Using advanced technologies to quantify beef cattle behavior[1]

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ABSTRACT: For decades, we have relied upon visual observation of animal behavior to define clinical disease, assist in breeding selection, and predict growth performance. Limitations of visual monitoring of cattle behavior include training of personnel, subjectivity, and brevity. In addition, extensive time and labor is required to visually monitor behavior in large numbers of animals, and the prey instinct of cattle to disguise abnormal behaviors in the presence of a human evaluator is problematic. More recently, cattle behavior has been quantified objectively and continuously using advanced technologies to assess animal welfare, indicate lameness or disease, and detect estrus in both production and research settings. The current review will summarize three methodologies for quantification of cattle behavior with focus on U.S. beef production systems; 1) three-axis accelerometers that quantify physical behavior, 2) systems that document feeding and watering behavior via radio frequency, and 3) triangulation or global positioning systems to determine location and movement of cattle within a pen or pasture. Furthermore, advances in Wi-Fi and radio frequency technology have allowed many of these systems to operate remotely and in real-time and efforts are underway to develop commercial applications that may allow early detection of respiratory or other cattle diseases in the production environment. Current challenges with commercial application of technology for early disease detection include establishment of an appropriate algorithm to ensure maximum sensitivity and specificity, reliable and repeatable data collection in harsh environments, cost:benefit, and integration with traditional methodology for clinical diagnosis. Advanced technologies have also allowed cattle researchers to determine temporal variance in behavior or variability between experimental treatments. However, these data sets are typically very large and challenges exist regarding statistical analysis and reporting.

Key words: accelerometer, behavior, cattle, disease detection, research

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INTRODUCTION

Electronic identification (**EID**) of cattle using radio frequency (**RFID**) was first available in the 1970s (Eradus and Jansen, 1999). More recently, the integration of RFID with sensors to monitor various behavioral patterns of livestock has received considerable attention. Continuous, non-invasive monitoring of cattle behavior using various technologies have potential to be powerful

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health management tools in beef feedlot (Wolfger et al., 2015a) and dairy (González et al., 2008; Rutten et al., 2013) production systems and may allow earlier disease detection compared to traditional methods of clinical assessment (Wolfger et al., 2015b; Pillen et al., 2016). Furthermore, sensitivity and specificity of traditional clinical assessment of bovine respiratory disease (**BRD**) is poor (61.8 and 62.8, respectively; White and Renter, 2009) and remote early disease identification with advanced technology systems may improve the accuracy and timeliness of disease detection in beef cattle (Theurer et al., 2013b). Continuous monitoring of behavior with advanced technologies may also provide important information to determine treatment or temporal effects in the research arena of animal health, pain, and welfare. There are currently three primary methods of determining behavior in beef cattle using advanced technologies: 1) physical behavior using accelerometers, 2) feeding and watering behavior using radio frequency tags and sensors, and 3) spatial behavior using triangulation or global-position system technology. The primary objective of this review was to outline the advanced technology currently in use to monitor beef cattle behavior and discuss their application in research and remote disease identification systems.

PHYSICAL BEHAVIOR MONITORING

Today's accelerometers, or pedometers, are devices that contain an enclosed accelerometer attached to a strap or belt mechanism to hold the device to the leg or they can be affixed to an animal via ear tag. They can quantify step count, standing and lying time, lying bouts, and an activity index that considers a combination of the individual activity variables. Leonardo de Vinci conceptualized the first pedometer for use in military applications (MacCurdy, 1938). The simple design of de Vinci's mechanical pedometer provided a foundation for the future of this technology. Most electronic accelerometers currently used in cattle applications consist of three-axis detection, the ability to continuously log data and summarize it in user-defined time increments (i.e., every 15, 30, 60, 120 min, etc.), and may have remote sensing capabilities using ultra-high frequency (**UHF**) radio waves that allow observation in real-time. Modern accelerometers function using the piezoelectric effect, in which a microscopic crystal structure, constructed of either quartz or ceramic, generates voltage when mechanically stressed from pressure or vibration (Reed, 2015). Once stressed, the microscopic crystal will send an electrical impulse to a processor chip within the accelerometer that records a movement and/or posture change in the three-plane axis (Reed, 2015). All three axes are recorded simultaneously and depending on the placement of the device on the animal the plane of the animal differs between standing and recumbence resulting in the ability to distinguish lying and standing. Changes in the accelerometer readings can also be used to calculate a baseline level of activity and this can be recorded as calculated step counts or other indices of movement such as activity ratios. Accelerometers have gained acceptance in beef cattle research because they allow for increased understanding of an animal's motion and behavior continuously and for long duration.

Commercially available accelerometer devices include the IceTag and IceQube products manufactured by IceRobotics, Ltd. (Edinburgh, Scotland, UK) that are designed and validated for use in cattle (McGowan et al., 2007; Robert et al., 2009; Trénel et al., 2009; Nielsen et al., 2010). Other commercial accelerometer products designed for use in cattle include CowScout (GEA Group, Dusseldorf, Germany), SCR (Allflex, Madison, WI), Pedometer Plus (Madero Dairy Systems, Houston, TX), GYUHO SaaS (Fujitsu, Fukuoka, Japan), and GP1 SENSR (Reference LLC, Elkader, IA). Another accelerometer device that has been successfully used to quantify cattle behavior, the HOBO Pendant G (Onset Computer Corp., Bourne, MA), requires the user to build a method of leg attachment and data management is more complicated (Brown et al., 2015), but the cost of this device is typically less than commercially developed accelerometers.

Accelerometers have been used extensively in dairy production systems for detection of mastitis, estrus, and locomotion problems (Rutten et al., 2013); however, their use in beef cattle is much less explored. Activity is reduced in cattle afflicted with lameness or diseases such as BRD. The biological mechanisms for reduced activity in disease-afflicted animals were surmised to include conservation of energy for metabolic costs of the immune system and indirect effects of the febrile and inflammatory responses to infection (Hart, 1988). In one study comparing several physiologic and behavioral parameters (Hanzlicek et al., 2010), the primary finding was decreased activity measured by accelerometers following *Mannheimia haemolytica* challenge. Pedometers were used in 364 high-risk, newly received feedlot cattle to determine behavior alterations in those clinically diagnosed with BRD (cases) vs. control animals never clinically diagnosed with BRD (Pillen et al., 2016). Reductions in behavior variables in cases began at 4 to 6 days prior to clinical BRD diagnosis, and were more pronounced the day before clinical disease identification. Average standing time on the day prior to diagnosis (d −1) was 559 min for cases compared to 613 min in controls. Step count on d −1 for cases and controls were 843 and 1,472 steps, respectively. The number of lying bouts for cases and controls was 11.4 and 14.5, respectively on d −1. Pillen et al. (2016) concluded that activity information provided by accelerometers, used as an objective method for identification of BRD in cattle, may assist in management and early detection of sick cattle. This field study supported research evaluating behavior in calves inoculated with *Mycoplasma bovis* (White et al., 2012). In that study, distance traveled (i.e., step count) was negatively associated with clinical illness score and the extent of lung consolidation, which suggested that a reduction in distance traveled or step count may reliably detect respiratory disease and differentiate its severity. Another study (Theurer et al., 2013b), reported increased lying time for calves challenged with *Mannheimia haemolytica* compared to unchallenged control.

Perhaps the most frequent use of accelerometers in beef cattle research to date is in the evaluation of behavior after castration; they have allowed researchers to determine distinct behavior differences between castration methods. White et al. (2008) observed increased standing time in surgically castrated beef calves relative to precastration standing using two-axis accelerometers. In yearling-age feeder cattle, Roberts et al. (2018) also reported increased standing time in surgically castrated bulls vs. band-castrated bulls or steer controls. Petherick et al. (2014) reported a tendency for surgically castrated mature bulls (i.e. stags) to take less steps following castration vs. banded bulls. Moreover, Roberts et al. (2018) observed reduced steps and greater standing time in surgically castrated bulls compared to banded cohorts or steer controls and concluded that these behaviors were likely in response to avoid contact with the open wound that existed for the surgically castrated animals. Alternatively, transient increases in motion index, steps, and lying bouts observed for the band-castrated cattle may have indicated acute pain-induced hyperactive reaction to ischemia experienced by application of the band. Correspondingly, band castration has been reported to increase restless activity compared to surgically or burdizzo castrated animals (Robertson et al., 1994).

Ball et al. (2018) used pedometers to evaluate the behavior of intact bulls, steers castrated using a rubber band, and cattle administered 1 mL of a Zn solution in each testis. Motion index was greater for the band-castrated and Zn-injected animals compared to bulls on the day of treatment application (d 0); on d 21 motion index was decreased for the band-castrated animals suggesting a delayed behavioral response to pain from the banding procedure. However, it was also noted that overall activity as indicated by motion index may have been influenced by testosterone production causing increased aggressive behavior in bulls. With regards to standing time, a marked increase was reported for the Zn-injected animals on d 2 and corroborated anecdotal observations of "statue standing" behavior in that treatment. Furthermore, step count was greater for bulls and Zn-injected animals compared to band-castrated animals from d 19 to 27 which may be explained by sexual differences or delayed pain-influenced behavioral responses in banded cattle, or both.

Temporal behavior patterns of feedlot cattle were also documented in Pillen et al. (2016). Throughout the 24-hour period in a commercial feedlot, a bimodal pattern in step count was observed; additionally, controls expressed more variability in step count throughout the day than pen cohorts diagnosed with BRD. An initial increase in steps was noted at approximately 05:00 in both cases and controls; this was likely in concert with the anticipation of initial feeding (06:56 ± 67 mins). Activity decreased near the time of the second feeding, which was 11:31 ± 182 mins. A second peak in steps occurred in both cases and controls beginning around 16:30, and this decreased at approximately 21:00 for controls and 19:30 for cases. The secondary peak in steps coincided with anecdotal observations of increased animal activity in the feedlot near the time of dusk. A noticeably similar bimodal pattern in the daily activity counts of cattle was observed in a small-pen study conducted in Kentucky with a single feeding time (Smith et al., 2015). This suggests that the bimodal pattern in the physical behavior of cattle throughout a 24-h period may be repeatable across different environments, housing conditions, and feeding regimens.

Pedometers have also been used to document the step counts and standing/lying activity of cattle during the beta-adrenergic agonist feeding period as well as during terminal marketing. Reed (2015) observed behavior of calf-fed Holstein steers concomitant with zilpaterol feeding; no difference was observed in step count or standing/lying time between zilpaterol and control fed animals, however those fed zilpaterol tended to lie down 0.5 times fewer daily. Reed (2015) also documented the diurnal activity behavior of cattle, illustrating that movement is closely tied to feeding behavior and time of sunlight. Lawrence and Richeson (2014) observed activity of finished steers during terminal marketing; they reported that step count increased 2.5 fold during transit and at the processor compared to the preceding day in the feedlot pen. Lawrence and Richeson (2014) also used the HOBO Pendant G to document acceleration and deceleration forces cattle experience during transit and observed maximum G-force to approach 3G.

FEEDING AND WATERING BEHAVIOR MONITORING

The duration and frequency of animal visits to a feed bunk or water tank, determined from RFID technology or transponders affixed to collars, can provide an assessment of feeding and watering behavior in beef and dairy cattle (DeVries et al., 2003; Mendes et al., 2011). Several commercially developed feeding behavior monitoring systems are available today. Perhaps the most common of these is the GrowSafe System (Airdrie, Alberta, Canada) which is used extensively in cattle research trials conducted in the United States and Canada. Cattle are tagged with a passive, ISO-approved EID tag consisting of a unique number and strategically placed sensors near feeding and watering areas detect the presence of the specific tag. Data consisting of feed bunk/water tank visits and duration are transmitted wirelessly to a central computer located on site and software can generate reports containing information on health, performance, and feed intake of individual animals.

Mendes et al. (2011) performed a validation study using the GrowSafe System to monitor feeding behavior in beef cattle. Feed bunk visits, frequency, and duration was determined using 10 heifers over a 6-d period with behavior data generated by the GrowSafe System at maximum parameter settings (**MPS**) used to terminate uninterrupted bunk visits of 30, 60, 100, 150, and 300 s. The authors reported that meal frequency and duration of the GrowSafe System did not differ from observed values recorded on a time-lapse video. In addition, MPS value of 100 s most accurately predicted meal frequency and duration events recorded by the GrowSafe System (Mendes et al., 2011). A number of research trials have used the GrowSafe System to quantify individual animal feeding behavior and intake in group-housed settings. A brief sample of the published research using the GrowSafe System to quantify feed behavior and individual intake in beef cattle includes determining the effects of vaccination (Arthington et al., 2013), trace mineral source in low- or high-sulfur diets (Hartman et al., 2017), genetics (Chen et al., 2014), and beta-adrenergic agonist growth technologies (Walter et al., 2016). Furthermore, the concept of residual feed intake (**RFI**; Arthur et al., 2001) has been validated with data generated from the GrowSafe System (Golden et al., 2008; Kayser et al., 2015).

Another type of feeding and watering behavior system (Insentec, Hokofarm Group, Marknesse, Netherlands) utilizes transponders fixed to a collar attached around the neck of the animal. The system can be programmed to provide animal-specific feeding/watering times or duration or monitoring an animals' feeding behavior in an ad libitum scenario. Because both the Insentec and GrowSafe systems require compartmentalization of the feeding area, they may be intimidating to cattle and typically require significant time for animals to acclimate. This can be particularly challenging when using these systems in high risk, newly received beef cattle and thus, in addition to cost, limits the practicality for their use as remote disease identification technologies in the commercial feedlot setting. Another feeding and watering behavior monitoring system, AniTrace (Santa Clara, CA), utilizes UHF RFID upon the animal and a simple receiver cable mounted above an open feed bunk line that is typical in commercial feedlots. This allows frequency and duration of feeding and watering without intimidating feeding stanchions that are part of other feeding behavior monitoring systems; however, individual animal feed intake data are not available with the AniTrace system. Nevertheless, this system can monitor large numbers of animals and objectively assess abnormal behavior or feedbunk attendance consistent with disease onset using remote transmission of data in real-time to a software system that alerts the user.

Using feeding behavior monitoring as an early method for BRD detection in feedlot cattle has shown promise (Theurer et al., 2013a; Wolfger et al., 2015a, 2015b). Buhman et al. (2000) monitored both feeding and watering behavior in newly arrived feedlot calves and reported that frequency and duration of drinking was increased 4 to 5 d after arrival in morbid calves. Conversely, morbid calves exhibited reduced frequency and duration of eating and drinking 11 to 27 d after arrival, but the eating frequency was increased from d 28 to 57, which suggests a compensatory effect on feeding behavior after convalescence. Similarly, Quimby et al. (2001) reported that changes in feeding behavior monitored by RFID in newly received steers was able to detect BRD 4.1 d earlier than conventional methods.

SPATIAL BEHAVIOR MONITORING

Monitoring spatial behavioral can provide additional information about specific cattle behaviors. In this manner, cattle are monitored throughout the housing area and their location within the pen is calculated at specific intervals via real-time location system (**RTLS**) or global positioning systems. RTLSs are used in several other industries (e.g., manufacturing, inventory in warehouses) and have been applied in livestock production systems. RTLSs function via communication between a tag and the readers monitoring the coverage area. Multiple readers surround the coverage area and provide overlapping communication radii to generate a pattern that allows at least three readers to communicate with an EID tag at any location within the coverage area (a concept typically referred to as triangulation). Systems function using different methods (e.g. time difference of signal arrival, signal strength, global positioning) and communications between tag and reader are used to calculate the expected coordinates of the tag within the coverage area. These coordinates can then be used to determine location and when combined with features of the housing area to determine proximity to areas of interest. The coordinates can also be combined temporally to monitor activity or movement of the tagged animals within the pen.

RTLSs have been used to quantify changes following painful procedures and associated changes in wellness status. Cattle exhibited altered behavioral patterns following a painful procedure such as dehorning and the RTLS system can be useful to document potential differences in behavior among differing analgesic protocols (Theurer et al., 2012). Systems monitoring behavior also can detect minor differences in behavioral changes associated with events such as transportation (Theurer et al., 2013c).

Remote monitoring can provide information on animal proximity to feed/water, activity patterns, and social behaviors. Alterations in these behavioral patterns can be useful for detection of changes in wellness status. BRD is the most common health disorder associated with beef cattle production. Remote early disease identification systems that incorporate data collected via real-time location have been shown to be an effective method to identify BRD with greater sensitivity and specificity compared to visual observations (White et al., 2015, 2016).

A novel aspect of a RTLS is the ability to monitor location of all animals in the coverage area at multiple time points. This information can be used to quantify true contact patterns among animals that may be useful in modeling disease transmission within the cohort. Previous work has illustrated that cattle contact patterns are dynamic within the cohort and vary among individual calves, time of day, and across multiple days (Chen et al., 2014, 2015). Improved understanding of true contact patterns can be useful when designing prevention or intervention techniques for transmissible diseases within a population.

SUMMARY AND CONCLUSIONS

The behavior monitoring technologies discussed in this review can each generate valuable, yet uniquely specific data in beef cattle research. The different behavior monitoring systems have potential to enhance research from a wide-range of animal science disciplines such as animal welfare, health, nutrition, and reproduction. Each type of behavior monitoring system discussed in this review has been reported to detect BRD early, with variable timing prior to clinical BRD identification. However, extensive commercial adoption of remote early disease identification systems will require a better understanding of the economic benefit (or detriment) of a particular behavior monitoring strategy. It is possible that overall morbidity rate and treatment cost in feedlot cattle would increase via improved sensitivity from monitoring by remote systems vs. traditional clinical assessment. Therefore, commercial implementation of remote disease identification technology hinges upon reduced labor cost, decreased mortality, and increased performance or other economically beneficial outcomes. Numerous challenges exist in the analytical approaches to behavior variables measured in beef cattle research and/or for use in early disease detection application. Statistical analysis frequently utilizes repeated measures designs, which can become memory intensive and may require computing power beyond the capability of a standard desktop computer and the large amount of data generated by continuous behavior monitoring systems can be difficult to display in tabular or graphical form. Finally, extensive research and development of algorithms and software applications is required to accurately signify health status of individual cattle using remote behavior monitoring systems.

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