these data can be converted or calibrated to represent more meaningful and standardized values such as time spent involved in vigorous activity, metabolic equivalence tests, aerobic capacity, and energy expenditure (Welk 2005; Pober, Staudenmayer et al. 2006). Besides the ability to correlate data to biometric measures of activity, the accelerometers also can classify behaviors which may include lying, sitting, standing, locomotion, and several other more specific activities. Decision tree frameworks are a common method described in the human literature, used to hierarchically classify activities; more general activities near the top, followed by more specific subclasses as data flows down the tree (Mathie, Celler et al. 2004; Karantonis, Narayanan et al. 2006; Parkka, Ermes et al. 2006). Postural orientations showed high accuracy in humans (94.1%) with walking and fall activity accuracy realizing 83.3% and 95.6% respectively (Mathie, Celler et al. 2004).

Several studies have used cranial mounted accelerometers do describe grazing behavior of goats and cattle (Watanabe, Sakanoue et al. 2008; Moreau, Siebert et al. 2009). The positional location of the accelerometer is critical for defining various behaviors; accelerometers mounted to the lower limbs of the animal to describe behaviors such as lying, standing, and walking (Robert, White et al. 2009; Trenel, Jensen et al. 2009). Hansen et al. (2007) found accelerometers could be used to describe spontaneous canine activity (Hansen, Lascelles et al. 2007). Correlation between accelerometer activity counts and video surveillance of distance traveled in cats was and found to be 0.82 overall (Lascelles, Hansen et al. 2008). This feline study indicated that an accelerometer-based monitoring system of free-moving individuals could be implemented as an objective measurement of improved mobility following analgesic treatment for conditions such as osteoarthritis. Keegan et al. (2004) implemented a wireless sensor-based accelerometer system to detect and quantify lameness in horses, and their findings showed high correlations (r-squared=0.9544 and 0.8235 for forelimb and hind limb respectively) with a video-based motion analysis system (Keegan, Yonezawa et al. 2004).

In cattle specifically, accelerometers have been used to: describe changes in behavior due to different environmental conditions (Endres and Barberg 2007); define behavior patterns in individuals and groups of dairy cows (Ito, Weary et al. 2009); evaluate changes in behavior due to surgical procedures (White, Coetzee et al. 2008) and describe changes in behavior due to the influence of changing disease status (Hanzlicek, White et al. 2010). Muller and Schrader (2003) applied accelerometers to cattle in order to describe varying activity levels and found the devices correlated significantly

(*P*<0.001) with periods of both high (r=0.75) and low (r=0.65) activity (Muller and Schrader 2003).

Other studies also have shown the utility of accelerometers to describe human activities in non-controlled environments (Bao and Intille 2004; Ravi, Dandekar et al. 2005; Pober, Staudenmayer et al. 2006). Direct observation is usually required to validate these systems and is usually accomplished by monitoring the sampling periods with video observation in order to correlate accelerometer data to actual known activities (Veltink, Bussmann et al. 1996; Bussmann, Tulen et al. 1998; Aminian, Robert et al. 1999). For decision tree classifiers to accurately define behaviors, a firm case definition for each behavior of interest must be defined before study commencement (Bussmann, Tulen et al. 1998). A sequence of studies was performed using one type of device in order to investigate the potential for three-dimensional (tri-axial) accelerometers to be used to describe both static and dynamic activities of free-moving humans and found sensitivity and specificity values of 99% and 94% respectively when using training and testing subsets of data (Mathie, Celler et al. 2002). A similar study investigated the potential of a three dimensional accelerometer accompanied by embedded intelligence to perform on-board calculation of signals (Karantonis, Narayanan et al. 2006). The study was aimed at developing a system where less stress would be put on the receiver to analyze the signals; observing the complexity of the tasks relative to battery life.

Conclusion

Monitoring cattle in U.S livestock production settings can be a difficult task to accomplish. Many obstacles are present including; the harsh outdoor environment cattle are housed in, grouping of large numbers of cattle in a single pen, and the alteration of their normal behavior in the presence of human observers. Subjective methods of observation have some utility in describing cattle behavior but these methods have been shown to have decreased association with physiological characteristics of the animal. Subjective observational methods also do not solve the issue of obtaining accurate observations because human presence can influence cattle behavior. Objective observational methods described previously such as video analysis, positional tracking, radio frequency transponders, pedometers, and accelerometers may be the new frontier of behavioral analysis technologies because of the ability to provide accurate descriptions of cattle behavior. Some devices are tailored for specific use in monitoring groups of individuals such as video analysis while others are implemented on an individual basis like pedometers and accelerometers. The actual device and monitoring strategy are contingent upon many different variables which may include the environment in which the individual lives as well as the goals of the research study. Looking to the future, as researchers continue to manipulate and further develop these technologies, the impact they will have on the monitoring of free moving individuals is obvious and the information gained will in no doubt better our knowledge about the behavior they exhibit.

CHAPTER 3 - Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle

As published in Computers and Electronics in Agriculture:

Robert, B., B. J. White, D.G. Renter, R.L. Larson (2009). "Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle." Computers and Electronics in Agriculture 67: 80-84.

Abstract

Cattle behavior is potentially a valuable indicator of health and well-being; however, natural movement patterns can be influenced by the presence of a human observer. A remote system could augment the ability of researchers, and eventually cattle producers, to monitor changes in cattle behavior. Constant video surveillance allows non-invasive behavior monitoring, but logging the movement patterns on individual animals over long periods of time is often cost prohibitive and labor intensive. Accelerometers record three-dimensional movement and could potentially be used to remotely monitor cattle behavior. These devices collect data based on pre-defined recording intervals, called epochs. Our objectives were to (1) determine if accelerometers can accurately document cattle behavior and (2) identify differences in classification accuracy among accelerometer epoch settings. Video-recorded observations and accelerometer data were collected from 15 crossbred beef calves and used to generate classification trees that predict behavior based on accelerometer data. Postural orientations were classified as lying or standing, while dynamic activities were classified as walking or a transition between activities. Video analysis was treated as the gold standard and logistic regression models were used to determine classification accuracy related to each activity and epoch setting. Classification of lying and standing activities by accelerometer illustrated excellent agreement with video (99.2% and 98.0% respectively); while walking classification accuracy was significantly ($P < 0.01$) lower (67.8%). Classification agreement was higher in the 3 s (98.1%) and 5 s (97.7%) epochs compared to the 10 s

(85.4%) epoch. Overall, we found the accelerometers provided an accurate, remote measure of cattle behavior over the trial period, but that classification accuracy was affected by the specific behavior monitored and the reporting interval (epoch).

Introduction

The development of an objective system for monitoring and assessing activity of beef cattle to identify animals at risk for disease could prove useful in alleviating health and economic costs associated with illness. Chen and Bassett (2005) reported that physical activity in humans is indicative of diseases such as cardiovascular disease and cancer. Behavioral activity is used as an indication of animal comfort as well, in that lying behavior is often used as a sign of cattle well-being (Cook et al., 2005). A real-time analysis of cattle activity could provide useful information for early detection of disease; in turn providing animal health providers the opportunity for earlier intervention in treating affected animals (Schoenig et al., 2004). By analyzing changes in, or levels of, behavioral activity, researchers can assess animal well-being (Muller and Schrader, 2003; White et al., 2008).

Evaluation of normal cattle behavior patterns and individual health status is difficult to accomplish due to the animal's response to human interaction. Cattle behavior may be altered by contact with people and exposure to processing procedures such as restraint in a squeeze chute (Ishiwata et al., 2007). Implementation of a remote sensor system to objectively measure and classify activity by measuring both static and dynamic activities has been shown to provide useful behavioral information in human medicine without interference from observers (Veltink et al., 1996; Mathie et al., 2004). Wireless three-dimensional accelerometers provide a non-invasive, objective measure of normal behavior patterns; however, minimal research has been performed evaluating the accuracy of these devices in cattle or the impact of different recording settings for categorizing specific cattle behavior patterns.

Research using accelerometers has been more extensive in human medicine, showing accelerometers can provide an objective measure to monitor and classify activity (Mathie et al., 2004; Lyons et al., 2005; Karantonis et al., 2006). Accelerometers have also been used in equine medicine to evaluate changes in gait after induced lameness

(Keegan et al., 2002, 2004), as well as overall activity in smaller animals such as cats and dogs (Hansen et al., 2007; Lascelles et al., 2008). Data collected from accelerometers can be used to create specific algorithms that can classify animal activity into specific postural or behavioral categories. Accelerometers may offer a viable system to monitor changes in cattle behavior, which in turn could be used to document animal wellness. However, prior to evaluating the ability of the devices to detect changes in health status, initial work must be done to validate the ability of the devices to consistently and accurately describe cattle activity patterns.

In this study of beef cattle, we tested different data-recording options to optimize accuracy in classifying animal behavior into specific activities. The objectives of this trial were to determine: (1) if accelerometers accurately measure cattle behaviors of standing, walking, and lying when compared to video analysis; (2) if classification accuracy differed among epoch settings selected to optimize device memory (3, 5, and 10 s epochs). This research is unique, as the ability of accelerometers to accurately monitor behavior in cattle is not documented, and no previous published literature illustrates potential differences in classification accuracy based on how devices are configured.

Materials and methods

Animal Management

Fifteen crossbred calves averaging 204 kg were purchased and randomly allocated into three groups (one for each accelerometer setting), resulting in fives calves per group. Cattle were housed together in a rectangular drylot (2415m2) and fed a typical beef cattle growing ration. Commercially manufactured GP1 SENSR units, consisting of a tri-axial capacitance type surface-micromachined (MEMS)±10 g integrated-circuit accelerometer (Reference LLC, Elkader, IA) were attached to the lateral aspect of the right rear leg just proximal the fetlock (Fig. 1). This mounting site on the calves was chosen because of the specific leg orientations associated with the activities of interest; the Y-axis is perpendicular to the ground when the animal is lying, while the X-axis is perpendicular to the ground during standing activity. The accelerometers were placed inside a waterproof case, which was padded and strapped to the leg. The entire apparatus consisting of case, padding, accelerometer, straps and two AA lithium batteries weighed 0.5 kg.

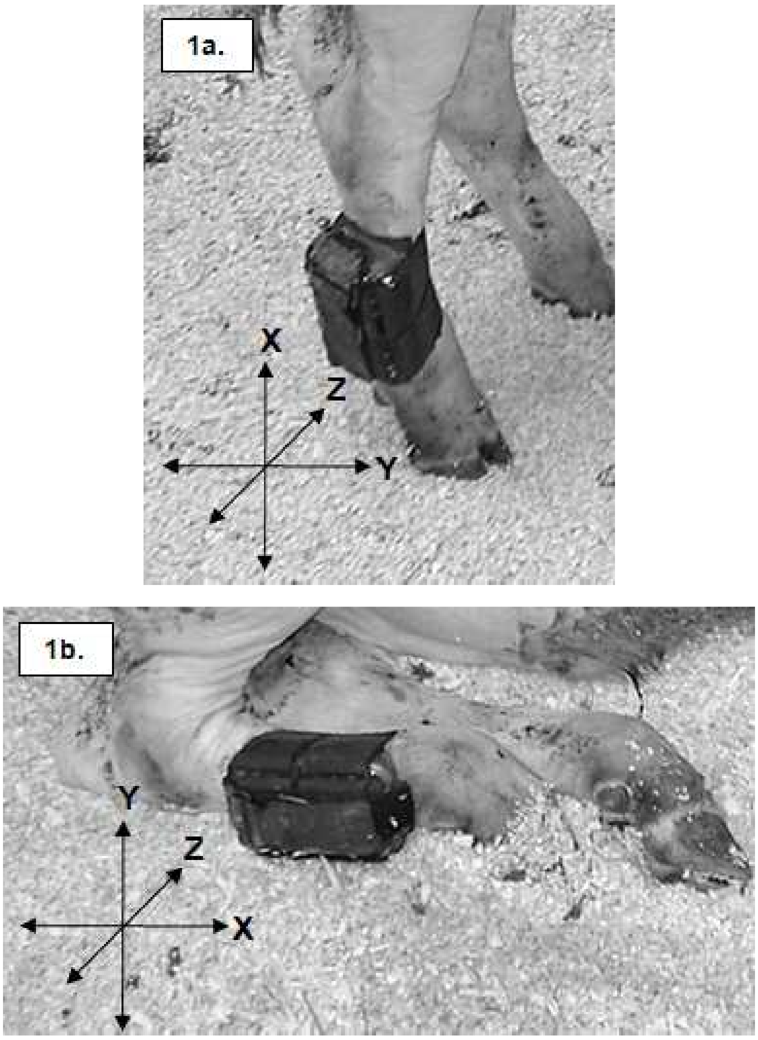

Figure 3-1. Position of the three-dimensional accelerometer (and illustration of measured X-, Y-, and Z-Axes) on the lateral aspect of the right rear limb in a standing (1a) and lying (1b) calf.

Accelerometer data collection

Accelerometers used in this project sampled at a rate of 100 Hz (100 samples/s), and data were summarized for selected variables based on user-defined reporting intervals (called epochs). For this trial, accelerometers were set to record with epoch length of 3, 5, or 10 s. Accelerometers were downloaded once (5 and 10 s epoch) or twice (3 s epoch) weekly based on memory storage (1 Mb) limitations. Five variables were recorded by the accelerometers over each epoch: average acceleration in each of the three axes (XavgG, YavgG, ZavgG), Vector Magnitude Average (VMavgG), and Vector Magnitude Max (VMmaxG). Average axis acceleration (XavgG, YavgG, ZavgG) and Vector Magnitude Average (VMavgG) were calculated by summing the inputs (100 samples/s) and dividing by the specified reporting interval (3, 5, or 10 s). Vector Magnitude (formula (1)) is calculated by:

$$Vector\ Magnitude = \sqrt{XavgG^2 + YavgG^2 + ZavgG^2} \qquad (1)$$

The VMmaxG is simply the highest combined axis instance per reporting interval (ReferenceLLC, 2007). Two additional variables were added to potentially increase the decision tree robustness. Signal Magnitude Area (SMA) (formula (2)) (Bouten et al., 1997; Mathie, 2003; Karantonis et al., 2006) and Signal Vector Magnitude (SVM) (formula (3)) (Karantonis et al., 2006) have been reported by previous authors to be useful in classifying behavior based on accelerometer data. The variables were calculated using the epoch summary average values and the following formulas:

$$Signal\ Magnitude\ Area = (|XavgG| + |YavgG| + |ZavgG|) \qquad (2)$$

$$Signal\ Vector\ Magnitude = \sqrt{XavgG^2 + YavgG^2 + ZavgG^2} \qquad (3)$$

Data were downloaded and transformed into a uniform structure for comparison and analysis using data mining software (Insightful Miner, Insightful Corporation, Seattle, WA). The seven continuous variables were used to create each classification decision tree.

Video analysis

Calf behavior was video-recorded over the 3-week trial period. The camera was time-synchronized to the computer used to initialize each accelerometer. This time stamp was used to match the video analysis to the accelerometer data for each calf similar to procedures reported by other researchers (Bussmann et al., 1998; Aminian et al., 1999;

Mathie et al., 2003; White et al., 2008). Timing of video taken varied from morning (08:00) to evening (18:00), attempting to get video of each calf involved in all activities (lying, standing, walking). Efforts were also made to get an equal amount of video of each epoch group, using a check sheet to follow which calves were allocated to each group. Video was downloaded onto a computer, and logged by a single individual. Activity (lying, standing, or walking) was determined and recorded for each second for every calf. Video-recorded activities were classified using the following criteria similar to previous research (White et al., 2008):

• Lying: If an animal was lying down for the entire 1 s video period, the activity would be classified as lying. When an animal transitioned from this position, the lying activity classification ended once the first movement of the transition occurred.

• Standing: Activity classified as standing would include static standing and standing with minor limb movements (shifting) for the entire 1 s video period. Like the lying activity, if a transition occurred, the standing activity classification ended once the first transitional movement began.

• Walking: Walking activity was defined as a minimum of two progressive steps (forward or backward) within the 1 s video period. If the animal took only one step for a 1-s span of time, this activity would be classified as standing, not walking.

The video logging procedure could result in a calf having more than one type of activity during a specific reporting interval (i.e. for a 5 s epoch there would be five video-log activity classifications and only one accelerometer reading). If all video-activity readings for the reporting interval (3, 5, and 10 s) agreed, that activity was matched to the corresponding accelerometer data. If the video logged activity was not the same for the entire recording period (epoch), then the activity for these data was marked as transitional activity (mixed). Transitional activities were not included in the final accuracy analysis as there was not a single behavior expressed during this period of time. The end result was a data set for each epoch matching accelerometer readings from a single calf over a period of time with known, video logged behavior over the same period of time.

Data and statistical analysis

The combined video-accelerometer data set was used to generate a classification tree (Insightful Miner, Insightful Corporation, Seattle,WA) for each epoch. The data set was partitioned based on standard data mining procedures (Berry, 2004); 70% used to create the classification tree and 30% used to test algorithm classification accuracy. The classification tree categorized the data based on the included variables and the known outcome (video activity). The purpose of the tree is to reduce uncertainty, or entropy, associated with each predicted outcome. Therefore, data were partitioned (or split) into multiple groupings of data points (nodes) until entropy was zero or the pre-split nodes size was less than 10. Entropy reduction was used as the splitting criterion, and minimum node size was set at five records.

Epoch and activity classification accuracy were determined by comparing the percent agreement between the observed video activity (considered the gold standard) and the classification trees predicted activity value in the test data set. Logistic regression was used on the test data to evaluate potential differences in classification accuracy among epochs and among activities. Epoch and activity were included as fixed effects in the models and individual calf identification was included in the models as a random effect to account for repeated measures on individuals. These generalized linear mixed models were developed using the GLIMMIX procedure in SAS (Version 9.1, SAS Institute, Cary, NC).

Results

Epoch length impacted memory capacity, and more frequent data collection resulted in shorter duration between downloads. Memory capacity for the 3 s epoch group was 4 days 6 h 24min, with the 5 and 10 s epoch groups capable of a sampling duration of 7 days 2 h 40min and 14 days 5 h 20 min respectively. Battery life was not a limiting factor in the length of time data could be recorded. Nearly 10 h of behavior video was recorded with approximately equal amounts of video captured for each epoch group; the 3 s epoch group compiling 3 h 36 min, with the 5 and 10 s epoch groups having 3 h 20 min and 3 h 6min respectively.

The test data set for the 3 s epoch consisted of 3097 records and the decision tree explained 4566.02 (85%) of the total entropy (5402.01). Of these records, the primary activity was standing (63%), followed by lying (32%) and walking (5%). All seven variables were used to make classification decisions, with XavgG and VMavgG having most of the total entropy reduction with 70.35% and 11.2% respectively. The remaining five variables achieved less than 1% information gain. The XavgG distinguished lying activity from the other three activities, while the VMavgG split the remaining data into either standing or walking behavior.

There were 1675 records in the 5 s epoch group and this decision tree explained 1734.54 (84%) of the total entropy (2062.99) using 15 splits. Eighty-five percent of these records represented standing activity, with lying, walking, and transitional (mixed) activities supplying 11%, 3%, and 2% respectively. The decision tree used six of seven variables, with YavgG, VMavgG, and VMmaxG producing most of the total entropy reduction with 55%, 22.7%, and 2.41% respectively. Other remaining variables used included ZavgG, SVM, and SMA; however, the decision tree did not use the XavgG variable. YavgG separated lying behavior from other activities while VMavgG made the distinction between dynamic (walking, mixed) and static (standing) activities.

The 10 s epoch group had the smallest number of records (791) due to the long collection time. This decision tree explained 652.9 (62%) of the total entropy (1052.58). In this data set 82% of the records represented standing activity; mixed activity accounted for 13% with walking and lying activity accounting for 3% and 2% respectively. The decision tree used all seven continuous variables to make classification decisions, with VMavgG and XavgG having most of the total entropy reduction with 22.3% and 18.3% respectively. YavgG, ZavgG, and SVM accounted for about 5.5% of the entropy reduced followed by VMmaxG (3.7%) and SMA (1%). VMavgG separated dynamic from static activities (lying and standing versus mixed and walking activity), but the tree had 40 splits, so activity nodes were mixed among the branches.

Lying and standing activities illustrated good agreement with video (99.2% and 98.0% respectively) (Fig. 2). Walking classification accuracy was significantly ($P < 0.01$) lower (67.8%) compared to lying and standing. Classification agreement with known video behavior was also evaluated by epoch and activity. There were no significant differences between the 3 and 5 s epochs, 98.1% and 97.7% respectively ($P = 0.73$); however, the 10 s epoch exhibited significantly lower agreement with an overall accuracy of 85.4% ($P < 0.01$) (Fig. 3).

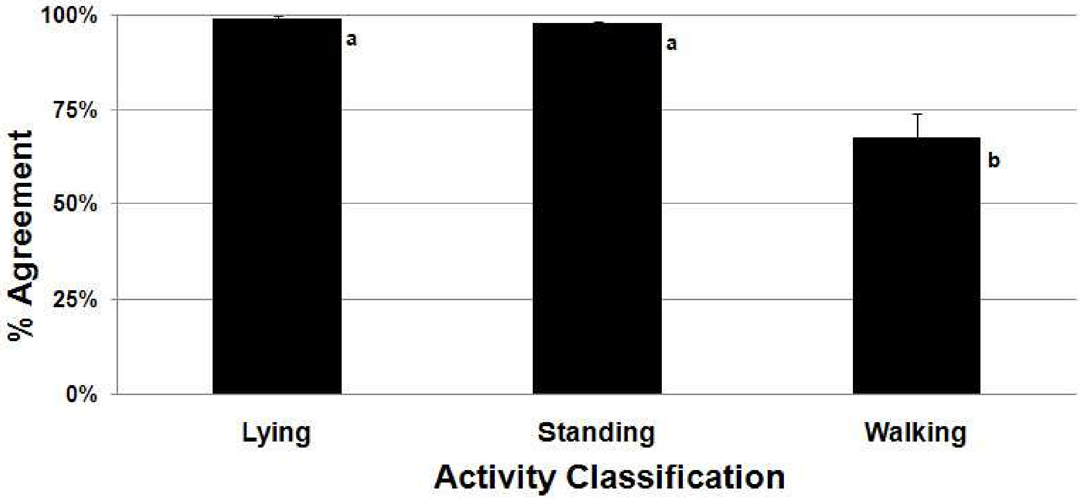

Figure 3-2. Mean[a] agreement between video and accelerometer data for lying, standing and walking activities of calves. Columns with different letters are significantly different ($P < 0.05$). [a]Generated from a linear mixed statistical model including epoch (three, five, or ten second) as a fixed effect and a random effect to account for repeated measure on individual calves.

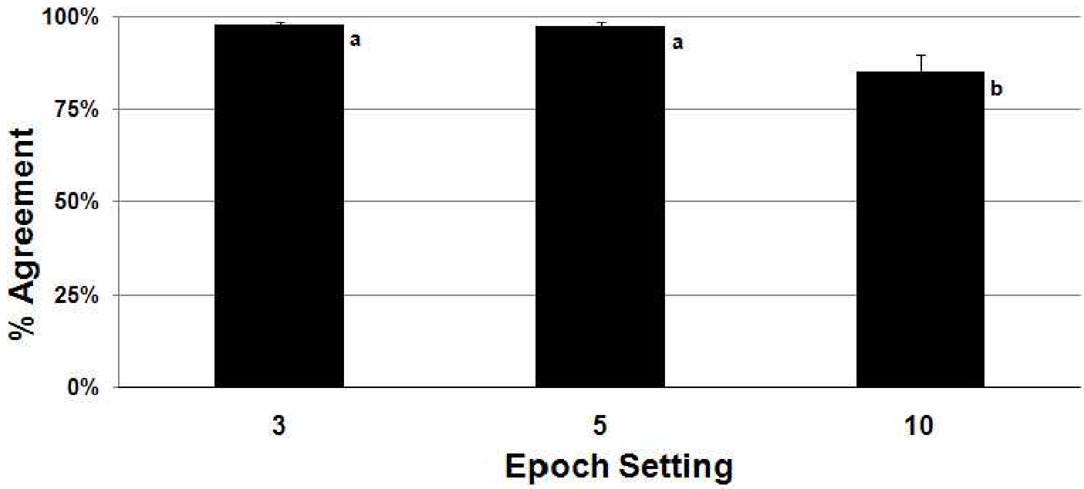

Figure 3-3. Mean[a] agreement between video and accelerometer data based on epoch. Columns with different letters are significantly different ($P < 0.05$). [a]Generated from a model including activity[b] as a fixed effect and a random effect to account for

repeated measures on individual calves. [b]Activities were logged as either standing, lying or walking.

Discussion

Monitoring cattle behavior could provide insight into an animal's wellness status; however, traditional observational techniques may influence results, are time and labor intensive, and may not provide the necessary level of diagnostic accuracy. One of the most costly syndromes in beef cattle production is bovine respiratory disease, and development of quantitative measures to diagnose this disease is considered critical (Duff and Galyean, 2007). Current diagnostic methods often rely heavily on clinical observation of signs of illness; yet, recent work estimated that the diagnostic sensitivity and specificity of this method were 61.8% and 62.8%, respectively (White and Renter, 2009) Utilization of technology to automatically record behavior allows for collection of objective values; however, systems should be developed that allow reliable, repeatable measurements of behaviors that may indicate animal wellness state (Weary et al., 2009). Our objective was to determine if accelerometers provided an accurate, objective measure of cattle behavior, and if so, which device settings were optimal.

Accelerometers offer the potential to remotely monitor animal behavior and document the percent of time an animal spends involved in each of several activities. The potential accuracy of the devices to determine actual behaviors influences the utility of this technique in future research or animal health monitoring. In this trial, the accelerometers were very accurate compared to video analysis when classifying cattle behavior into one of three activities: standing, walking, or lying. This accurate method of behavioral monitoring can now be applied in a research setting to evaluate the effect of technical procedures or product administration on behavioral outcomes. Accelerometers can also be used to evaluate the potential of diagnosing specific disease syndromes using behavioral measurements. If subsequent research supports the ability of behavioral monitoring to identify animal wellness status, the accelerometers could be applied to larger populations of animals deemed at high risk for developing disease.

Static postural activities of lying and standing were accurately classified by the decision trees (Fig. 1). The primary discrimination between these two activities is related to the specific orientation of the leg in respect to the gravitational field. Posture does not vary during these static activities (Veltink et al., 1996), and accelerometer readings are very distinct between the two postures due to placement of the devices. When an animal is standing, the full force of gravity is recorded on the X-axis while the Y-axis is in a nearly neutral position (Fig. 1a). However, when the animal lies down, these readings are reversed—providing clear data points to distinguish between the two postures. Dynamic activities exhibit more variation that may be related to the individual as well as intensity of the activity. The variables recording the vector magnitude of all three axes (VMmax, VMavg, SMA, SVM) were useful in distinguishing walking behavior from standing activity. However, if a bout of higher-intensity activity is shorter than the span of the epoch, the resulting average data will result in smaller intensity readings, contributing to misclassification (Chen and Bassett, 2005). This seems to be evident by the lower classification accuracy of all decision trees in identifying walking behavior.

The Signal Magnitude Area (formula (2)) used by Bouten et al. (1997) and Mathie (2003) and Karantonis et al. (2006) has shown an ability to discriminate periods of dynamic activity from periods of rest, while the Signal Vector Magnitude (formula (3)) (Karantonis et al., 2006) is able to differentiate between intensities of dynamic activities. Although these two variables did not play a major role in decreasing overall entropy, they differentiated standing activity from either mixed or walking activity in all three decision trees. Although the walking activity classification had the lowest accuracy of the three activities monitored, sampling frequency used for this trial was 100 Hz, and satisfied the Nyquist criterion, which states the sampling frequency must be at least twice that of the highest frequency movement being classified (Oppenheim et al., 1983). Most human physical activity monitors sample at a rate between 1 and 64 Hz (Chen and Bassett, 2005). Therefore, modifying the sampling frequency would not likely increase the accuracy of walking activity classification.

Optimizing the epoch setting is important as it could allow increased data-recording length without compromising classification accuracy. Determining the optimum device settings is critical before field application as these modifications impact effective battery and memory life. Epochs available for the commercial accelerometers used in this project range from 1 to 120 s. Shorter data-recording periods increase labor involved in downloading data, and may also cause artifact activities due to human-influenced behavior during processing procedures. Using an epoch that is shorter than the period of time an activity of interest occurs will result in more false positive classifications for dynamic activities, perhaps due to transitioning between activities or body shifts during static activities (Aminian et al., 1999). However, our shortest recording interval of 3 s was long enough to accurately capture the dynamic activity of interest (walking). Our findings indicate no differences in classification accuracy between the 3 and 5 s epochs, yet lower accuracy in the 10 s epoch. The relative inability to classify activities with the 10 s epoch is related to more variability of accelerometer readings within the longer time frame. All variables were calculated based on summaries over the reporting interval, and the longer time period did not allow behavior classification with accuracy as high as the 3 or 5 s epoch. These findings indicate that using a 5-s epoch provides added accuracy and based on the memory constraints of the current units, downloads were only necessary once every 7 days, making the project feasible to use in subsequent research projects.

The current project provides preliminary evidence that accelerometers can be used to accurately monitor cattle behavior. This technology can be used immediately in research endeavors where the objective is to determine differences in cattle behavior between treatment or management groups. Further research is required to determine the long-term sustainability of this technology in the field including methods for fitting the cattle with the devices, potential adverse events, and economic viability in commercial production systems. Following this trial, research should also be performed to evaluate the ability of the devices to monitor animal wellness status and the accuracy of the technology to diagnose disease will greatly impact the potential adoption in production systems.

Conclusions

Overall, our research illustrates that three-dimensional accelerometers are highly discriminatory for static acceleration (posture) activities in cattle. The 3 and 5 s reporting intervals yielded accurate classification of the static activities, but due to the increased potential recording time the 5 s epoch may be the most practical for monitoring cattle. Behavior or activity has been linked to the wellness status of animals, and we found accelerometers provided an objective, non-invasive measure of activity that may be linked to specific animal health or performance outcomes. Further research is needed to determine the ability of behavioral measurements to predict animal wellness status.

CHAPTER 4 - Determination of normal beef cattle activity patterns utilizing wireless accelerometers: circadian rhythms, variation among days, and differences between individual calves.

As accepted by the American Journal of Veterinary Research:

Abstract

Objective- To describe the undermining daily, hourly, and calf to calf effects of behavior while determining overall behavior patterns in cattle

Animals- Twenty-five crossbred beef steers.

Procedures- Wireless accelerometers collected cattle behavioral data in two 20-day trials (Winter 2007, n=10, and Spring 2008, n=15) in a drylot beef cattle production setting. Accelerometer data were categorized into lying, standing, and walking behavior for each time point. Logistic regression models were used to determine potential associations between the proportion of time lying and several factors including; time of day (hour), day of the trial, and individual calves.

Results- Lying behavior was associated ($P < 0.01$) with the hour of the day and a distinct circadian rhythm was identified. Calves spent most (> 55%) of the nighttime hours (2000 to 0400) lying and were most active (< 30% lying) during feeding time periods (0700 and 1700). Mean lying time was associated ($P < 0.01$) with trial day with most days (67.5%) cattle spending between 45 and 55% of time lying. Lying behavior varied by individuals and model estimated means (SE) ranged from 29% (0.28) to 66% (0.37) of time lying among calves.

Conclusions and Clinical Relevance- Our findings indicate that cattle exhibit distinct circadian patterns in lying behavior and the proportion of time spent lying varies by day and among calves. This trial illustrates the need to account for factors that affect calf lying patterns (time of day, day of trial, and individual animal variation) when performing research with behavioral outcomes.

Introduction

Quantifying normal behavior patterns of cattle can provide researchers and animal health providers with baseline activity information useful for determining the effects of various environmental and procedural stimuli on behavior. Developing a baseline for behavior also may allow evaluation of disease effects on different activities (feeding, drinking, lying, standing). Commercial production settings, as well as experimental research settings for production, health, and welfare research, routinely house cattle together in large groups making monitoring individual calf behavior difficult.

The ability of current subjective scoring systems to act as behavioral assays is limited, (Frost, Schofield et al. 1997; Duff and Galyean 2006; Weary, Huzzey et al. 2009) and more technological and objective methods have been suggested as potential methods to identify signs of clinical illness or abnormal behavior in cattle. Schaefer et al. (2007) stated that infrared thermography may be capable of detecting bovine respiratory disease (BRD) while Reid and Dahl (2005) used temperature monitoring devices implanted in steers to allow for the early detection of diseases like BRD, which cause elevations in body temperature. Roelofs et al. (2005) used pedometers in their study of dairy cattle, finding the devices could be used as a predictor of ovulation for improving fertilization rates. There have been other studies (Sowell, Bowman et al. 1998; Sowell, Branine et al. 1999; Buhman, Perino et al. 2000) investigating the use of behaviors (feeding and drinking) as an indication of animal health and this work has shown a distinct relationship between these behaviors and unfavorable health outcomes. Cattle behavior (e.g. standing, lying, feeding, and drinking) may be useful for identifying individuals at risk for disease, but in order to delineate behavior associated with disease, we must be able to define and monitor normal cattle behavior patterns at the individual level.

Accelerometers are small, remote, and non-invasive devices providing objective monitoring of behavior and are not likely to influence natural activity patterns. These devices use continuous and individual-animal sampling methods to generate unique behavioral information that would be difficult to acquire with other monitoring schemes. The quantification of cattle activity utilizing accelerometers has been proven to be very accurate (99.2% for lying and 98% standing) in describing normal behaviors that can prove difficult to capture with conventional methods (Robert, White et al. 2009).

Previous studies have implemented accelerometer-based activity monitoring systems for several species including cattle, dogs, cats, and horses and demonstrated the devices' utility as a behavioral monitoring tool (Keegan, Yonezawa et al. 2004; Hansen, Lascelles et al. 2007; Lascelles, Hansen et al. 2008; White, Coetzee et al. 2008). In cattle specifically, accelerometer-type automatic activity monitors have been validated (Munksgaard, Reenen et al. 2006) and used to describe behaviors of dairy cattle (Endres and Barberg 2007) and also used to describe behavior in dairy calves (Trenel, Jensen et al. 2009). With animal behavior and activity being used as an assay of health and well-being, there is a need for an objective analysis of natural, undisturbed behavior. By more effectively defining normal cattle behavior, situations where an intervention is required can be more precisely and efficiently identified.

The objectives of this study were to describe effects impacting normal cattle behavior patterns, specifically the percent time cattle spent lying, based on: hours throughout the day, day to day variation, and calf to calf variation. The overall hypotheses were that cattle exhibit both circadian and daily patterns of behavior and individual calves have varied levels of activity. This research is unique as individual calf lying behavior patterns or differences in lying behavior between calves are not well documented and results could influence the design of future health and welfare research projects evaluating behavior as an outcome.

Materials and Methods

Two field studies were completed near Manhattan KS, USA (November 20 – December 9, 2007 and April 15 – May 4, 2008) where accelerometers were used to record behavior of steers in a drylot beef cattle research facility. All experiments and procedures were approved by the Animal Care and Use Committee at Kansas State University (approval number: 2518).

The beef research facility contained two drylot pens with a total capacity of 97 individuals, 38 and 59 respectively with cattle for both trials housed in the same rectangular dirt floor drylot of dimensions 62.7 m x 33.9 m which was the smaller of the two available pens. Pen capacities were calculated using the higher bound weight range given in the Guide for the Care and Use of Agricultural Animals in Research and Teaching 3rd Edition in order to present minimum densities for a pen of this dimension.(Societies 2010) A 1.5 m high steel pipe fence comprised the perimeter of the pen except for over the bunk area where adjustable steel cables were strung. Steers had access to an automatic waterer with a 100 head capacity at all times during the study periods. Animals were acquired from a local cattle auction through a livestock order buyer with the only stipulation being the group must be comprised of beef steers with weights between 181.4 kg and 226.8 kg.

On arrival day steers were processed in order to: weigh, apply ear-tag identification, and give vaccinations. Also at this time, commercially manufactured accelerometers[a], consisting of a tri-axial capacitance type +/- 10g integrated-circuit were attached to the lateral aspect of the right rear leg just proximal the fetlock in accordance with methods used in previous studies (Robert, White et al. 2009). Calves were not given an acclimation period as they were being simultaneously observed for another study that required the devices be put on immediately upon arrival. However, for the information presented here, the first 24 hours of recorded data were removed from the analysis to simulate a brief acclimation period as well as to account for altered behavior due to the attachment of the accelerometer. The Winter 2007 trial consisted of ten steers (mean weight 190.1 kg) while the Spring 2008 trial followed fifteen steers (mean weight 191.2 kg); the same continuous sampling accelerometer-based monitoring system was used for both trials. No other animals were present at the research facility during either study period and the location of the research facility was relatively void of any human disturbances except for feeding times.

Environmental condition data were also gathered from a local airport weather station located 13.1 km southwest of the research facility. Temperature during the Winter 2007 study ranged from -8° C to 13°C and averaged 0° C. Precipitation occurring during this trial period consisted mainly of light rain and light snow with an overall accumulation of 15 cm. Temperature during the Spring 2008 study ranged from 7° C to 22° C and averaged 13° C. Light rain comprised the majority of precipitation for this trial period with an overall accumulation of 19 cm.

Cattle were fed a pellet beef growing ration that included; wheat middlings, cracked corn, corn gluten feed, extender pellets, cottonseed hulls, and dried distillers grain. Prairie hay was offered during initial study days while calves were acclimated to the growing ration, but was weaned off as the study progressed. During feeding times (twice daily), cattle were evaluated by a single licensed veterinarian as to the health of each individual. The veterinarian spent as much time as needed (not less than 30 minutes per feeding time) in order to fully evaluate each calf individually. Calves were designated for further evaluation subsequent to each feeding time based on a subjective clinical illness score greater than 1 (where 1 = normal, 2 = slightly ill, 3 = moderately ill, 4 = severely ill). If an animal had a rectal temperature greater than 40o C at this examination, it was treated in accordance with standard health protocols. Improper attachment of an apparatus to the leg of a calf has the potential to cause health and welfare issues such as the formation of lesions and can also cause swollen hooves caused by impaired blood flow to the extremity of the leg. In order to avoid such situations, calves were also examined during this time to ensure: 1) proper apparatus orientation and 2) un-impaired mobility of the calf. No instances of decreased welfare of the calves due to accelerometer placement were noted for either trial.

Accelerometers sampled at 100 Hz, and data were summarized for variables based on user-defined reporting intervals (epochs). Accelerometers were downloaded once (5s epoch) or twice (3s epoch) weekly based on memory storage (1 Mb) limitations. For data downloading, calves were processed through a restraint chute where the accelerometer and mounting apparatus were removed from the leg, the accelerometer was connected to a laptop via USB cable, and then the device within the apparatus was re-affixed to the leg. Upon completion of the Winter 2007 study it was determined there was no significant activity classification accuracy differences between the 3s and 5s epochs (Robert, White et al. 2009) therefore the 5s epoch would be used for future studies (Spring 2008) as this reporting interval maximizes mission length in turn reducing the number of times the steers would need to be processed for downloading.

The accelerometers recorded five variables including: average acceleration in each of the three axes (X, Y, Z), vector magnitude average, and vector magnitude maximum. Axis average and vector magnitude average values were calculated by summing the inputs (100 samples per second) and dividing by the different reporting intervals (3s or 5s). Vector magnitude maximum was simply the single highest combined axis acceleration per reporting interval. Commercial data mining software[b] was used to transform data into a uniform structure for comparison and analysis. A previously validated (Robert, White et al. 2009) classification tree categorized individual calf behavior at each data point (epoch) as walking, standing, or lying. This system utilizes combinations of the parameters recorded by the accelerometer to estimate the posture and activity of the calf at a given point in time. Lying causes distinct changes in the X- and Y-axes compared to standing based on the positional change of the accelerometer relative to the pull of gravity. Movement associated with walking typically results in increased vector magnitude average and vector magnitude maximum. Categorized behavioral data points (one for each epoch) were aggregated by hour to create proportions where the count of each individual behavior classified was the numerator and the total possible count of behaviors per hour was the denominator.

Our objectives were to quantify natural uninterrupted activity; therefore, any periods of disturbances (when the animals were subject to human interaction) were removed from the final dataset utilized for analysis. Times were recorded when anyone was in contact with the cattle and the entire hour containing a disturbance was removed. Examples of these times would include hours when cattle were processed for downloading of accelerometers as well as times where an individual calf was removed from the pen and evaluated for suspected illness. If an individual was treated for illness, accelerometer data were removed from that point forward as well as the twenty-four hours prior to the calf being treated. Feeding periods remained in the data for analysis so we could evaluate these periods; feeding periods were not defined as disturbance periods as no persons entered the pen or handled any calves.

Associations between the proportion of time each calf spent lying and the fixed effects of trial replicate (Winter 2007 or Spring 2008), day within trial replicate, hour within day, and individual calf within trial were analyzed using generalized linear logistic regression models (PROC GLIMMIX, SAS 9.1)[c]. The proportion of time lying per calf hour was modeled as a binomial (with logit link) events/trials response where number of epochs classified as lying was the event and number of recorded epochs within the hour was the number of trials. Effects were modeled as categorical variables with day of trial modeled within trial replicate and hour modeled within day of trial replicate. Calf identification within trial also was included as a fixed effect to account for repeated measures on calves over time and to facilitate description of differences between individual calves within this study. Estimation method was restricted maximum likelihood and Type 3 likelihood ratio statistics were used to test for associations of effects (Agresti 1996). A conservative alpha level of $P < 0.001$ was selected to account for multiple pair-wise comparisons in each model. Standard deviations for model estimated percent of time lying were calculated using model estimates of standard error and number of observations (calf hours) for each calf.

Results

Each trial period consisted of 20 days with the representative data void of all partial hours, periods of disturbances, and calves classified as ill. The Winter 2007 trial initially had a possible 4800 calf hours available for analysis; however, 288 hours of data from two calves were removed from the analysis due to illness. The Spring 2008 trial initially had a possible 7200 calf hours available for analysis; however, this trial resulted in more data loss than the previous trial caused by incorrect battery placement in the accelerometers resulting in power interruption issues. For the Spring 2008 trial 792 hours of data from 6 calves were removed due to device/operator malfunctions, along with 240 hours from one calf removed due to illness. Data removed due to device/operator malfunctions had a mean value of 132 hours but ranged from 192 to 48 hours. Of the grand total initially possible calf hours (12000), a total of 9999 hours of continuous calf-hour data were available for analysis on the 25 calves with an average of 399.96 hours per calf. The studies of 10 (Winter 2007) and 15 (Spring 2008) individuals resulted in 4387 and 5612 calf-hours of data available for analysis, respectively.

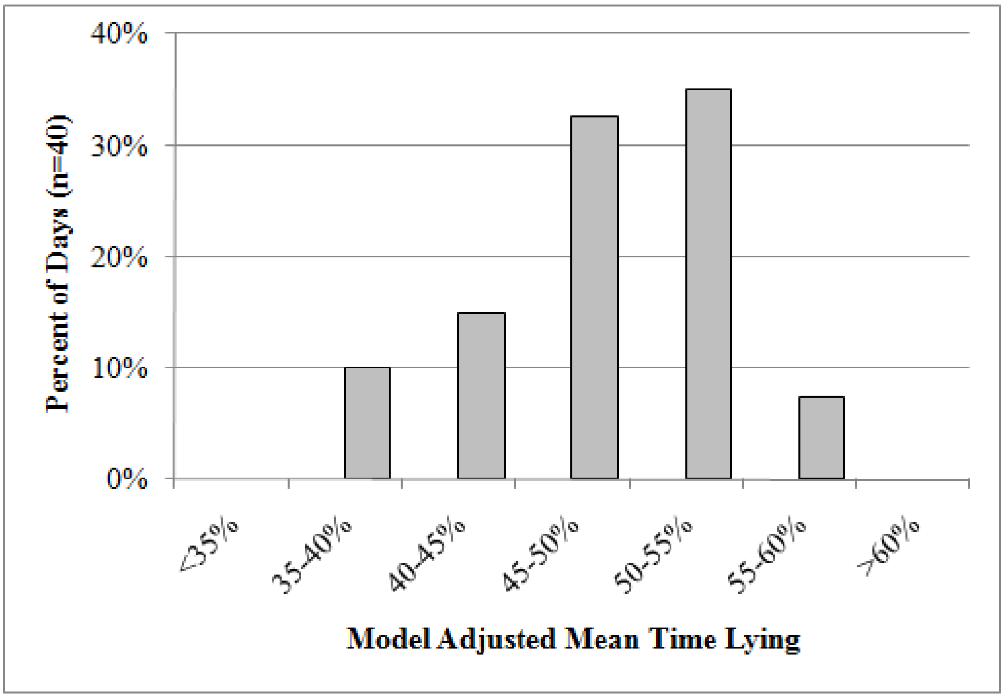

Figure 4-1. Frequency distribution of days by model[a] adjusted mean percent of time calves spent lying. [a]Logistic regression model, which also included significant effects of trial (replicate), day within trial, hour within day and calf identification.

The majority (97.1%) of activity during the study periods was classified as either lying (%) or standing (%) behavior. The remainder of time was classified as walking activity, and calves spent a small (2.9%) of time in this activity during study periods. The percent time lying was associated (*P* < 0.001) with trial replicate, day within trial replicate, hour within day, and individual calf. Calves spent more (*P* < 0.001) time lying in the Spring 2008 trial period (48.9%) compared to the Winter 2007 trial period (47.6%). Calves spent between 45% and 55% of the day exhibiting lying behavior for 67.5% (27/40) of all trial days. The frequency distribution showing percent of trial days by model adjusted percent time lying is displayed in Figure 1.

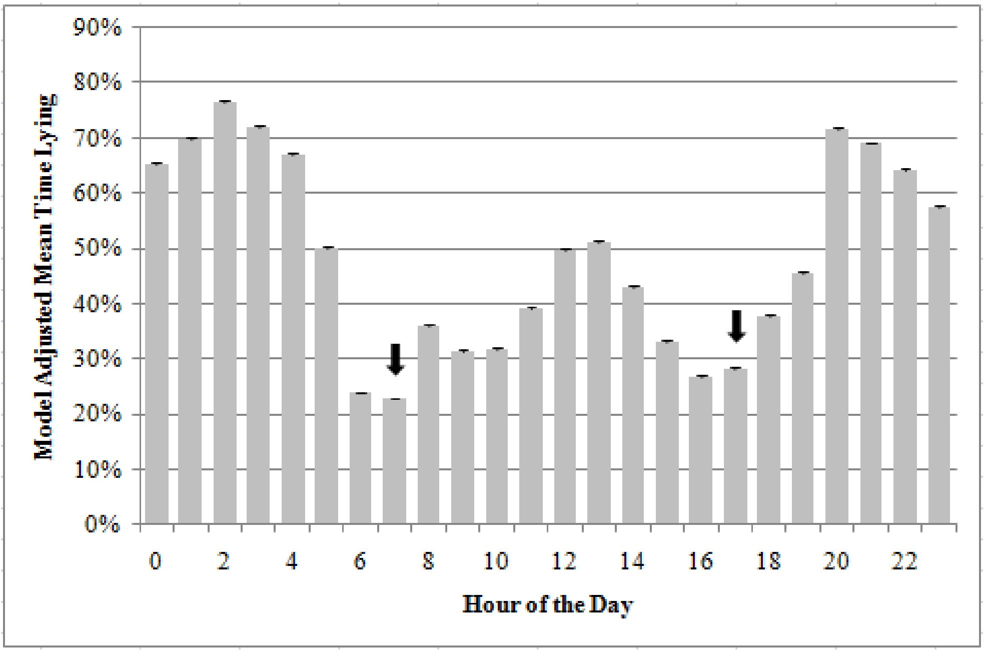

Figure 4-2. Frequency distribution of hours by the model[a] adjusted mean percent time calves spent lying (SE). [a]Logistic regression model, which also included significant effects of trial (replicate), day within trial, hour within day and calf identification. Arrows denote hours of feeding (0700 and 1700).

Hourly percent of lying behavior ranged from 22.7% to 76.4% and the pattern exhibited a distinct circadian rhythm (Figure 2). During the nighttime hours (2000 to 0400) calves spent most (>55%) of their time lying while they were least recumbent (< 30% lying) during feeding time periods (0600-0700 and 1600-1700). Most hours differed (P < 0.001) in the percent of time cattle spent lying; however, hours that did not differ from another included: 0000 and 2200, 0100 and 2100, 0300 and 2000, 0500 and 1200, 0500 and 1300, 0600 and 0700, 0900 and 1000, and 1100 and 1800. The model adjusted mean (StdDev) time spent lying for individual calves ranged from 28.9% (6.1%) to 66.1 % (6.6%), with several pair-wise differences (P < 0.001) in the percent of time individual calves spent lying (Table 1). Most calves (19/25, 76%) spent between 40% and 60% of their time lying down (Figure 3).

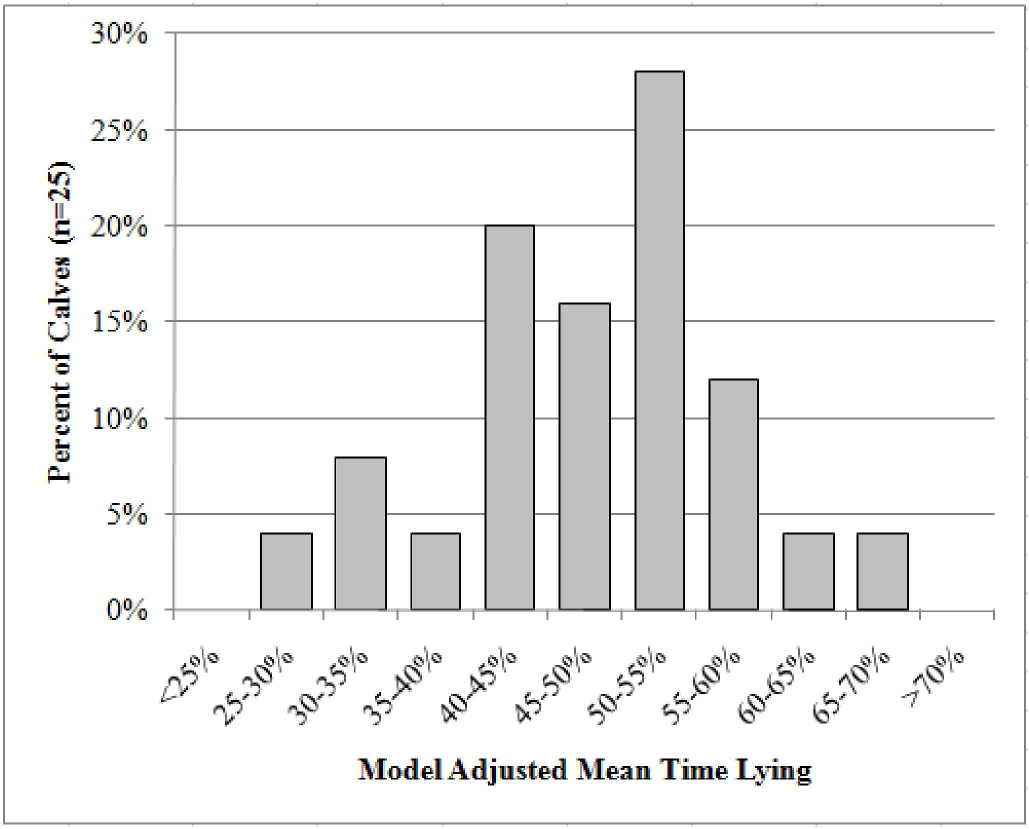

Figure 4-3. Frequency distribution of the model[a] adjusted mean percent time lying for all calves (n=25) during two trials (Winter07, Spring08) aggregated by 5% intervals. [a]Logistic regression model included significant effects of trial (replicate), day within trial, hour within day, and calf identification.

Table 4-1. Model[a] adjusted mean percent time lying, standard deviation (Std Dev), and number of recorded hours for each calf (n=25). Superscripts represent significant (*P*< 0.001) differences in the percent of time lying between calves. [a]Logistic regression model, which also included significant effects of trial (replicate), day within trial, and hour within day.

Calf	Trial	Percent Time Lying	Std Dev	Calf Hours
28	Winter07	28.9% [a]	6.1%	478
9	Winter07	32.3% [b]	6.3%	478
4	Spring08	34.7% [c]	6.5%	441
6	Spring08	38.4% [d]	6.8%	249
15	Spring08	41.9% [e]	6.9%	324
17	Winter07	44.7% [f]	6.9%	478
23	Winter07	44.9% [f]	6.9%	480
26	Winter07	45.0% [f]	6.9%	445
18	Spring08	45.0% [f]	6.8%	480
7	Spring08	45.2% [f]	6.9%	408
10	Spring08	46.3% [fg]	7.0%	190
11	Winter07	48.2% [g]	6.9%	478
12	Spring08	48.2% [g]	6.9%	426
1	Spring08	50.6% [h]	6.9%	404
5	Spring08	50.7% [h]	7.0%	323
8	Spring08	51.6% [h]	6.9%	446
20	Spring08	51.8% [h]	6.9%	480
14	Winter07	53.8% [i]	6.9%	440
2	Winter07	54.4% [ij]	6.9%	475
13	Spring08	54.8% [ij]	7.0%	224
19	Spring08	55.5% [j]	6.8%	456
16	Spring08	58.3% [k]	6.8%	480
25	Winter07	59.2% [k]	6.9%	317
3	Spring08	62.2% [l]	6.7%	278
24	Winter07	66.1% [m]	6.6%	317

Discussion

Continuous accelerometer data in this study provided an objective description of normal cattle behaviors in a cattle production environment. Mitlohner et al. (2001) investigated video surveillance techniques to monitor cattle behavior for groups in a feedlot setting, and although successful in determining group behavior, they were less capable of identifying an individual's behavior within a pen. Our procedure of classifying accelerometer data using decision tree analysis has been shown to be an accurate and objective method as compared to a gold standard real-time video (Robert, White et al. 2009). By implementing a remote monitoring system using accelerometers we were able to not only describe differences in activity among individual animals, but also circadian patterns and activity differences among days. These novel data may be pivotal for future studies using behavior to assess cattle health and welfare.

Accelerometer data for our trial were recorded continuously with minimal interruption, allowing the devices to capture natural activity patterns void of human influence (except feeding time periods); therefore, the effects identified to impact the percent of time lying should be applicable to common, group-housed cattle management systems. Lying activity was chosen for our analysis because if the individual was not lying they were either standing or walking, with walking activity comprising a negligible portion (2.9%) of time in our study. Therefore, lying activity is reflective of the overall behaviors of the calf for the selected period of time.

Our finding that most calves spent between 45% and 55% of a day exhibiting lying behavior agrees with Hoffman and Self (1973) where the investigators monitored randomly selected individual steers within pens and found those animals to have a mean time lying of 49.8%. The previously described study had limited ability to quantify multiple steers within each pen because monitoring was achieved through direct human observer, in contrast to our study where we were able to objectively monitor all calves within the pen yielding a more thorough representation of lying behavior. We attempted to eliminate instances of artifact behavior removing known human contact times from the analysis, but realize that normal production settings present periods of time when cattle behavior may be artificially altered by uncontrollable external effects. Aside from the effects we accounted for in the model (day, hour, calf), our observed behavioral differences between days may have been impacted by environmental and/or temperature changes as this has been reported to have an effect on cattle behavior (Armstrong 1994; Hahn 1999; Olson and Wallander 2002). Our results indicate that behavior differs by day, and further research should be performed to identify the major factors influencing the percent of time cattle spend lying on specific days.

Our results showing that lying behavior was highest from 2000 to 0400 agrees with previous work where lying behavior of pastured (Gary, Sherritt et al. 1970; Arnold 1984/85) and feedlot (Ray and Roubicek 1971; Hoffman and Self 1973) cattle was most common in hours of darkness. Periods when feed was presented at the bunk are clearly evident (0700 and 1700) as these hours represented decreased model estimated percent time lying (Figure 2). DeVries et al. (2005) also found feeding time significantly impacted when dairy cows lie down after returning from milking. As calves for our study remained in the pen at all times, it can be assumed that behavior changed (lying to standing) with the period of time around presentation of feed at the bunks; hence the increased percentage lying behavior prior and subsequent to morning and evening feeding times.

Our findings are consistent with Ray and Roubicek (1971) who concluded that feedlot steer behavior varies hour to hour and this variation should be accounted for in research where calf activity is a variable of interest. Percent lying behavior in our study potentially could be used to categorize calf activity into different activity levels. Hours of darkness (e.g. 2000 to 0400) represent a period of low activity evidenced by the increased percent time lying (>55%) while late morning and afternoon hours (0800 to 1500) contain moderate amounts of activity with lying behavior representing between 30% and 55% of total activity for those hours. Periods of high activity corresponded with morning and evening feeding times (0600 to 0700 and 1600 to 1700) where the percent lying behavior was the lowest (<30% for those hours). The variability of the percent time cattle spend lying during periods throughout the day can influence how herdsmen evaluate the behavior of certain individuals. It may be more beneficial for animal health providers and researchers to assess individuals during periods of high and low activity (e.g. not during periods of normal calf to calf variation in order to decrease noise in data) thus identifying cattle deviating from the normal behaviors of the group for that particular span of time.

Feeding behavior has been actively pursued as an indicator of animal well-being and our results illustrate calves spent the lowest proportion of time lying during the hours associated with feeding. Often, malaise toward feeding is a subjective measure used by animal health personnel to identify ill individuals in several species including dogs and horses (Hornbuckle 1992; Speirs and Wrigley 1997) as well as cattle. Sowell et al. (1999) and Buhman et al. (2000) were able to show feeding and watering behavior was related to overall health in their studies of feedlot cattle. As discussed above, we found lying behavior was the lowest during periods when feed was presented at the bunk; however, if a calf were depressed or ill it may exhibit increased lying behavior during these periods of time. Because we eliminated data from sick calves we are unable to evaluate the efficiency of accelerometers to identify behavior changes caused by sickness during feeding periods. We recommend further investigation into the use of accelerometer monitoring schemes as to their utility in identifying behavioral changes of cattle due to disease.

Individual calf behaviors in our two trials tended to be highly repeatable within individuals over hours and days, evidenced by the standard deviations for individual calves' model adjusted mean time lying (Table 1). This finding corroborates findings from Schrader et al. (2002) where dairy cow activities of lying, standing, and locomotion were found to be highly repeatable within individuals. Behavior repeatability within an individual promotes the use of a calf as its own control rather than using group measurements when comparing behavioral changes before and after a stimulus; with previous research on castrated calves11 showing this method to be successful. We also were able to show that within a group of cattle different individuals displayed varying degrees of lying behavior (Table 1). In our study we have shown calves exhibit different levels of activity; perhaps indicating a need to reassess the criteria used to evaluate individuals for signs of illness. These model-adjusted estimates of mean lying behavior are individually displayed to illustrate the variability of cattle behavior in a group housing setting. This behavioral variability indicates that monitoring of cattle on an individual basis rather than on a pen level may lead to more efficient study designs for research attempting to identify behavioral changes.

Results from this study should be interpreted cautiously as data was generated from 25 calves in two separate trials. Numerous factors could influence the percent time cattle spend lying including facilities, access to other cattle, interactions with people, and weather events. Although the results in this study cannot be used to predict the exact percent of time a calf will spend lying, this trial illustrates that this behavior differs based on time of day, day of the trial, and between individual calves.

Conclusion

In this study we found that accelerometers were successful in describing cattle behavior in a drylot research setting; providing us with valuable information about continuous activity for an extended period of time. We were able to show the day to day variation in activity, as well as its pattern across hours within a day. Our results showed that behavioral tendencies for individual cattle were repeatable and that there are differences in activity between individuals. These findings advocate the use of an individual animal as its own control for future treatment and intervention research. This research demonstrates a successful monitoring system capable of analyzing overall behaviors for use in comparing different treatments to individual and groups of cattle. Because all data that we assessed were from healthy cattle, research should be continued looking at the effects of different stimuli (disease, stressors) to natural behavior patterns.

Footnotes

[a] GP1 Programmable Accelerometer, Sensr Company, Elkader, IA.

[b] Insightful Miner, Insightful Corporation, Seattle, WA.

[c] GLIMMIX procedure in SAS (Version 9.1, SAS Institute, Cary, NC).

Acknowledgements

This research was supported in part through Kansas State University Animal Health – 1433 Funds, project NO. 481850.

CHAPTER 5 - Thesis Conclusion

Behavioral evaluation of animals involved in research is not a new; however, the methods by which we as researchers describe behavior are. Initially, animal health care providers used subjective indices to describe the behavior of their animals; however, these methods were found to be incapable of accounting for the multitude of effects that can modify behavior. The new trend in behavioral monitoring consists of using electronic devices to provide consistent and objective descriptions of behavior. Some of these devices may be implemented at the group level while others may be attached to individual animals in order to obtain a more thorough description of activity patterns. These new devices are also capable of recording data remotely, which alleviates the pressure that human presence can impose on animals.

Accelerometers, like the one presented in this thesis, are effective monitoring devices due to the flexibility in their application. Many accelerometer-based studies discussed in this thesis use very similar techniques and processes; however, species and behavioral outcomes can be very different. These devices are small, record data remotely, and provide an objective analysis of behavior; all three being key components of a successful cattle monitoring system. As studies by the author have evidenced, accelerometers can be validated for use in classifying cattle behaviors of lying, standing, and walking in typical production settings. Also, once validated, three-dimensional accelerometer monitoring systems coupled with decision tree classification can then be implemented in a variety of different scenarios in order to provide an objective, remote, and non-invasive description of cattle behavioral patterns.

In this thesis, we were successful in describing the accuracy of different accelerometer classification settings; specifically the reporting interval over which the accelerometers recorded data. These findings impacted the length of time the devices could be left monitoring in the field, and more importantly, influence the potential for accelerometers to be used in long-term cattle monitoring schemes. Using this knowledge regarding the set-up of our accelerometer system, we were able to develop a monitoring protocol that increased the time the devices could record in the field without hindering the accuracy of cattle behavior classification. The subsequent implementation study yielded positive results for the application of accelerometers for describing individual cattle behavior housed in a group setting. We found that our accelerometer monitoring system can provide a thorough description of lying behavior for multiple animals within a pen while concurrently indicating behavioral differences among study periods, days, hours within the day, and individual calves.

These studies highlighted the capabilities of accelerometers in describing cattle behavior; laying the groundwork for the future implementation of accelerometers in bovine clinical research. Our findings implicate the importance of providing behavioral assessments during research; and more importantly, offer the opportunity to learn more about animals we study.

CHAPTER 6 - References

Agresti A. An introduction to categorical data analysis. 1st Edition New York, NY: John Wiley and Sons, Inc., 1996.

Aminian, K., P. Robert, et al. (1999). "Physical activity monitoring based on accelerometry: validation and comparison with video observation." Medical & Biological Engineering & Computing 37: 304-308.

Aminian, K.A., J. Bijan (2004). "Capturing human motion using body-fixed sensors: outdoor measurement and clinical applications." Computer Animation and Virtual Worlds 15: 79-94.

Anderson, D.M. and M.M. Kothmann (1977). "Monitoring animal travel with digital pedometers." Journal of Range Management 30(4): 316-317.

Armstrong, D.V. (1994). “Heat stress interaction with shade and cooling.” Journal of Dairy Science 77:2044-2050.

Arnold, G.W. (1984). “Comparison of the time budgets and circadian patterns of maintenance activities in sheep, cattle and horses grouped together.” Applied Animal Behaviour Science 85;13:19-30.

Bach, A., C. Iglesias, et al. (2004). "Technical Note: A computerized system for monitoring feeding behavior and individual feed intake of dairy cattle." Journal of Dairy Science 87: 4207-4209.

Bao, L. and S.S. Intille (2004). Activity recognition from user-annotated acceleration data. Pervasive Computing, Second International Conference, PERVASIVE 2004, Vienna, Austria, Massachusetts Institute of Technology.

Berger, A., K.M. Scheibe, et al. (2003). "Evaluation of living conditions of free-ranging animals by automated chronobiological analysis of behavior." Behavior Research Methods, Instruments, & Computers 35(3): 458-466.

Berry, M.J.A. 2004. Data Mining Techniques. Wiley Publishing, Inc., Indianapolis, IN.

Bouten, C.V., K.T. Koekkoek, et al., (1997). “A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity.” IEEE Transactions on Biomedical Engineering 44 (3): 136–147.

Buhman, M.J., L.J. Perino, et al. (2000). "Association between changes in eating and drinking behaviors and respiratory tract disease in newly arrived calves at a feedlot." American Journal of Veterinary Research 61: 1163-1168.

Bussmann, B.J., H.M. Tulen, et al. (1998). "Quantification of physical activities by means of ambulatory accelerometry: A validation study." Psychophysiology 35: 488-496.

Chapinal, N., A.M. de Passille, et al. (2009). "Using gait score, walking speed, and lying behavior to detect hoof lesions in dairy cows." Journal of Dairy Science 92: 4365-4374.

Chapinal, N., D.M. Veira, et al. (2007). "Technical Note: Validation of a system for monitoring individual feeding and drinking behavior and intake in group-housed cattle." Journal of Dairy Science 90: 5732-5736.

Chen, K.Y. and J.D.R. Bassett (2005). "The technology of accelerometry-based activity monitors: current and future." Medicine and Science in Sports and Exercise 37(11(Suppl)): S490-S500.

Cook, N.B., T.B. Bennett, et al. (2005). "Monitoring indices of cow comfort in free-stall housed dairy herds." Journal of Dairy Science 88: 3876-3885.

Currah, J.M., S.H. Hendrick, et al. (2009). "The behavioral assessment and alleviation of pain associated with castration in beef calves treated with flunixin meglumine and caudal lidocaine epidural anesthesia with epinephrine." Canadian Veterinary Journal 50: 375-382.

DeVries, T.J., M.A.G. von Keyserlingk, et al. (2003). "Technical Note: Validation of a system for monitoring feeding behavior of dairy cows." Journal of Dairy Science 86: 3571-3574.

DeVries T.J., von Keyserlingk M.A.G. (2005). "Time of feed delivery affects the feeding and lying patterns of dairy cows." Journal of Dairy Science 88:625-631.

Drissler, M., M. Gaworski, et al. (2005). "Freestall maintenance: Effects on lying behavior of dairy cattle." Journal of Dairy Science 88: 2381-2387.

Duff, G.C. and M.L. Galyean (2007). "Board-Invited Review: Recent advances in management of highly stressed, newly received feedlot cattle." Journal of Animal Science 85: 823-840.

Endres, M.I. and A.E. Barberg (2007). "Behavior of dairy cows in an alternative bedded-pack housing system." Journal of Dairy Science 90: 4192-4200.

Finn, K.J. and B. Specker (2000). "Comparison of Actiwatch® activity monitor and childrens activity rating scale in children." Medicine and Science in Sports and Exercise 32(10): 1794-1797.

Frost, A.R., C.P. Schofield, et al. (1997). "A review of livestock monitoring and the need for integrated systems." Computers and Electronics in Agriculture 17(2): 139-159.

Gary, L.A., G.W. Sherritt, E.B. Hale. (1970). "Behavior of Charolais cattle on pasture." Journal of Animal Science 30:203-206.

Geers, R. (1994). "Electronic monitoring of farm animals: a review of research and development requirements and expected benefits." Computers and Electronics in Agriculture 10: 1-9.

Gibb, D.J., T.A. McAllister, et al. (1998). "Bunk attendance of feedlot cattle monitored with radio frequency technology." Canadian Journal of Animal Science 78: 707-710.

Grandin, T. (1993). "Behavioral agitation during handling of cattle is persistent over time." Applied Animal Behaviour Science 36: 1-9.

Grandin, T. (1997). "Assessment of stress during handling and transport." Journal of Animal Science 75: 249-257.

Grignard, L., A. Boissy, et al. (2000). "The social environment influences the behavioural responses in beef cattle to handling." Applied Animal Behaviour Science 68: 1-11.

Guo, Y., G. Poulton, et al. (2009). "Using accelerometer, high sample rate GPS and magnetometer data to develop a cattle movement and behaviour model." Ecological Modeling 220: 2068-2075.

Gupta, S., B. Earley, et al. (2008). "Effect of repeated regrouping and relocation on behaviour of steers." Applied Animal Behaviour Science 110: 229-243.

Hahn, G.L. (1999). "Dynamic responses of cattle to thermal heat loads." Journal of Animal Science 77:10-20.

Hanninen, L. and M. Pastell (2009). "CowLog: Open-source software for coding behaviors from digital video." Behavior Research Methods 41(2): 472-476.
Hansen, B.D., B.D. Lascelles, et al. (2007). "Evaluation of an accelerometer for at-home monitoring of spontaneous activity in dogs." American Journal of Veterinary Research 68(5): 468-75.
Hanzlicek, G.A., B.J. White, et al. (2010). "Serial evaluation of physiologic, pathological, and behavioral changes related to disease progression of experimentally induced *Mannheimia haemolytica* pneumonia in post-weaned calves." American Journal of Veterinary Research 71(3): 359-369.
Hemsworth, P.H. (2003). "Human-animal interactions in livestock production." Applied Animal Behaviour Science 81: 185-198.
Hoffman, M.P., H.L. Self. (1973). "Behavioral Traits of Feedlot Steers in Iowa." Journal of Animal Science 37:1438-1445.
Hornbuckle, W.E. General physical examination of the cat and dog. Page 3 in Handbook of Small Animal Practice. 2nd ed. R.V. Morgan, ed. Churchill Livingstone, New York, NY. 1992.
Huzzey, J.M., D.M. Veira, et al. (2007). "Prepartum behavior and dry matter intake identify dairy cows at risk for metritis." Journal of Dairy Science 90: 3220-3233.
Ishiwata, T., R.J. Kilgour, et al. (2007). "Choice of attractive conditions by beef cattle in a Y-maze just after release from restraint." Journal of Animal Science 85: 1080-1085.
Ito, K., D.M. Weary, et al. (2009). "Lying behavior: Assessing within- and between- herd variation in free-stall-housed dairy cows." Journal of Dairy Science 92: 4412-4420.
Karantonis, D.M., M.R. Narayanan, et al. (2006). "Implementation of a real-time human movement classifier using a triaxial accelerometer for ambulatory monitoring." IEEE Transactions on Information Technology in Biomedicine 10(1): 156-67.
Keegan, K.G., Y. Yonezawa, et al. (2002). "Accelerometer-based system for the detection of lameness in horses." Biomedical Sciences Instrumentation 38: 107-112.
Keegan, K.G., Y. Yonezawa, et al. (2004). "Evaluation of a sensor-based system of motion analysis for detection and quantification of forelimb and hind limb lameness in horses." American Journal of Veterinary Research 65(5): 665-70.
Kiddy, C.A. (1977). "Variation in physical activity as an indication of estrus in dairy cows." Journal of Dairy Science 60(2): 235-243.
Kluever, B.M., S.W. Breck, et al. (2008). "Vigilance in Cattle: The influence of predation, social interactions, and environmental factors." Rangeland Ecology & Management 61(3): 321-328.
Kluever, B.M., L.D. Howery, et al. (2009). "Predator and heterospecific stimuli alter behaviour in cattle." Behavioural Processes 81: 85-91.
Lascelles, B.D., B.D. Hansen, et al. (2008). "Evaluation of a digitally integrated accelerometer-based activity monitor for the measurement of activity in cats." Veterinary Anaesthesia and Analgesia 35(2): 173-183.
Leroy, T., C. Bahr, et al. (2008). "Automatic detection of lameness in dairy cattle- image features related to lameness." Proceedings of 15th Symposium and 7th Conference on Lameness in Ruminants: 289-293.

Lyons, G.M., K.M. Culhane, et al. (2005). "A description of an accelerometer-based mobility monitoring technique." Medical Engineering & Physics 27(6): 497-504.
Mathie, M.J., N H. Lovell, et al. (2002). "Determining activity using a triaxial accelerometer." Second Joint EMBS/BMES Conference, Houston, TX.
Mathie, M.J., A.C. Coster, et al. (2003). "Detection of daily physical activities using a triaxial accelerometer." Medical & Biological Engineering & Computing 41(3): 296-301.
Mathie, M.J., B.G. Celler, et al. (2004). "Classification of basic daily movements using a triaxial accelerometer." Medical & Biological Engineering & Computing 42(5): 679-687.
Mitlohner, F.M., J.L. Morrow-Tesch, et al. (2001). "Behavioral sampling techniques for feedlot cattle." Journal of Animal Science 79: 1189-1193.
Mitlohner, F.M., J.L. Morrow, et al. (2001). "Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle." Journal of Animal Science 79: 2327-2335.
Moreau, M., S. Siebert, et al. (2009). "Use of a tri-axial accelerometer for automated recording and classification of goats' grazing behaviour." Applied Animal Behaviour Science 119: 158-170.
Morrow-Tesch, J.L., J.W. Dailey, et al. (1998). "A video data base system for studying animal behavior." Journal of Animal Science 76(10): 2605-2608.
Muller, R. and L. Schrader (2003). "A new method to measure behavioral activity levels in dairy cows." Applied Animal Behaviour Science 83(4): 247-258.
Muller, R. and M.A.G. von Keyserlingk (2006). "Consistency of flight speed and its correlation to productivity and to personality in Bos taurus beef cattle." Applied Animal Behaviour Science 99: 193-204.
Munksgaard, L., C.G. Reenen, R.E. Boyce (2006). "Automatic monitoring of lying, standing and walking behavior in dairy cattle." Journal of Dairy Science 89 (Suppl. 1):304.
O'Callaghan, K.A., P.J. Cripps, et al. (2003). "Subjective and objective assessment of pain and discomfort due to lameness in dairy cattle." Animal Welfare 12: 605-610.
O'Connor, A., S.W. Martin, et al. (2001). "The relationship between the occurrence of undifferentiated bovine respiratory disease and titer changes to bovine coronavirus and bovine viral diarrhea virus in 3 Ontario feedlots." The Canadian Journal of Veterinary Research 65: 137-142.
Olson B.E., R.T. Wallander (2002). "Influence of winter weather and shelter on activity patterns of beef cows." Canadian Journal of Animal Science 82:491-501.
Oppenheim, A.V., A.L. Willsky, et al. (1983). "Signals and Systems. Englewood Cliffs, NJ: Prentice-Hall."
Overton, M.W., D.A. Moore, et al. (2003). "Comparison of commonly used indices to evaluate dairy cattle lying behavior." Fifth International Dairy Housing Proceedings of the 29-31 January Conference Fort Worth, Texas USA: 125-130.
Overton, M.W., W.M. Sischo, et al. (2002). "Using time-lapse video photography to assess dairy cattle lying behavior in a free-stall barn." Journal of Dairy Science 85(9): 2407-2413.

Parkka, J., M. Ermes, et al. (2006). "Activity classification using realistic data from wearable sensors." IEEE Transactions on Biomedical Engineering 10: 199-128.
Pate, R. R., M. Pratt, et al. (1995). "Physical activity and public health. A recommendation from the Centers of Disease Control and Prevention and the American College of Sports Medicine." Journal of the American Medical Association 273: 402-407.
Pepin, D., P.C. Renaud, et al. (2006). "Identifying activity patterns from activity counters in ETHOSYS collars on red deer." Applied Animal Behaviour Science 96: 103-114.
Perino, L.J. and M. Apley (1998). "Clinical trial design in feedlots." Veterinary Clinics of North America: Food Animal Practice 14: 243-266.
Petherick, J.C., V.J. Doogan, et al. (2009). "Quality of handling and holding yard environment and beef cattle temperament: 2. Consequences for stress and productivity." Applied Animal Behaviour Science 120: 28-38.
Petherick, J.C., R.G. Holroyd, et al. (2003). "Productivity, carcass and meat quality of lot-fed Bos indicus cross steers grouped according to temperament." Australian Journal of Experimental Agriculture 42: 389-398.
Pober, D.M., J. Staudenmayer, et al. (2006). "Development of novel techniques to classify physical activity mode using accelerometers." Medicine and Science in Sports and Exercise 38(9): 1626-1634.
Ravi, N., N. Dandekar, et al. (2005). Activity recognition from accelerometer data. Seventeenth Innovations in Applications of Artificial Intelligence Conference, Pittsburgh, PA, The AAAI Press.
Ray, D.E., C.B. Roubicek (1971). “Behavior of feedlot cattle during two seasons.” Journal of Animal Science 33:72-76.
Redden, K.D., A.D. Kennedy, et al. (1993). "Detection of estrus by radiotelemetric monitoring of vaginal and ear skin temperature and pedometer measurements of activity." Journal of Dairy Science 76: 713-721.
Reference LLC, 2007. GP1 Progammable Accelerometer User Manual (Version 2.2), pp. 1–53.
Reid, E.D, G.E. Dahl. (2005). “Peripheral and core body temperatures sensing using radio-frequency implants in steers challenged with lipopolysaccharide.” Journal of Animal Science 83:352.
Reinhardt, C.D., W.D. Busby, et al. (2009). "Relationship of various incoming cattle traits with feedlot performance and carcass traits." Journal of Animal Science 87: 3030-3042.
Robert, B., B.J. White, et al. (2009). "Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle." Computers and Electronics in Agriculture 67: 80-84.
Roelofs, J.B., F.J. van Eerdenburg, et al. (2005). "Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle." Theriogenology 64: 1690-1703.
Schlecht, E., C. Hulsebusch, et al. (2004). "The use of differentially corrected global positioning system to monitor activities of cattle at pasture." Applied Animal Behaviour Science 85: 185-202.

Schaefer, A.L., N.J. Cook, et al. (2007). “The use of infrared thermography as an early indicator of bovine respiratory disease complex in calves.” Research in Veterinary Science 83:376-384.
Schlecht, E., C. Hulsebusch, et al. (2004). "The use of differentially corrected global positioning system to monitor activities of cattle at pasture." Applied Animal Behaviour Science 85: 185-202.
Schoenig, S.A., T.S. Hildreth, et al. (2004). “Ambulatory instrumentation suitable for long-term monitoring of cattle health.” 26th Annual International Conference of the IEEE EMBS. San Fransico,CA, USA.
Schrader, L. (2002). “Consistency of individual behavioural characteristics of dairy cows in their home pen.” Applied Animal Behaviour Science 77:255-266.
Schwartzkopf-Genswein, K.S., S. Atwood, et al. (2002). "Relationships between bunk attendance, intake and performance of steers and heifers on varying feeding regimes." Applied Animal Behaviour Science 76: 179-188.
Schwartzkopf-Genswein, K.S., C. Huisma, et al. (1999). "Validation of a radio frequency identification system for monitoring the feeding patterns of feedlot cattle." Livestock Production Science 60: 27-31.
Societies FoAS. Guide for the Care and Use of Agricultural Animals in Research and Teaching. 3rd Edition. Champaign, IL, 2010.
Sowell, B.F., J.G.P. Bowman, et al. (1998). "Radio frequency technology to measure feeding behavior and health of feedlot steers." Applied Animal Behaviour Science 59: 277-284.
Sowell, B.F., M.E. Branine, et al. (1999). "Feeding and watering behavior of healthy and morbid steers in a commercial feedlot." Journal of Animal Science. 77(5): 1105-1112.
Speirs, V.C., R.H. Wrigley. Clinical Examination of Horses. W.B. Saunders, Philadelphia, PA. 1997.
Steele, B.G., B. Belza, et al. (2003). "Bodies in motion: Monitoring daily activity and exercise with motion sensors in people with chronic pulmonary disease." Journal of Rehabilitation Research and Development 40(5): 45-58.
Steele, B.G., L. Holt, et al. (2000). "Quantitating physical activity in COPD using a triaxial accelerometer." Chest 117(5): 1359-1367.
Trenel, P., M.B. Jensen, et al. (2009). "Technical note: Quantifying and characterizing behavior in dairy calves using the IceTag automatic recording device." Journal of Dairy Science 92: 3397-3401.
Trost, S.G., K.L. Mciver, et al. (2005). "Conducting accelerometer-based activity assessments in field-based research." Medicine and Science in Sports and Exercise 37(11): S531-S543.
Turner, L.W., M.C. Udal, et al. (2000). "Monitoring cattle behavior and pasture use with GPS and GIS." Canadian Journal of Animal Science 80: 405-413.
Ungar, E.D., Z. Henkin, et al. (2005). "Inference of Animal Activity from GPS Collar Data on Free-Ranging Cattle." Rangeland Ecology & Management 58: 256-266.
Vasilatos, R. and P.J. Wangsness (1980). "Feeding behavior of lactating dairy cows as measured by time-lapse photography." Journal of Dairy Science 63: 412-416.

Veltink, P.H., H.B. Bussmann, et al. (1996). "Detection of static and dynamic activities using uniaxial accelerometers." IEEE Transactions on Rehabilitation Engineering 4(4): 375-85.

Voisinet, B.D., T. Grandin, et al. (1997). "Feedlot cattle with calm temperaments have higher average daily gains than cattle with excitable temperaments." Journal of Animal Science 75: 892-896.

Walker, J.W., R.K. Heitschmidt, et al. (1985). "Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems." Journal of Range Management 38(1): 90-93.

Wang, Z., J.D. Nkrumah, et al. (2006). "Test duration for growth, feed intake, and feed efficiency in beef cattle using the GrowSafe System." Journal of Animal Science 84: 2289-2298.

Watanabe, N., S. Sakanoue, et al. (2008). "Development of an automatic classification system for eating, ruminating and resting behavior of cattle using an accelerometer." Grassland Science 54: 231-237.

Weary, D.M., J.M. Huzzey, et al. (2009). "Using behavior to predict and identify ill health in animals." Journal of Animal Science 87: 770-777.

Welk, G.J. (2005). "Principles of design and analyses for the calibration of accelerometery-based activity monitors." Medicine and Science in Sports and Exercise 37(11): S501-S511.

Whay, H.R., D.C.J. Main, et al. (2003). "Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records." Veterinary Record 153: 197-202.

White, B.J., J.F. Coetzee, et al. (2008). "Evaluation of two-dimensional accelerometers to monitor beef cattle behavior post-castration." American Journal of Veterinary Research 69(9): 1005-1012.

White, B.J. and D.G. Renter. (2009). “Bayesian estimation of the performance of clinical observations and harvest lung scores for diagnosing bovine respiratory disease in post-weaned beef calves.” Journal of Veterinary Diagnostic Investigation 21(4): 446-453.

Appendix A - Permission for Publication (Chapter 4)

AVMA ® American Veterinary Medical Association

Diane A Fagen, Librarian
Copyright & Permissions
1931 N. Meacham Rd.
Suite 100
Schaumburg, IL
60173-4360

phone 800.248.2862
fax 847.925.9329

Wednesday 28 April 2010

Brad White, DVM, MS on behalf of Bradley Robert
Beef Production Medicine
Q211 Mosier Hall
Manhattan, KS 66506
Phone: 785-532-4243

Dear Drs. White and Robert:

Permission is granted to include in your thesis, the content of your paper that has been provisionally accepted for publication in the *American Journal of Veterinary Research (AJVR)*. We grant permission to you to include the paper but will embargo the distribution of this paper in print and online until the paper has been published in *AJVR*. The print version will, of course, be available to your committee and for submission to Proquest.

Subsequent to the publication of the article in *AVJR*, Proquest may begin issuing the print version of the thesis immediately; the electronic public-access version will be embargoed until one year after the cover date of the *AJVR* issue in which the article is published. If Kansas State University deposits these to an institutional repository and makes them available online and open access, the embargo is the same: this cannot be open access until one year after publication in *AJVR*. This should allow sufficient time for you to receive royalties from your thesis, which begin after Proquest has received $100 in orders.

You do not indicate when your thesis will be complete; if you receive notification that the article is in galleys prior to the publication of your thesis, you may change the notation to "in press".

> Robert, B; White, BJ; Renter, DG; Larson, RL
> Determination of lying behavior patterns in beef steers utilizing wireless accelerometers: circadian rhythms, variation among days, and differences between individual calves.
> *American Journal of Veterinary Research (AJVR)*: **accepted**.

Permission is not granted for translations; translations of complete articles require the receipt of a signed indemnification agreement, which protects author and publisher from litigation stemming from errors in translation. If you would like to have this article translated in the future, please contact me for the appropriate paperwork.

Thank you for your commitment to veterinary medicine.

Congratulations on your achievement; I look forward to seeing many citations to this work.

Best regards,

American Veterinary Medical Association

Diane A. Fagen

Diane A Fagen, Librarian / Copyright & Permissions