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System specification and validation of a noseband pressure sensor for measurement of ruminating and eating behavior in stable-fed cows

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ABSTRACT

Rumination and eating behavior are important indicators for assessing health and well-being in cattle. The objective of this study was to develop and validate a novel scientific monitoring device for automated measurement of ruminating and eating behavior in stable-fed cows to provide research with a measuring instrument for automated health and activity monitoring. The RumiWatch noseband sensor (Itin+Hoch GmbH, Liestal, Switzerland) incorporates a noseband pressure sensor, a data logger with online data analysis, and software. Automated measurements of behavioral parameters are based on generic algorithms without animal-specific learning data. Thereby, the system records and classifies the duration of chewing activities and enables users to quantify individual ruminating and eating jaw movements performed by the animal. During the course of the development, two releases of the system-specific software RumiWatch Converter (RWC) were created and taken into account for the validation study. The results generated by the two software versions, RWC V0.7.2.0 and RWC V0.7.3.2, were compared with direct behavioral observations. Direct observations of cow behavior were conducted on 14 Swiss dairy farms with an observation time of 1 h per animal, resulting in a total sample of 60 dairy cows. Agreement of sensor measurement and direct observation was expressed as Spearman correlation coefficients (r_s) for the pooled sample. For consolidated classification of sensor data (1-h resolution), correlations for rumination time were $r_s = 0.91$ (RWC V0.7.2.0) and $r_s = 0.96$ (RWC V0.7.3.2), and for eating time $r_s = 0.86$ (RWC V0.7.2.0) and $r_s = 0.96$ (RWC V0.7.3.2). Both software versions provide a high standard of validity and measuring performance for ruminating and eating behavior. The high to very high correlations between direct observation and sensor data demonstrate that the RumiWatch noseband sensor was successfully developed and validated as a scientific monitoring device for automated measurement of ruminating and eating activity in stable-fed dairy cows.

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1. Introduction

Research in the field of Precision Livestock Farming has put a major effort on development and evaluation of technologies allowing early recognition of pathological and management-relevant behavioral changes and assessment of the individual health state in dairy cows (cf. review by Rutten et al., 2013). Hence, sensor devices for automated detection of health impairments in livestock are increasingly available and can provide effective management support in various types of farming systems. In dairy cattle nutrition, chewing activity has been identified as an important parameter to assess the adequate composition of a diet and the risk of

ruminal acidosis (Yang and Beauchemin, 2007). Furthermore, ruminating activity may provide meaningful information on calving time and subclinical diseases or health disorders (Goff and Horst, 1997; Soriani et al., 2012). Accordingly, continuous measurements of cow feeding variables enable us to develop a more complete understanding of the dietary effects on digestive function and performance (Dado and Allen, 1993). The timeline and intensity of feeding activity provide information on the diurnal pattern of the behavior of ruminants, and identification of deviations may be used for detection of health impairments (Weary et al., 2009; Braun et al., 2014). Direct observation for measurement of ruminating and eating behavior is labor intensive, error-prone and hardly applicable for continuous observations on several animals simultaneously (Penning, 1983). For these reasons, several methods have been developed for automated, non-invasive measurement of chewing activity in ruminants. The working principle of

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these devices is mainly based on detection of jaw movements via strain or pressure sensors fitted to a halter (Luginbuhl et al., 1987; Matsui and Okubo, 1991; Dado and Allen, 1993). The best known approach is the IGER Behaviour Recorder (Penning, 1983; Penning et al., 1984; Rutter et al., 1997; Rutter, 2000). However, continuous recording is hereby limited to approximately 24 h and Nydegger et al. (2010) reported frequent damages of the IGER Behaviour Recorder when applied in loose housing systems, as the recorder's dimensions impeded the animals, particularly on entering and leaving the feed rack. Therefore, Nydegger et al. (2010) developed a compact-built pressure sensor system integrated into a halter (ART-MSR Jaw Movement Sensor, MSR Electronics GmbH, Seuzach, Switzerland), which allowed individual jaw movements to be recorded but required animal-specific learning data. The necessity of creating learning datasets for classification of the activities before starting the measurement is laborious, and recording time of this device was limited to a maximum of 40 h due to storage capacity and power supply (Nydegger et al., 2012). Meanwhile, technological progress in electronics led to increased battery lifetime, storage capacity, continuous recording time, and accuracy of automated measurements. Considering both scientific and commercial requirements for detailed analysis of the behavior and activity of ruminants, automated measurement technologies should generate information on the duration, intensity and diurnal pattern of chewing activities. Furthermore, a suitable method for automated recording of jaw movements needs to allow classification and quantification of individual jaw movements for a long operating time (i.e., weeks to several months) at a high resolution and with satisfactory measuring performance. The aim of this study was to develop and validate a novel scientific monitoring device for automated health and activity monitoring in dairy cows. The presented RumiWatch noseband sensor was developed by Agroscope Institute for Sustainability Sciences (Ettenhausen, Switzerland) in collaboration with Itin+Hoch GmbH and InnoClever GmbH (both Liestal, Switzerland) and enables automated measurements of ruminating, eating, and drinking behavior. Our aim in this paper was twofold. Firstly, to provide a complete and detailed technical specification of the functionality of this device and, secondly, to perform a validation focusing on the system's ability to quantify the duration of chewing activity and the number of jaw movements during rumination and eating. As the algorithms have undergone successive development, two releases of the device-specific software for behavior classification are currently available that allow repeated analysis of previously recorded noseband sensor data. Hence, a further aim of this study was to validate these two commercially available versions of the software applied to the same data set recorded by the RumiWatch noseband sensor in comparison with direct observation under field conditions in stable-fed cows.

2. Materials and methods

2.1. RumiWatch noseband sensor

The RumiWatch noseband sensor (Nydegger and Bollhalder, 2010, Swiss Patent CH 700 494 B1, Agroscope, Ettenhausen, Switzerland; manufactured and distributed by Itin+Hoch GmbH, Liestal, Switzerland) is a non-invasive sensor-based system enabling automated measurement of rumination, eating, drinking, movement and posture of the head in cattle. It comprises a noseband sensor, a data logger with online data analysis, and evaluation software. The noseband sensor consists of a glycol-filled silicone pressure tube with a built-in pressure sensor placed in the casing of a fully adjustable polyethylene halter over the bridge of the cow's nose (Fig. 1). Adjustable straps provide a proper fit of

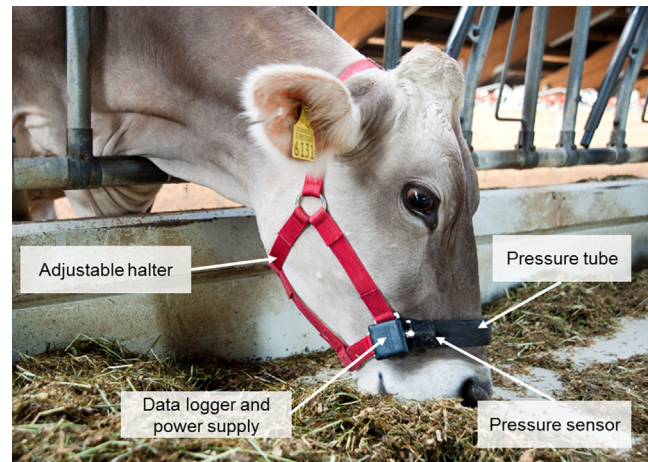


Fig. 1. Technical components of the RumiWatch noseband sensor.

the padded halters to the dimensions of the animal's head, in order to ensure wearing comfort, correct positioning of the sensor unit, and collection of valid data. The total weight of the noseband sensor including all components is approximately 700 g.

The pressure sensor is connected to a data logger placed in a protective casing on the right side of the halter. A second, identically constructed casing on the left side of the halter stores two 3.6-V lithium-ion batteries (Tadiran SL-761, Tadiran Batteries Ltd., Kiryat Ekron, Israel) for power supply of the electronic components. The data logger registers the pressure changes in the noseband sensor, triaxial accelerations of the halter, and ambient temperature at a constant logging rate of 10 Hz and saves the raw data as a binary file to a specific microSD memory card (Swiss-bit AG, Bronschhofen, Switzerland). Online data analysis with preliminary classification of measurement data is conducted via the device firmware that is operated by the onboard 16-bit CPU (MSP430, Texas Instruments Inc., Dallas, Texas, USA). During chewing activity, the curvature of the noseband is altered by the cow's jaw movement, exerting a pressure change in the pressure tube. Thus, the pressure sensor allows individual jaw movements to be recorded. Automatic classification and quantification of chewing activity is based on the logging of individual pressure peaks, whereby every peak above a detection threshold of 28 mbar is counted as a chew. Absolute peak height is not considered for classification of chewing activity, as the pressure head inside the silicone tube is not standardized. In consequence, chewing activity is classified according to the frequency of peaks, as characteristic peak rates and peak intervals during rumination, eating, drinking, and other activity (e.g., idling) allow distinguishing between jaw movements of these behaviors. Peak frequencies recorded by the noseband sensor during measurement of rumination, eating, and drinking behavior are shown in Fig. 2a–c. The diagrams show that rumination is clearly distinguishable from eating activity. Homogeneous phases of jaw movements interrupted by bolus regurgitation cause the significant peak profile of ruminating activity. Peak rates during eating are more heterogeneous with irregular interruptions and altering peak frequencies due to the animal's partly increased bite rate and feed selecting behavior. A specific peak profile during drinking activity recorded by the noseband sensor is clearly distinguishable from those of rumination and eating (Fig. 2a–c). The shown diagrams represent typical measures that are obtained from noseband sensor recordings under normal operating conditions.

The raw data files of noseband sensor recordings contain all information logged at 10 Hz, comprising the date and time of mea-

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