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The use of infrared thermography and accelerometers for remote monitoring of dairy cow health and welfare

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ABSTRACT

Increasing reliance on automated systems on-farm has led to a need for remote monitoring of health and welfare. We aimed to validate 2 methods that could be integrated into automated systems currently in use: infrared thermography (IRT) to measure respiration rate (RR), and accelerometers to measure the flinch, step, kick (FSK) response and assessing stress and discomfort. We monitored 22 multiparous, nonlactating, Friesian and Friesian × Jersey cows (average 5.1 yr of age) during a baseline period (2 min), a restraint in a crush (2 min), and then a recovery period after exposure to a startle (2 min). We measured RR with continuous IRT imaging of airflow through the nostrils and by counting flank movements from video and live recordings. We recorded heart rate (HR) and HR variability using HR monitors, and we recorded FSK from continuous video analysis of leg movements and indirectly using accelerometers attached to both hind legs. The FSK response was scored between 1 and 4 based on the height and direction of each leg movement. We observed no change in RR, HR variability, or FSK in response to the startle; however, HR increased briefly by 10 bpm. Bland-Altman plots indicated good agreement between the different methods of measuring RR, with average differences of -0.01 ± 0.87, 0.83 ± 0.57, and 0.37 ± 1.02 breaths/min for video versus live, IRT versus live and IRT versus video, respectively. Acceleration was also highly correlated with FSK scores of ≤ 3 ($R^2 = 0.96$) and ≤ 2 ($R^2 = 0.89$) and moderately correlated with FSK scores of 1 ($R^2 = 0.66$) over the 4-min sampling period. The results show that accelerometers can provide an indirect measure of the FSK response, and IRT can be used reliably to measure RR. With further development, both technologies could be integrated into existing systems for remote monitoring of dairy cows' health and welfare on-farm.
Key words: dairy cow, respiration rate, accelerometers, heart rate, infrared thermography

INTRODUCTION

In recent years in the dairy industry, reliance on automated in-shed systems (such as automatic cup removers and drafting gates) to reduce labor has been increasing. The wide use of radiofrequency identification systems has opened up opportunities for the remote monitoring of individual cows. Remote monitoring systems allow noninvasive, non-contact data collection that can be streamed in real time or downloaded to provide information about an animal's biological state (e.g., activity, behavior, physiology). For example, rumination and activity monitors (using accelerometer or pedometer technology) attached to the leg or neck collar have become common for detecting estrus in dairy cows (Roelofs and van Erp-van der Kooij, 2015). Due to this shift toward automation and the declining number of experienced stock people entering the industry, along with increasing herd sizes (Lyons et al., 2016; DairyNZ, 2015), automated remote monitoring of health and welfare on-farm is needed. For example, the size of the average dairy herd in New Zealand (419 cows) has tripled in the last 30 years, and herds of 2,000 to 3,000 cows are not uncommon (DairyNZ, 2015). Increasing herd size leads to less individual monitoring of cows.

Respiration rate (**RR**) can be affected by stress and heat exposure (Schütz et al., 2014), pain (Stewart et al., 2013), and disease (Gershwin et al., 2015); therefore, changes in RR can be a useful indicator of these physiological states. Respiration is the physiological act of breathing, or more specifically, the act of taking in oxygen, which is conveyed to the tissues and cells in the body, followed by the release of carbon dioxide. One method for measuring RR in dairy cows is to record the time it takes for a cow to take 10 breaths: the number of flank movements as the animal inhales and

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exhales. Although this method has been used reliably, for example to assess heat stress in cows (Schütz et al., 2014), it is very labor-intensive, and flank movements can be difficult to observe in colder climates or with shallow breathing (e.g., during disease onset). This method also requires that observers be near the animal, which could cause a stress response in some animals and affect the validity of the recordings. Some remote devices have been developed to measure RR in cattle. Typically, they involve sensors that measure chest-wall movements (e.g., strain gauges or pressure transducers). For example, Eigenberg et al. (2000) developed a RR monitoring system for cattle that used a thoracic belt to keep the transducer in place. Although remote monitoring is possible, this equipment is cumbersome and not practical for long-term recording. Similar to heart rate (**HR**) monitoring systems, this approach is impractical and susceptible to displacement and damage. Also, having such bulky equipment fitted to the animal could cause changes in normal behavioral patterns and increase stress, affecting the accuracy of the results. Pastell et al. (2006) developed a laser-based contactless method for measuring RR in an automatic milking system. However, a major limitation was that it could not be used on black cows, because the laser was absorbed by their dark hair. To be practical on-farm, a RR monitoring system must be contactless, capable of real-time monitoring, and account for variations in animal characteristics.

Infrared thermography (**IRT**) measures radiated heat, and studies in cattle have shown that this technology can detect thermal changes before clinical signs occur in the onset of bovine viral diarrhea (Schaefer et al., 2004), bovine respiratory disease (Schaefer et al., 2012), and neonatal calf diarrhea (Lowe et al., 2016). Other studies have investigated IRT as a noninvasive tool for detecting mastitis (Polat et al., 2010), lameness (Alsaaod and Büscher, 2012), stress (Stewart et al., 2008), pain (Stewart et al., 2009), and estrus (Talukder et al., 2014) in cattle. The study by Schaefer et al. (2012) was the first demonstration of an automated IRT system, whereby IRT images were captured every time the animal visited a water trough to drink. The diseases mentioned above are all associated with localized inflammatory response (e.g., respiratory tract, intestines), and during their onset, animals use other mechanisms for heat loss (e.g., radiated heat) to maintain a normal core body temperature. By combining RR monitoring with IRT, it could be possible to detect other conditions that may not cause an inflammatory response, such as metabolic diseases (e.g., ketosis, rumen acidosis, bloat) or stress and discomfort. Human studies have investigated IRT for measuring RR (Abbas et al., 2011; Lewis et al., 2011). Lewis et al. (2011) developed an algorithm that could accurately extract RR and relative tidal volume in 25 adult participants. Using continuous IRT video recording of the nostrils, changes in temperature during the breathing cycle can be detected: inhaling brings in external air and cools the nostrils, whereas exhaling expels air from the body core and warms the nostrils. This technology could be developed for non-contact RR monitoring, without interfering with the animal or fitting equipment.

It is becoming increasingly common for dairy farms to use accelerometers, mainly to assist farmers with estrus detection. One survey of dairy producers reported that 41.3% of respondents used technologies that measured activity (Borchers and Bewley, 2015). These small devices are attached to the hind leg or neck collar and are likely to be less invasive for the animal and less susceptible to damage or displacement than other devices, such as thoracic belts. It would be beneficial for the farmer if other valuable animal information indicative of pain or discomfort due to lameness, mastitis, or other disease onset could be collected from these devices. One method may be automated monitoring of the flinch, step, kick (**FSK**) response. The FSK response during milking has been associated with milk production (Willis, 1983; Breuer et al., 2000; Hedlund and Løvlie, 2015); udder health and clinical signs of mastitis (Rousing et al., 2004; Pastell et al., 2006; Medrano-Galarza et al., 2012; Fogsgaard et al., 2015); and lameness (Pastell et al., 2006). However, the method used to measure FSK involves manual scoring of kicks and foot movements, which is labor-intensive and prone to inaccuracies, due to the speed of the movements being recorded and low inter-observer reliability.

The aim of this study was to validate (1) IRT to measure RR, and (2) accelerometers to measure FSK in dairy cows, using a startle as a stress model. Both methods could be developed and integrated into a noninvasive, automated system and replace manual recordings for the on-farm monitoring of animal health and welfare.

MATERIALS AND METHODS

Animals and Handling Facilities

The protocol and procedures in this study were approved by the Ruakura Animal Ethics Committee under the New Zealand Animal Welfare Act 1999. This study was conducted in June 2014 (Southern hemisphere winter) in a cattle-handling facility at Ruakura Research Centre, Hamilton, New Zealand. We used 22 pregnant, multiparous, nonlactating Friesian and Frie-