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Development of a noninvasive system for monitoring dairy cattle sleep

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ABSTRACT

Limited research has been conducted to assess sleep in production livestock primarily because of limitations with monitoring capabilities. Consequently, biological understanding of production circumstances and facility options that affect sleep is limited. The objective of this study was to assess if data collected from a proof-of-concept, noninvasive 3-axis accelerometer device are correlated with sleep and wake-like behaviors in dairy cattle. Four Holstein dairy cows housed at the University of Kentucky Coldstream Dairy in September 2013 were visually observed for 2 consecutive 24-h periods. The accelerometer device was attached to a harness positioned on the right side of each cow's neck. Times of classified behaviors of wake (standing, head up, alert, eyes open) or sleep-like behaviors (lying, still, head resting on ground, eyes closed) were recorded continuously by 2 observers who each watched 2 cows at a time. The radial signal was extracted from 3 different axes of the accelerometer to obtain a motion signal independent of direction of movement. Radial signal features were examined for maximizing the performance of detecting sleep-like behaviors using a Fisher's linear discriminant analysis classifier. The study included 652 min of high-activity wake behaviors and 107 min of sleep-like behavior among 4 cows. Results from a bootstrapping analysis showed an agreement between human observation and the linear discriminant analysis classifier, with an accuracy of 93.7 ± 0.7% for wake behavior and 92.2 ± 0.8% for sleep-like behavior (±95% confidence interval). This prototype shows promise in measuring sleep-like behaviors. Improvements to both hardware and software should allow more accurate determinations of subtle head movements and respiratory movements that will further improve the assessment of these sleep-like behaviors, including estimates of deep, light, and rapid eye movement sleep. These future studies will require simultaneous electroencephalography and electromyography measures and perhaps additional measures of arousal thresholds to validate this system for measuring true sleep.

Key words: behavior, sleep, accelerometer

INTRODUCTION

Monitoring dairy cattle physiology and behavior has extensive implications within both research and on-farm settings. Dairy consumers and producers often express concern over animal well-being. Sleep is essential to the welfare of the animal and is vital to brain function and maintenance of homeostatic control (Hobson, 2005). According to Siegel (2005), sleep can be defined as a state of immobility with greatly reduced responsiveness. Both non-rapid-eye movement (**NREM**) and rapid eye movement (**REM**) sleep are homeostatically regulated in separate ways suggesting that each has important functions for optimal health. Increasing evidence suggests a clear link with the immune system and disease resistance. A hypnogram, discussed by Ruckebusch (1975), is a circadian sleep profile defined by brain waves from an electrocorticogram and indicates an animal's ecological niche, suggesting that sleep is an adaptation to its environment.

Sleep research in human medicine has advanced considerably in recent years by the development of activity-based monitoring systems (Chen et al., 2013). Although the basic physiological functions of sleep are not well understood, a breakthrough in this area has recently been made by Maiken Nedergaard's laboratory at Rochester University (Rochester, NY). A primary function of sleep appears to be flushing the brain of toxic waste products that accumulate during wake (Xie et al., 2013). This feature of sleep seems to be a fundamental and core function that may be critical to other sleep functions, including improved learning, memory, optimal immune function, endocrine function, and many aspects of general health.

Research on dairy cattle sleep is limited and has primarily consisted of studying brain electrophysiology

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through electroencephalography (**EEG**; Ruckebusch, 1965). Very few of these studies exist because of their cost and the physical invasiveness of the procedures. Dairy cattle sleep research has been limited because of the inability to accurately and easily measure sleep versus wake states. It could also be argued that most researchers have not thought to measure sleep. Current related research looks at lying time, which focuses on the quantity of resting behaviors rather than the quality of rest behaviors. Understanding and monitoring dairy cattle sleep under typical dairy farm conditions may improve health, increase milk production, and reduce involuntary culls resulting from disease (Gamaldo et al., 2012). Research from Ruckebusch (1972) used EEG and electrocorticographic patterns to classify slow-wave sleep (characterized with low muscle tone) and paradoxical sleep (absence of muscle tone) along with drowsy states. Results showed that cows spend most of their time awake in a drowsy state when accustomed to their environment and are not sleeping or eating.

A noninvasive sleep monitoring system for mice has recently been developed for research purposes. This system relies on piezoelectric materials affixed to the floor of the mouse cage that function as exquisitely sensitive motion detectors. When the mice are asleep, virtually all movements are associated with respiration. When the mice are awake, even in "quiet wake," subtle postural adjustments and head movements disrupt the respiratory tract, and during active wake, large voluntary movements produce highly erratic wave patterns. (Donohue et al., 2008).

Understanding sleep in humans is still very limited and researchers have many questions with uncertain answers. Sleep deprivation in humans is followed by sleep compensation (Rechtschaffen, 1998) just as cows increase lying time after lying deprivation (Munksgaard and Simonsen, 1996). This pattern could possibly imply that cows may compensate for sleep after deprivation. More recently, new commercial technologies measuring sleep based on wrist movement (Fitbit, Fitbit Inc. San Francisco, CA; Jawbone UP, Jawbone, San Francisco, CA) and stillness have become popular. Smartphone applications have also become a convenient way to track sleep behavior based on stillness (Chen et al., 2013). Montgomery-Downs et al. (2012) reported that the intradevice reliability for the Fitbit in comparison with standard actigraphy was 96.5 to 99.1%. Both overestimated sleep efficiency and sleep time. The Fitbit appeared to be an acceptable activity measurement for the average population, but it should not be used to assess sleep disorders at this time because results can be misleading.

Similar to the current study, human sleep researchers are also seeking alternatives to invasive and expensive polysomnography sleep duration studies and instead are using wrist accelerometers. A study conducted by Jean-Louis et al. (2001) validated a wrist accelerometer (Actillume, Ambulatory Monitoring Inc., Ardsley, NY) against polysomnography and found an 85% agreement when tested on women (50–77 yr old) and a 91% agreement for young adults (19–34 yr old), proving the device to be effective.

The objective of the current study was to test if a noninvasive device can measure sleep-like behaviors in dairy cattle. The long-term objective is to continue developing this device to characterize sleep patterns in dairy cattle to assess sleep quality and how it relates to immune function, health, and productivity.

MATERIALS AND METHODS

The study was conducted at the University of Kentucky Coldstream Dairy using lactating Holstein (n = 4) cows in September 2013. The cows were housed in a tiestall barn for the duration of the study. The barn consisted of tiestalls measuring 125 cm wide by 170 cm long with Dual Chamber Cow Waterbeds (Advanced Comfort Technology Inc., Reedsburg, WI) as the base. Kiln-dried sawdust (5 cm) was added for bedding twice daily. Cows were provided ad libitum water and TMR. Fans were on during most observation periods for ventilation. Natural light was used to observe cows during the day and at night, 2 barn lights created a dim light that allowed observers to see the cows, with the least disturbance.

Live Observations

Observers sat approximately 2 m directly behind the 4 cows. Human observer presence may have influenced the amount of sleep time. However, this influence would not affect the relationship between sleep behaviors recorded by human observers and the monitoring device.

Cows were observed continuously for two 24-h periods to record behavior. Two observers watched 2 cows during 4-h shifts. Observers were trained to recognize wake-, drowsy-, and sleep-like behaviors (Table 1).

Accelerometer Monitor

The 3-axis accelerometer device, developed by the coauthors, sampled at 32 Hz. The system consisted of a low-cost battery-powered accelerometer that fit on a halter attached to the cow's neck (Figures 1 and 2).