Sensor-based Control of Chewing and Rumination Behavior of Dairy Cows

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List of Abbreviations

Abbreviation	Explanation
a	agreement
Ah	ampere-hour
BLE	Federal Office for Agriculture and Food
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection
D	disagreement
DC	DairyCheck
dev.	deviation
DM	dry matter
DMI	dry matter intake
EMG	electromyography
FT	feeding time
GHz	gigahertz
GmbH	company with limited liability
h	hour
HF	Holstein Frisian
HR	Lely Qwes HR
Hz	hertz
Inc.	Incorporated
κ	Cohen's kappa coefficient
kg	kilogram
km	kilometer
Ltd.	Limited
M.	Musculus
max.	maximum
min/Min.	minute/Minute
min.	minimum
n	number
P	p-value
p.p.	post partum
r	correlation coefficient

Abbreviation	Explanation
R^2	coefficient of determination
RT	rumination time
RW	RumiWatchSystem
σ	asymptotic standard deviation
S	Simmental cow
SD	Secure Digital
TM	Trockenmasse
V	volt

Meinen Eltern

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1 INTRODUCTION

1.1 State of the Art

The development of modern animal husbandry is characterized by production methods striving for a continuous growth in milk yields. Globally, the average milk performance per cow and per year has increased enormously in the past decades (Faostat, 2012). International competitiveness and price-oriented consumer behavior are the driving forces behind the increase in milk performance in dairy cows worldwide. Negative side effects of this development are manifold and encompass amplified risk for various physiological, metabolic and immunological disorders (Rauw et al., 1998).

Thus, the tension increases between the conflicting aims of higher milk performance, on the one hand, and the maintenance of the health status of dairy cows on the other hand (Harrison et al., 1990; Lucy, 2001; Knaus, 2009). To comply with the nutritional requirements of high yielding dairy cows, diets in general contain high proportions of concentrate and energy (Krause and Combs, 2003; Harvatine and Allen, 2006). Because of the physiological limitations in feed intake capacity, the energy content of feeding rations should meet the performance related requirements (Allen, 1996; Grant and Albright, 2001). The inevitable conflict in feeding diets is that they are relatively low in dietary fiber and adequate particle size (Beauchemin et al., 2003; Beauchemin and Yang, 2005). In contrast, a well-adapted energy supply as well as an appropriate fiber content in the diet are immensely important for ruminant's health (Beauchemin and Yang, 2005; Zebeli et al., 2008). The fiber magnifies the particle surface for better microbial digestion, stimulates the chewing motion and increases saliva production (Van Soest et al., 1991; Kononoff et al., 2002). Saliva contributes to maintain a physiological pH-value in the range of 6.5 favorable for microbial activity (Bailey and Balch, 1961; Petrujkić et al., 2008) and thus ensures optimal and stable conditions for them inside the rumen (Cassida and Stokes, 1986; Mertens, 1997; Yang et al., 2001).

Unbalanced rations with excessive starch and easily fermented carbohydrates in relation to the content of effective fiber result in reduced chewing activity (Steinwiddder and Gruber, 2002). Consequently, the ruminal pH drops beneath a critical value below 5.6 and often leads to unsuitable conditions for microbial activity and increases the risk of metabolic or digestive disturbances (NRC, 2001; Krajcarski-Hunt et al., 2002; Kleen et al., 2003; Nordlund, 2003).

A lot of disturbances and diseases, such as metabolic disorders (ketosis, milk fever) (Gustafsson et al., 1995; Goldhawk et al., 2009; Suthar et al., 2013), udder-related problems (edema, teat injury, local and systemic mastitis) (Dann et al., 2005; Lukas et al., 2008), reproductive disorders (difficult calvings, retained placenta, metritis) (Urton et al., 2005) and acidosis (Britton and Stock, 1987; Nocek, 1997; Maekawa et al., 2002;) affect the individual feeding behavior of ruminants. Also enteritis, decreased rumen motility and displaced abomasum (Østergaard and Gröhn, 2000) are associated with altered feeding behavior. These different diseases are accompanied by reduced dry-matter intake and decreased feeding and rumination time (Bareille et al., 2003; Harvatine and Allen, 2005). Even social stress can be linked to a decrease in time spent feeding and ruminating, which is a direct response of ruminants to acute stressors (Bristow and Holmes, 2007, Schirmann et al., 2011).

Health problems have a negative impact on production in dairy herds. Most of them are prevalent throughout the dairy industry and can be a costly problem (Stone, 2004; Morgante et al., 2007). They lead to milk yield and quality reduction (Dohoo and Martin, 1984; Rajala-Schultz et al., 1999), increased veterinary treatment costs, mortality (Kossaibati and Esslemont, 1997) and reveal animal welfare problems (Broom, 1991; Krause and Oetzel, 2006).

Thus, consideration of feeding behavior is a high priority (González et al., 2008). Monitoring daily feeding and rumination time serves as a crucial and helpful parameter (Beauchemin and Yang, 2005; Urton et al., 2005; De Vries et al., 2009) in gaining relevant information about the individual animal and its ability to cope with farm-specific feeding, housing, and the farm management situation (Owens et al., 1998; DeVries et al., 2009). Data from feeding behavior may be suitable for the early detection of deviations from normal conditions and diseases in dairy cows deriving thereof (Hansen et al., 2003; Krause and Oetzel, 2006), which shall allow a timely intervention against several feeding-related or health-related impairments. The earlier management changes and veterinary treatments are initiated during the disease process, the more effective they are (González et al., 2008).

1.2 Overall Aim

The aim of this work is to develop a new measurement system for recording the feeding behavior of dairy cows. The development of this new system is part of the project "NutriCheck" labeled as "DairyCheck", which was initiated in association with the department of Crop and Animal Science at the Humboldt University of Berlin. The other two partners are BITSz engineering GmbH, Zwickau and BIJO-DATA Information GmbH, Seßlach. They are in charge of technical development. The whole project was funded by the Federal Office for Agriculture and Food (BLE) and the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) in Germany.

Measurement of feeding behavior ensues through electromyography with modified electrodes which are integrated into a measuring halter. During the development, the sensor-based, non-invasive and automatic system should be able to identify single jaw movements. Later, the algorithm of the automatic analysis software should categorize jaw movements into active feeding and rumination phases and non-active dormant phases. At the end of the project, the analysis software should indicate deviations of feeding behavior, which are able to be interpreted individually for each animal by means of initially defined reference values.

Thus, the diurnal feeding and rumination time of individual cows can be observed and deviations of the feeding behavior from normal conditions shall be recognizable. The timely identification of suboptimal feeding conditions and possible health disorders for corresponding intervention may be realized through this new measurement tool. The system should enable farmers to anticipate and act upon any associated problems.

The overall objective of this work is the development of an early warning system for inadequate feeding rations and digestive and metabolic disorders, the prevention of which constitutes the basis for health, performance, and reproduction.

The development of this new measurement system comprises different steps which build upon one another and are essential for its success and its desired benefits:

1. The first step is an evaluation of different measurement methods and techniques for recording feeding behavior to give a detailed overview of previously developed measurement tools. Thus, a classification of the new system within measurement tools existing up to now is possible.
2. The next stage of the development is the evaluation of the new system. Significant and reliable results with high concordance to the validation method used and greater usability in practice are essential for further trials.

3. The third step includes the first trial of the DairyCheck system in practice. The reliability, applicability and generation of valid data of this system were compared to data of two other systems for measuring rumination time in dairy cows. In this way, it was possible to classify it within current systems as well as comparing it to them.
4. The fourth stage of development is the application of the system to record feeding behavior to generate data for a specific question. This trial investigated whether rumination time is affected by the onset of calving and whether the individual rumination time of animals can be a useful indicator for predicting imminent birth in dairy cows.

2 PRELIMINARY WORK

2.1 Halter development and design

2.1.1 Introduction

The measurement of chewing and rumination behavior by the DairyCheck system is based on electromyographic control. Surface electrodes record electrical oscillations of the exterior masticatory muscle, the *musculus (M.) masseter* during jaw movements. The required electrodes and the sensor are integrated into a measuring halter. An ideally adapted halter constitutes the basis for the best positioning of the electrodes close to the skin on the *M. masseter* and ensures the exact measurement of chewing and rumination activity, which is a fundamental requirement for generating suitable and valid data. Therefore, precise fit and size of the halter are very important.

The head measurements of cows do not constitute an essential characteristic for significance of breeding. This explains the lack of suitable literature references regarding head measurements. Due to missing or outdated information in the literature, independent measurements of different cow heads have been implemented (Sciuchetti, 1933; Nadai, 1949; Stobbs, 1970; Nydegger et al., 2011). In this way, it was possible to include individual variations in measurements when designing an ideal halter.

2.1.2 Materials & Methods

Working principle

Electromyographic control occurs through modified electrodes which, by way of the halter, are placed close to the skin. The finely feathered muscle *M. masseter* is an essential component of the motion system of the mandible and is well suited for placement of the measuring electrodes. Besides the *M. temporalis*, the *M. masseter* is the most powerful chewing muscle in terms of size and power performance and has a large cross section area. It is involved in the closure of mouth, in forward movements and sideways-looking movements, which are typical grinding movements of herbivores (Surwald, 2001). The region of the *M. masseter* is located below the cow’s eye and is illustrated in Figure 1 as the lighter area.

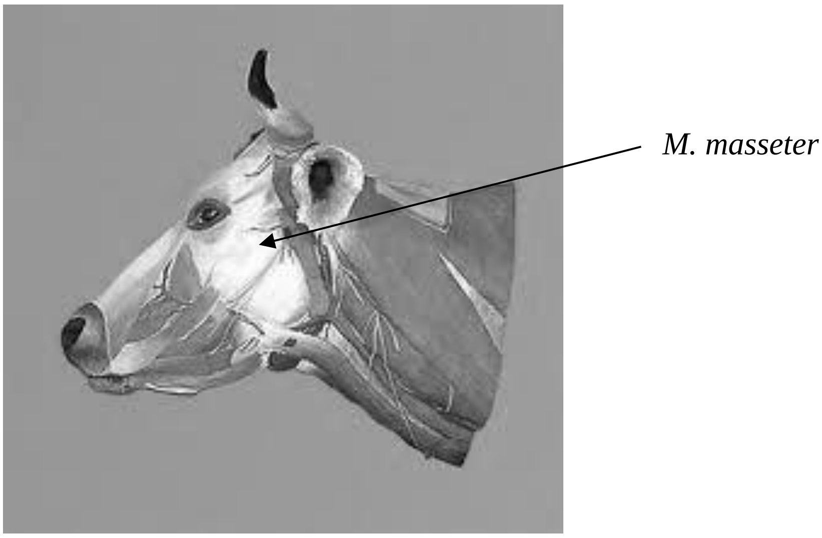

Figure 1. Head of a cow, Budras and Wünsche (2007)

Study Design

Cow heads of the two most common dairy species in Germany were measured for the conception of the halter. The percentage of these breeds of the total share of German dairy species was 90.8% (ADR, 2010) and is divided into 61% of Holstein Friesian and 29.8% of Simmental cows. As measurement parameters have been selected and modified, according to Richter (2010), into three different sizes, these measures should ensure the design of an ideal halter. The parameters are muzzle breadth, cheek measurement and throat breadth and are illustrated in Figure 2.

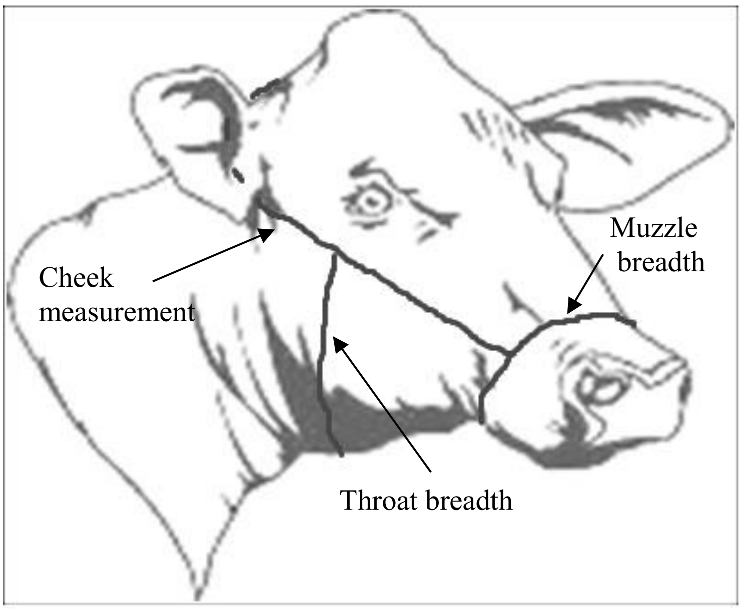

Figure 2. Cow head measurements for halter design

2.1.3 Results

In total more than 250 cow heads from the selected dairy species have been measured, which are subdivided into 173 Holstein Friesian cow heads and 83 Simmental cow heads. With this number of animals sufficient data could be identified for a suitable statistically evaluable analysis and calculation. The results of the species specific cow head measurements are represented in Table 1. Listed are mean, standard deviation, minimum and maximum by each of the three used measurement parameters.

Table 1. Measures of mean, standard deviation, minimum and maximum in cm by each of the three measurement parameters muzzle breadth, cheek measurement and throat breadth, divided into Holstein Friesian (HF) and Simmental (S).

	Cow race	Muzzle breadth	Cheek measurement	Throat breadth
mean	HF	50.7 ± 2.6	106.7 ± 4.1	56.8 ± 3.2
	S	53.2 ± 2.3	105.8 ± 3.3	57.8 ±3.8
min.	HF	45	98	47
	S	46	99	49
max.	HF	58	119	67
	S	59	114	68

The measurements of the three parameters differ considerably. But the variability of the different measurements inside and among the two breeds is weak. These results confirmed the need for the manufacture of adjustable halters. All measurements of the halter should be optimally adaptable using adjustable buckles and the muzzle breadth should, in addition, be flexible by using an elastic rubber band.

2.1.4 Conclusion

The three measuring parameters: muzzle breath, cheek measurement and throat breadth constitute substantial measurements for an optimal halter design. Attachment of three adjustable buckles enables an ideal positioning of the halter with its integrated electrodes. In this way sufficient pressure is generated, which should ensure the calm and permanent fixing of the electrodes onto the *M. masseter*.

2.2 Examination of the measuring halter in relation to impairments to cow feeding behavior

2.2.1 Introduction

The measurement of chewing and rumination behavior through the DairyCheck system is based on non-invasive measuring parameters. The equipment of the sensor system is integrated into a halter. The development of this measuring halter from the first version right up to a viable and valid measuring tool induced a huge number of test measurements, which were carried out in 2012 at the State Institute for Agriculture, Forestry and Horticulture, Saxony-Anhalt in Iden, Germany. During this trial phase, varying sensor and halter versions were tested to ascertain the ideal positions of the electrodes, to test their resistance against climatic and mechanical influences, to search out the best material for the halter production and to get more information about cow feeding behavior for further development of the technical software components.

Wearing the measuring halter can lead to different manifestations of behavior in the cow. To preclude the possibility that wearing the halter could have a negative impact on cow feeding behavior, the feed intake of individual dairy cows was verified.

2.2.2 Materials & Methods

The objective of this study was to examine whether the measuring halter had any negative effects on the feeding behavior of dairy cows. A total of 24 Holstein cows were tested with access to automatic feed bins. When a cow approached the feed bin, an antenna detected the cow's unique neck collar-mounted transponder and lowered the barrier, allowing the cow access to the feed. The amount of feed intake was analyzed before, during and after the cows had worn the halter within a longitudinal trial. For this examination a period of 12 days was chosen, which was divided into three four day periods:

- Day 1-4 without halter as lead time,
- day 5-8 wearing the halter and
- day 9-12 without halter as subsequent period.

Additionally, feed intake data of 12 control cows which had not been wearing a halter in the corresponding period was analyzed. The examination period was in the 3.-5. week p.p. and was selected for all cows, equally.

2.2.3 Results

No significant effects of wearing the measuring halter on the feed intake of dairy cows were detected. In the results, mean and standard deviation of feed intake of each of the 12 cows over a period of four days are represented; therefore 48 initial dates underlie each of three periods.

Comparison of the longitudinal trial of feed intake based on a dry matter basis (DM) in kilogram (kg) over each four days is presented in Table 2.

Table 2. Longitudinal trail of feed intake (DM) in kg over 4 days in each case (n=12).

Lead time	With halter	Subsequent period
20,69 ± 2,85	20,72 ± 2,19	21,54 ± 1,77

Results of mean and standard deviation of feed intake (kg) of the comparative trial of the control group without a halter is represented in Table 3.

Table 3. Comparative trail of feed intake (DM) in kg of the control group without a halter over 4 days in each case (n=12).

Lead time	Comparative period	Subsequent period
21,16 ± 4,16	21,32 ± 3,60	22,47 ± 3,43

For statistical analysis of the experimental group of the longitudinal trial, the Kruskall-Wallis test for independent samples was used. With the aid of this test it was noted that there was equal distribution between the three experimental periods with regard to feed intake (significant level: 0.278).

Likewise, there was not found to be any difference between feed intake of the control group and that of the experimental group. For this the Wilcoxon signed rank test was used for related samples (significant level: 0.263). For the evaluation of the results of this study, it must be remembered that only a small number of dairy cows over a short period were included in this examination.

2.2.4 Conclusion

The findings clearly demonstrate that wearing the measuring halters does not have a significant influence on the feed intake of evaluated cows. The possibility that individual animals might react adversely to wearing the halter cannot, however, be ruled out. Thus, the continuous development and improvement of the halter and the corresponding hardware is necessary to reduce the number of cows which are possibly affected, and which could, as a result, show signs of reduced feed intake or modified feeding behavior.

3 CHAPTER 1. Evaluation of Different Measurement Methods to Determine Feeding Behavior of Dairy Cows

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3.1 Abstract

With increasing milk performance, it has become more and more difficult for the farm management to fulfill the increased requirements of high yielding dairy cows in terms of an appropriate supply of energy, nutrients, composition and structure of the entire feeding ration. Measurement of feeding behavior is gaining increasing importance within the field of Precision Dairy Farming. Feeding behavior of ruminants is characterized by feed intake, chewing and rumination activity. It can be assumed that deviations from reference values might provide suitable information for the early detection of risks which could lead to metabolic disorders and other diseases deriving from deviant behavior.

A multitude of different measurement methods exists to assess feeding behavior. Their stage of development and practical usage is different and their reliability is variable. The aim of this study is to evaluate the methods and measurement tools for chewing and rumination activity which are described in current literature. Five measurement methods, based on different methodological approaches (visual observance, pressure transducer, electrical switches, electrical deformation sensors and acoustic biotelemetry), and three selected measurement techniques (the IGER Behavior Recorder, the Hi-Tag rumination monitoring system and the RumiWatchSystem) are described, assessed and compared to each other.

Evaluation of measurement methods and techniques took place due to assessment on the basis of defined scientific criteria: accuracy, reproducibility, sensitivity and specificity, applicability and functionality. The evaluation according to the used criteria revealed that the pressure transducer measurement methods met the requirements for a reliable and usable method for automatic measurement of feeding behavior to a higher degree than the others. Within evaluation of measurement techniques, the RumiWatchSystem achieved

most of the demands, and is therefore assessed as the most developed technique for reliable use in practice.

The evaluation revealed further, that the development of reliable, resilient and transferable reference values to determine pathogenic deviations of chewing and rumination behavior have been neglected up to now and should receive more attention in the future. As a result of individual variations in feeding behavior, the definition of reference values is seen as one of the greatest challenges for further development.

Keywords: Measurement systems, Rumination behavior, Validation

3.2 Introduction

In dairy production, the measurement of feeding behavior is a highly relevant source of information. The daily rumination time provides information about the fiber content and composition of the ration and its effect on rumen health function (Sudweeks et al., 1977; Murphy et al., 1983; Leonardi et al., 2005) and is strongly associated with dry matter intake (Metz, 1975; Welch, 1982; Harvatine and Allen, 2005; Yang and Beauchemin, 2006). Hence, reduced feed intake, smaller meal sizes and decreased time spent eating are often used to identify declining health status (Owens et al., 1998; Hansen et al., 2003; Huzzy et al., 2007; Goldhawk et al., 2009). High-yielding cows require greater proportions of concentrate and energy (Krause and Combs, 2003; Harvatine and Allen, 2006) to meet their nutrient and energy demands (Allen, 1996). Corresponding feeding diets are relatively low in dietary fiber and adequate particle size (Beauchemin et al., 2003; Beauchemin and Yang, 2005), thereby impairing optimal conditions for microbial activity in the rumen. Consequently, there may be disturbances of fermentation and of rumen activity, as well as decreased feed intake, all of which can lead to subclinical and clinical disorders of metabolism (Nocek, 1997; Maekawa et al., 2002). Accordingly, the observation of feeding behavior of individual animals appears to be a reasonable and helpful indicator in gaining relevant information about those animals which develop into critical conditions (Urton et al., 2005; DeVries et al., 2009).

The more high producing animals are successfully able to cope with farm-specific feeding situations, the better the balance will be between their diet and the maintenance of their health. In general, veterinary treatments or management measures are more effective the earlier they are initiated in the disease process (González et al., 2008). Automatic measurement and appraisal of feeding behavior offers valuable clues for early detection of diseases in dairy cows (Burfeind et al., 2010). Therefore, animal health and welfare could be improved and the decrease in performance parameters could be reduced (Dohoo and Martin, 1984; Rajala-Schultz et al., 1999; Kleen et al., 2003).

Feed intake as well as chewing and rumination activity is affected by a multitude of animal-, feed- and housing-related factors which cause a considerable variation in measured data (Dado and Allen, 1994). Because animals respond differently to external variables, feeding behavior needs to be interpreted for individual animals (De Boever et al., 1990) and in relation to farm-specific feeding and housing conditions. The importance of a qualified possibility of identifying feeding faults constitutes the development of an adequate measurement method to generate resilient, meaningful and transferable data.

Wide variations in the chewing and rumination activity of individual cows, as well as within a herd, are particularly challenging when determining reliable reference values. These values can be used to identify an animal that is unable to cope with external influences or internal suboptimal health status. These individual animal reference values will provide the farmer with a useful measurement tool to specifically counteract and intervene when the regulating ability of an animal is exhausted.

For several decades, many scientists have been engaged in the development of functional and reliable methods to measure, assess and evaluate individual chewing and rumination activity of cattle and sheep (Balch, 1958; Rutter et al., 1997; Kononoff et al., 2002). Thereby, different technical measurement approaches have been developed and tested. Feasibility studies such as assessing saliva secretion (Kaufmann and Orth, 1966) or making use of the crude fiber content of feed diets (Mertens, 1997) have proven as impractical and fraught with methodological difficulties.

In the past, the demand for higher margins in the agriculture sector as well as expensive development costs has antagonized the implementation and establishment of measurement methods for feeding behavior. The techniques were often only used for research experiments involving small numbers of animals (Kononoff et al., 2002). However, the increasing demand for automatic management and medical assessment tools and technological advances within the Precision Dairy Farming industry have brought about improvements by way of the development of new sensor- and computer-based techniques, which are the foundation for new functional, practicable and reliable measurement tools (Pietersma et al., 1998; Marra et al., 2003; Bewley, 2010). In particular, the specific emphasis on the monitoring of individual animals in major herds is essential for adjusting usage (Van Asseldonk et al., 1999; Spilke and Fahr, 2003).

The objective of this review is to provide an overview of the tools existing currently. On the basis of different bibliographical references and by means of defined scientific criteria, the five most essential measurement methods and three of the measurement techniques selected from them are specified, assessed and finally discussed.

3.3 Materials & Methods

In the following section, five different measurement methods and three selected measurement techniques dedicated to evaluating feeding behavior are described, assessed and compared to each other. The measurement methods contain diverse methodological approaches relying on a range of physical processes. The assessed measurement methods are: visual observance, pressure transducer, electrical switches, electrical deformation sensors and acoustic biotelemetry. In addition, three measurement techniques (the IGER Behavior Recorder, the Hi-Tag rumination monitoring system and the RumiWatchSystem) encompassing different devices, data transmission paths and analysis software are evaluated with respect to their potential for usability in practice.

The measurement methods and techniques are specified with regard to the underlying physical and technical processes, the measurement mechanism of chewing activity and the analysis procedure of the generated data. Furthermore, the previous fields of application are described. Measurement methods and techniques are assessed based on the scientific criteria: accuracy, reproducibility, sensitivity and specificity, applicability and functionality. In the case of the three measurement techniques, the assessment is based on bibliographical references. While the IGER Behavior Recorder and the Hi-Tag rumination monitoring system have been validated by the developing scientists themselves, the RumiWatchSystem has been validated by external scientists.

3.3.1 Measurement methods

Visual Observance

Visual observance is a measurement method used to determine the chewing and rumination activities of ruminants through counting by human observers, usually with a hand-held counter or a stopwatch (Erlinger et al., 1990; Schirmann et al., 2009; Burfeind et al., 2011). This method is often used for the validation of other measurement methods (Law and Sudweeks, 1975; Penning et al., 1984).

The method of visual observation can be divided into continuous observation, where the animal is steadily observed or a scanning method. During continuous observation, only a few animals can be monitored simultaneously (Erlinger et al., 1990; Schirmann et al., 2009). Generally, two or more independent observers are deployed to measure chewing and rumination behavior. Before the beginning of live observations, the observers are trained to determine the animal behavior by individual and precisely defined details (Burfeind et al., 2011). During the scanning method, the recording should be arranged in well-defined time intervals, such as one- or five-minute recordings, whereby several animals can be observed coevally (Grant et al., 1990; Krause et al., 1998; Maekawa, 2002; Margerison et al., 2002; Couderc et al., 2006).

In general, visual observance can be improved by using video recording, which allows a superior number of observations (Lindström and Redbo, 2000). Sometimes, cow behavior and locations are quantified by time-lapse photography at one-minute intervals, or the video-camera is connected to a time-lapse recorder (Friend et al., 1977; Vasilatos and Wangsness, 1980; Rotger et al., 2006; Robles et al., 2007).

Pressure Transducer

The pressure transducer is based on hydraulic or pneumatic processes. With this sensor method, which had its beginnings in the late fifties (Balch, 1958), a pressure typist is mounted beneath the animal's muzzle and consists of a water-, oil-, foam- or air-filled plastic ball or plastic tube (Deswysen and Ellis, 1990; Schleisner et al., 1999; Dado and Allen, 1993; De Boever et al., 1993; Kaske et al., 2002; Nydegger et al., 2011; Zehner et al., 2012). If the animal opens its muzzle, the generated pressure is devolved to the pressure transducer and is then conducted by tubes to the pressure sensor, which converts the pressure into electrical signals. These electrical signals are processed and recorded on a microcomputer or assigned on a multichannel recorder. The jaw movements can be identified by an algorithm, aiming to differentiate the electrical signals into chewing, ruminating or idling (Deswysen and Ellis, 1990; Dado and Allen, 1993; Schleisner et al., 1999; Nydegger et al., 2011). The method was initially used in the case of cows kept in metabolism crates and tie-stalls (De Boever et al., 1993; Schleisner et al., 1999; Kaske et al., 2002), and later with animals kept on pasture and in loose-housing systems (Nydegger et al., 2011; Zehner et al., 2012).

Electrical Switches

A third measurement method of chewing and rumination activity comprises electrical switches, which act without using a measurement transformer (Law and Sudweeks, 1975; Nagel et al., 1975; Luginbuhl et al., 1987). With this method the switch is activated by jaw movements of the animal. These movements are transformed into binary notations. The measurement tool is attached to a halter and placed under the jaw. It consists of two contact points which are inserted into a piece of rubber tubing. Whilst chewing, the electrical circuit between the contact points is either disconnected (Luginbuhl et al., 1987) or the micro switch or transducer is activated by the extensions and elongation of a cable mounted on the animal's jaw (Stobbs and Cowper, 1972; Law and Sudweeks, 1975; Kennedy, 1985). These electrical switching operations during chewing and rumination are recorded individually. The systems have been applied to stall-fed cattle and sheep (Law and Sudweeks, 1975; Nagel et al., 1975; Deswysen and Ehrlein, 1981; Kennedy, 1985; Luginbuhl et al., 1987) and to cattle and sheep grazing on different pastures (Stobbs and Cowper, 1972; Chambers et al., 1981).

Electrical Deformation Sensors

Electrical deformation sensors are another alternative means of measuring the chewing and rumination behavior of dairy cows. This measurement method belongs to more recent developments and had its beginnings in the Eighties (Penning, 1983; Beauchemin et al., 1989). Deformation sensors are integrated into a halter and positioned under the jaw or fixed at the side of the lower jaw. The sensors are used as strain gauge transducers (Beauchemin et al., 1989; Beauchemin and Iwaasa, 1993; Richter, 2010), as silicon tubes filled with carbon granules (Penning, 1983; Penning et al., 1984; Matsui and Okubo, 1991; Matsui, 1993; Rutter et al., 1997) or as piezo discs (Beauchemin and Yang, 2005). What each of these applied techniques has in common is that they are activated by the chewing actions of the animals. The chewing actions of the jaw opening generate a deformation of the transducer which changes the electrical resistance or pulse height of the sensors. The electrical signals are then converted by a pulse generator or data logger. Different deformation variations induced by chewing, ruminating, idling or other behavior patterns generate various electrical signals. These electrical signals are transformed into discrete pulse signals and interpreted by an algorithm or with the aid of utilization software on the basis of different amplitudes (Penning et al., 1984) or resistances as chewing, ruminating or idling (Matsui and Okubo, 1991; Matsui, 1993; Richter, 2010).

The system was first applied to free-ranging cattle, sheep and goats on pasture (Penning, 1983; Penning et al., 1984; Matsui and Okubo, 1991; Matsui, 1993; Rutter et al., 1997; Rutter, 2000); it has been used with stall-fed cattle (Richter, 2010) and with cattle housed in individual tie-stalls (Beauchemin et al., 1989; Beauchemin and Yang, 2005).

Acoustic Biotelemetry

The method of acoustic biotelemetry uses acoustic signals and was first employed in foraging studies by Alkon and Cohen (1986) and Alkon et al. (1989) in their research study monitoring the detailed behaviors of Indian crested porcupines. Demment et al. (1992) also used acoustic sounds to monitor jaw movements in cattle during short-duration grazing trials, applying an inward-facing microphone attached to the forehead of ruminants.

In further developments, Laca et al. (1992) and Laca and WallisDeVries (2000) used a wireless microphone mounted on the forehead of grazing steers to measure different jaw movements. They demonstrated that sounds of various jaw movements are considerably different. Clapham et al. (2006) indicated that sound analysis can also be deployed to measure ingestive disorders in ruminants. Laca et al. (1992) and Laca and WallisDeVries (2000) further developed their technique to measure rumination activity by a touch-sensitive microphone, which is incorporated in a plastic gadget or tag and attached to the left side dorsally on the head collar. To ensure the correct positioning of this tag, a counterweight is fixed to the collar ventrally. The system measures rumination activity through the sound of regurgitation of boluses during a rumination phase.

The latest version of acoustic biotelemetry consists of rumination loggers, stationary or mobile readers and software for processing and digitally storing the electronic data (Lindgren, 2009; Bar and Solomon, 2010). The information of summarized and stored data in the memory of the logger is downloaded via infrared communication to an antenna installed at highly frequented areas within the barn (Lindgren, 2009; Schirmann et al., 2009; Burfeind et al., 2011). Therefore the method is primarily restricted to use in stall-fed cattle.

3.3.2 Measurement techniques

The IGER Behavior Recorder

The first purchasable technique for use in research or practice was the IGER Behavior Recorder with the corresponding *Graze* program for analyzing jaw movement recordings. The technique was developed by Rutter et al. (1997) and Rutter (2000) at the Institute of Grassland and Environmental Research, North Wyke, Devon, UK. The technique is usable for free-ranging ruminants (Ungar and Rutter, 2006). It is based upon the technique initially developed by Penning (1983) and Penning et al. (1984) and corresponds to electrical deformation sensors. Rutter et al. (1997) replaced the analogue cassette recorder of the initial technique of Penning et al. (1984) with a microcomputer-based system for the digital recording of jaw movements (Ungar and Rutter, 2006). A jaw strap attached to a noseband of a halter (Figure 3) is stretched by jaw movements of cattle and sheep, causing changes in the electrical resistance. A data logger converts the signals into eight-bit integers 20 times a second and stores the data on a CompactFlash card. Afterwards, data are transferred to a computer and processed by the Graze Analysis Program which displays a plot of the jaw movement amplitudes. Individual jaw movements of the animals are identified by an experienced Graze user and classified into eating, ruminating or other behaviors.

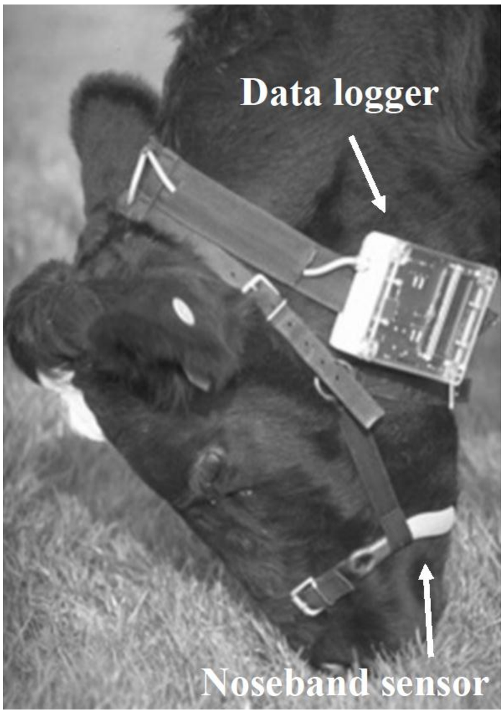

Figure 3. The IGER Behavior Recorder device, Ultra Sound Advice (2006)

The Hi-Tag rumination monitoring system

The acoustic biotelemetry system is an additional commercially available technique to measure feeding behavior of dairy cows in loose-housing systems or partially on pasture. The first prototype of this technique was developed by Israeli scientists at the dairy equipment development company, SCR Engineers Ltd., in Netanya, Israel (Lindgren, 2009; Bar and Solomon, 2010). The Hi-Tag system is labeled as Vocal Tag, RuminAct™ or HR-Tag and was evaluated by Lindgren (2009), Schirmann et al. (2009) and Burfeind et al. (2011).

Figure 4. The Hi-Tag rumination device monitoring technique, Lely (2012)

The sensor consists of a neck collar with a tag and data logger (Figure 4) which registers the noise deriving from the rumination activity. In contrast to other techniques, only the regurgitation and swallowing of one bolus during a rumination period can be measured by this technique, whereas jaw movements are not captured. Rumination is recorded with a resolution of two minutes, which results in 60 possible agreements or disagreements per two-hour interval (Burfeind et al., 2011). The technology is construed for the collection of eleven two-hour intervals. Consequently, only 22 hours can be recorded, whereupon the first interval is overwritten and the results of data are lost if they are not downloaded in due time. Data are transferred via infrared communication and downloaded by antennas positioned at important locations within the barn, such as above the water trough or in the milking parlor, or by a handheld reader to a receiver and transmitted by wire connection to a computer (Lindgren, 2009; Schirmann et al., 2009; Burfeind et al., 2011). The different programs produce graphs which reflect the rumination activity during the course of a day for each documented cow. Data transferal takes places constantly and battery life for recording is three to four years. (VocalTag, 2008). Rumination duration is analyzed by automatic analysis software based on an algorithm, which considers rumination events as separately identifiable successive regurgitations.

The RumiWatchSystem

The pressure transducer RumiWatchSystem developed by Nydegger et al. (2011) and advanced by Zehner et al. (2012) at the Agroscope Reckenholz-Tänikon ART Research Institute, in Ettenhausen, Switzerland, is the most recent measurement technique to record feeding behavior of dairy cows in loose-housing systems. The initial technique, called the ART rumination sensor, was developed by Nydegger et al. (2011) and is similar to the RumiWatchSystem.

Figure 5. The RumiWatchSystem device, Nydegger et al. (2011)

The technique consists of a halter with a noseband sensor comprising a vegetable oil-filled silicon tube with a built-in pressure sensor, a data logger (Figure 5) and the corresponding evaluation software (Nydegger et al., 2011), and a pedometer (Zehner et al., 2012). The data logger registers the pressure at a frequency of 10 Hz, saves the raw data to a SD Memory Card and stores them for up to four months. Under laboratory conditions the battery life is up to three years. Data are transmitted wirelessly or via SD Memory Card to a computer (Zehner et al., 2012). For automatic measurement, a generic algorithm, without animal-specific learning data, divides individual jaw movements with regard to different amplitudes and chewing bout pauses into ruminating, eating, drinking or other activities (Zehner et al., 2012).

3.3.3 Scientific criteria

Assessment criteria are defined as follows: The criterion *accuracy* reveals the validity of measurement methods and techniques due to visual concordance or aberrance of generated data. Through this criterion, the parameter accuracy and precision of results in relation to chewing activities and data analysis are assessed. *Reproducibility* describes the repeatability of results and is the main criterion for the assessment of significance of different methods and techniques essential to the resilience of measured and analyzed data. Sample sizes and duration of validity are important parameters for assessing repeatability and for comparing their significance with regard to each measurement technique. With the criterion *sensitivity* and *specificity*, measurement methods and techniques are assessed for their potential with respect to the discrimination and differentiability of single jaw movements or jaw movement phases and classification into chewing, rumination and other behaviors. Thus, the capability of the physical and technical process of each method and technique and its measurement precision are rated.

To compare the measurement techniques, the criterion of *functionality* is introduced by assessing the robustness of each technique against climatic and mechanical influences, susceptibility to possible breakdown and usefulness. It is assessed by the extent to which the exact positioning of the corresponding device is important to generate valid data, and on the possible tolerance limit regarding the mounting positions. Finally, the criterion *applicability* is used to describe and assess the ease and feasibility of use. The recording and transmission of generated data, analysis software and application field are evaluated. Recording duration and memory capacity, labor-intensity and mode of data interpretation are all used for the assessment.

3.4 Results and discussion

3.4.1 Measurement methods

Visual Observance

In the past, visual observance was the main method of animal observation due to the restricted availability of technical know-how. Even now, this method is often used for validation of other techniques (Law and Sudweeks, 1975; Penning et al., 1984; Burfeind et al., 2011). However, visual observance and video recording are labor-intensive, time-consuming, and hard to arrange at night. Measurement on pasture or in loose-housing systems is difficult, because major areas are not easy to observe by humans or video cameras (Mosley et al., 1987; Matsui and Okubo, 1991; Mitlöhner et al., 2001; DeVries et al., 2003; Hailu, 2003).

The method can be arranged as continuous observation or as a scanning method. During continuous observation, typically only a few animals can be monitored simultaneously (Erlinger et al., 1990; Margerison et al., 2002; Schirmann et al., 2009). With the scanning method, short time intervals such as one- or five-minute recordings are highly correlated with continuous observation and enable a higher number of animals to be observed. According to Mitlöhner et al. (2001), the longer the interval between the scan sampling is, the lower the correlations are, especially for animal behavior patterns of short duration. The great expenditure of time when using this technique is accompanied by a short monitoring duration for every single animal and results in a low number of measured animals (Schirmann et al., 2009). Recording duration of visual observance takes place from 2 hours (Schirmann at al., 2009) to 24 hours (DeVries et al., 2003). Recording of several consecutive days is not possible using this measurement method. Variability within-cow and between cow feeding behavior is very high (Schirmann et al., 2012). Therefore, an extrapolation of these data is not very reliable. Repeatability through reproducibility of precise results is reasonable, but influenced negatively by low sample sizes and short monitoring durations. Direct and continuous visual observance provides a useful technique for valid data collection (Burfeind et al., 2011), which constitutes high accuracy. By visual observance, jaw activities can be differentiated into chewing, ruminating or other behaviors, thus fulfilling the criteria of sensitivity and specificity. The obvious classification of feeding behavior into feeding, ruminating or idling makes this method the gold standard for validation of other measurement techniques.

During video recording, not all performance parameters can be measured as a result of the fixed position of the angle of view (Rutter et al., 1997). Only a small locomotion and lying area can be observed by videotaping. Consequently, the observed animals are kept in a restricted access area. Often, this limited access area of the animals observed can lead to interferences in common behavior patterns. The methods of connecting video cameras to time-lapse recorders and of time-lapse photography serve to accelerate long-term recordings of motion sequences and increase the possibility of monitoring many animals over longer time intervals. However, the transcription of these videos is labor-intensive (DeVries et al., 2003). Low usage of expensive techniques and uncomplicated implementation are the main benefits of this method of measurement.

Pressure Transducer

Each pressure alteration corresponds to a deflection on the analog output in terms of graphs, whereby exact allocation into chewing, rumination or other behaviors is possible, making this an effective and highly accurate method for measuring jaw activities. In addition, sensitivity and specificity through classification into the right behavioral patterns of each cow are very high. Furthermore, the energy required to open the muzzle turns out to be a disadvantage for some of these systems. The more an animal wants to open its muzzle, the more power it has to use, which can result in behavior modifications in the animal (Richter, 2010). Smaller sample sizes and the length of monitoring periods lead to reasonable significance of repeatability and reproducibility. The use of the pressure transducer is, however, restricted to animals housed in metabolism crates or in tie-stalls, a limitation which is a crucial disadvantage of this measurement method (De Boever et al., 1993; Schleisner et al., 1999; Kaske et al., 2002). These limitations do not occur, however, with the latest system called the ART-rumination sensor developed by Nydegger et al. (2011), and further developed into the RumiWatchSystem by Zehner et al. (2012).

Electrical Switches

The measurement method using electrical switches is simple and very cost-efficient (Law and Sudweeks, 1975; Nagel et al., 1975; Luginbuhl et al., 1987). The validation of the electrical switches measuring system show high accordance with the comparison of visual observance and automatic recording: The electronic transducer developed by Law and Sudweeks (1975) consigns pen deflection evoked by jaw movements onto an event recorder, where data is processed and stored. This system has been successfully used for approximately 1400 hours of feed test-recordings with less than 0.5% error for input chew rates. The electrical micro-switch developed by Stobbs and Cowper (1972) offers a correlation coefficient (r) of r = 0.97 between observed and automatically recorded bites. According to the authors, this is a useful method for accurately recording the jaw movements of dairy cows. However, data storage of quantitatively determined jaw movements is restricted to a few days due to the short life of batteries. Data processing is done by visual analysis (Stobbs and Cowper, 1972). The electronic switching device developed by Luginbuhl et al. (1987) stores data automatically at the end of every hour and later transfers them to disks for storage and processing. The system allows the simultaneous monitoring of up to eight animals and has been successfully used for approximately 2500 hours of recording. The electronic pressure transducer developed by Deswysen and Ehrlein (1981) stores data for only 24 hours. The micro-switch developed by Kennedy (1985) was used for up to 48 hours to monitor jaw movements in animals, whereby the number of jaw movements was recorded by a digital counter. Through a micro-feeler of the developed device, described as the RMBZ by Nagel et al. (1975), the time-consuming work of analyzing strip charts can be avoided. The average deviation from values registered with the electrical switch device is only ± 5%.

According to the previous studies, validations of different devices represent very high accordance with regard to the accuracy of measuring jaw activities. Monitoring durations are long enough, but the numbers of animals measured should be increased, so that reproducibility can be rated as reasonable. Being as individual jaw movements cannot be determined qualitatively, sensitivity and specificity are absent. Given that the techniques have been applied to stall-fed ruminants and to cattle and sheep grazing on different pastures, a large spectrum of different livestock conditions has been captured. However, this measurement method was only used in the 1970s and 80s (Nagel et al., 1975; Kennedy, 1985; Luginbuhl et al., 1987) and no further development has been initiated until now.

Electrical Deformation Sensors

As far as measurement with electrical deformation sensors is concerned, a range of tools with varying degrees of success has been developed up to now: Some of these specified systems include the first automatic analysis software (Beauchemin et al., 1989; Beauchemin and Iwaasa, 1993). The data logging system developed by Matsui and Okubo (1991) and Matsui (1993) allows data to be recorded every minute for a maximum of 22 days in one recording session. The data are transferred to floppy disks which are compatible with other computers for downloading and analyzing the signals. Due to visual observation, consistency is acceptable (Matsui and Okubo, 1991; Matsui, 1993). The ambulatory data-logging system by Penning (1983) and Penning et al. (1984) is able to record electrical signals for up to 24 hours on a cassette recorder. The data is then processed and analyzed by a microprocessor and the results are stored on floppy disks. Compared to visual observation, only 80% of recording attempts are successful. The system was further developed by Rutter et al. (1997) and Rutter (2000) and is referred to as the IGER Behavior Recorder. This automatic, microcomputer-based system for the digital recording of jaw movements can differentiate between eating and ruminating periods with the aid of an analysis program. The concordance between manual observers and this automatic system amounts to 91% (Rutter, 2000).

However, the comparison of visual observation and the automatic recording of the chewing counter developed by Richter (2010) indicate some problems. In the study of Richter (2010), eating activity was significantly overrated and rumination activity was significantly underrated. This was caused by the software, which could only distinguish between chewing and rumination if there was a three minute gap between chewing and rumination. If chewing and rumination activity overlapped, then differentiation was not possible.

Electrical signals from the system used by Beauchemin et al. (1989) and Beauchemin and Yang (2005) are counted as jaw movements. The number of single jaw movements per minute is calculated and stored by a data logger. The jaw movements are then differentiated into chewing and rumination activity or idling. Comparing visual records to the chart recorder and to computer records for 24 hours over five days results in an overestimation of eating by both automatic systems. Consequently, the inadequate differentiability between chewing and grooming activity is a disadvantage of this system (Beauchemin et al., 1989). Another disadvantage is that there is only one way of processing and analyzing measured jaw movements after uploading the generated data to a computer. Continuous monitoring of feeding behavior of observed cows is not practicable.

In the previous studies, sample sizes are small and validation durations are short when using these measurement tools, and thus repeatability is restricted. The concordance between manual observation and automatic recording assumes largely satisfying results with high reliability and accuracy. One of the most important aspects of this method is its precise differentiation of jaw activities into the correct behavioral patterns, because each deformation of the sensor induces various electrical signals, which attest very high sensitivity and specificity.

Acoustic Biotelemetry

The technique of acoustic biotelemetry constitutes a new measurement method that is able to ascertain rumination activity by sound signals and can be used to quantify and discriminate ingestive behaviors of ruminants (Clapham et al., 2006). The clear differences between sound signals suggest that acoustic monitoring might be more reliable for counting bites than visual observation (Ungar and Rutter, 2006). Initially, acoustic biotelemetry showed a concordance of individual behavior measured by sounds and visual observing of 82% with a standard deviation of 12% (Alkon and Cohen, 1986; Alkon et al, 1989). A first prototype of a collar-mounted transmitter and a receiver system enabled the determination of sound signals ≤ 1 km in the field. From their results, the authors thus concluded that acoustic biotelemetry is a potentially powerful tool for field animal research (Alkon et al., 1989).

Therefore, measured data indicate only reasonable repeatability of acoustic recordings due to ascertained results. As some of the first measured data and their results have been recorded by acoustic biotelemetry from porcupines (Alkon et al., 1989), data are only available to a limited extent for transferability to cows, and trials have to be extended in order for them to be significant in the use of this technique with cows. When using acoustic measurements, only the regurgitation process during rumination can be measured (Lindgren, 2009; Bar and Solomon, 2010). Other jaw movements are not ascertainable. Therefore, it is not possible to accurately measure individual jaw movements; the differentiation of jaw activities into behavior patterns is also not feasible. For this reason, sensitivity and specificity cannot be assessed.

3.4.2 Measurement techniques

The IGER Behavior Recorder

Validation of the IGER Behavior Recorder was implemented by a field test with eight free-ranging sheep during grazing (Rutter et al., 1997). The foraging behavior was recorded on three consecutive days by different observers at five-minute intervals during daytime. Results indicate reasonable repeatability (considering the small sample size and short length of validation time) and designate an overall index of concordance among manual observation and automatic analysis of 91.0% (Rutter et al., 1997), which demonstrates high accuracy. However, the overall error rate of total numbers of chewing bouts identified is 22.1% (Ungar and Rutter, 2006). Each jaw movement produces a specific deformation of the sensor and these deformations induce various electrical signals which are processed by the Graze Analysis Program into a plot of jaw movement amplitudes. Sensitivity and specificity are therefore high. However, classification into different bouts of grazing and ruminating takes place according to pre-selected but user-adjustable criteria, assigned by an experienced user of the Graze Analysis Program (Ultra Sound Advice, 2006; Ungar and Rutter, 2006). This person selects the appropriate parameters for analysis on the basis of experience (Ungar and Rutter, 2006), wherefore, interpreted data are highly dependent on the user.

Recording duration amounts to only 50 hours of continuous recording or up to ten days of intermittent recording (Ultra Sound Advice, 2006). Therefore, the IGER Behavior Recorder is not usable for longer time trials. Because manual data must be interpreted by an experienced software analysis user, labor-intensity is comparatively high. Applicability is restricted and offers a lot of opportunity for improvement.

The IGER Behavior recorder is composed of a noseband sensor, head collar and recorder fitted to the cattle. The size of the recorder could have a negative influence on the cows, as there is a high stocking density in housing systems and tie-stalls. Ruggedness against mechanical and climatic influences is not specified by the scientists. Close-fitting positioning of the halter on the muzzle is important to generate valid data, which is why the tolerance range of mounting options of the halter is slight. Functionality is reasonable, but also offers ample room for improvement.

The Hi-Tag rumination monitoring system

Schirmann et al. (2009) compared the estimates from the Hi-Tag system to those from direct observation in dairy cows. Data were collected in three trials in the year 2008. The first trial was conducted with six cows over two hours and resulted in a correlation coefficient of $r = 0.96$. The second trial used 12 cows. Each cow was observed for three observation periods, each lasting for two hours. Results of correlation between automatic and visual observation were $r = 0.92$. In the third trial, 20 cows were monitored over a period of three days. Results of correlation coefficients for rumination time per 24 hours between raw data obtained from the rumination loggers and processed by the software were $r = 0.96$. The mean difference between rumination time, assessed by the Hi-Tag system, and visual observance amounted to -0.45 minutes for the third trial (Schirmann et al., 2009).

Burfeind et al. (2011) tested the accuracy of the rumination monitoring system in Holstein heifers and calves by comparing values measured by the electronic system to those from a human observer. Six groups of five animals were observed for three two-hour intervals. Correlation coefficients varied from r = 0.47 to r = 0.89. According to the scientists, these findings offered a reasonable estimate of rumination time in heifers older than nine months. When heifers younger than nine months were used, the accuracy of data generated from the automated system decreased (Burfeind et al., 2011). The Hi-Tag rumination monitoring system measures rumination behavior only. Chewing activity or other behavior patterns are not distinguished. Therefore, neither the differentiation of jaw movements nor the assessment of sensitivity and specificity are possible. Accuracy of the measuring data regarding rumination behavior is high with reference to high correlation coefficients measured with adult cows. Because sample sizes of the measured animals are small and the validation duration is comparably short, repeatability of results is only assessed as reasonable.

Due to the constant data transmission and the battery life of three to four years, the system is well-suited for permanent use in practice (VocalTag, 2008). Rumination duration is analyzed by an algorithm, which considers rumination events as separately identifiable successive regurgitations. Labor-intensity is low when data interpretation is conducted by automatic analysis software. Thus, applicability of this technique seems to be at a high level.

The Hi-Tag consists of a neck collar, rumination logger and a counterweight. Side effects for the animal when using this technique are minor. Ruggedness against mechanical influences is high, however, exact positioning is important, for which reason a counterweight should ensure the right logger position behind the left ear (Burfeind et al., 2011). Incorrect positioning can influence measurement of rumination, which is why the tolerance limit of the mounting position is very small. Functionality is also on a high level, but requires correct placement of the tag.

The RumiWatchSystem

For the validation of the ART rumination sensor, which is the ancestor system of RumiWatchSystem, 60 random samples of 5 minutes each were taken from 145 measurement files to compare automatic and visual assessment (Nydegger et al., 2011). In this study, comparison of activity allocation of visual and automatic evaluation was 100%. For cowshed eating, the mean value of concordance was 88% in a range of +31.4% to -1.91% and a standard deviation of 9.0%. Furthermore, the system revealed a mean value of deviation between visual and automatic counting of jaw movements per bolus of -0.24% within a range of +1.09% to -2.36%. Results of the validation of the advanced RumiWatchSystem showed a concordance in quantification of jaw movements by automatic and by visual evaluation of $R^2 = 0.79$ for ruminating and $R^2 = 0.77$ for eating. For validation, a total number of 12 cows were used over 14 days for validation (Zehner et al., 2012). Due to small sample sizes of measured animals and short validation duration, repeatability of results was only reasonable. Accuracy of measuring single jaw movements by this technique appears very high, because each pressure alteration corresponds to a specific deflection on the analog output in terms of graphs, which allows direct allocation of jaw movements to different behavior patterns. Thus, sensitivity and specificity of differentiation of jaw movements can be assessed as very high.

Battery lifetime is up to three years under laboratory conditions and enables long-term operating time at minimized energy consumption (Zehner et al., 2012). Data interpretation takes place automatically, approves low labor-intensity and is based on a generic algorithm without animal-specific learning data. Thus, applicability turns up as high and easily feasible.

The RumiWatchSystem incorporates a noseband sensor, data logger and power supply. The data logger and power supply are small and integrated into the halter. Ruggedness against mechanical influences is good as a result of this positioning. Robustness against climatic influences is not specified by the scientists. Correct positioning of the halter is important to generate valid data, but a small tolerance limit of mounting options of the halter is reasonable. Therefore, functionality is on a high level.

3.4.3 Comparative Analysis

Several measurement methods and techniques are currently available to determine chewing and rumination behavior of dairy cows. Each method and technique possesses different options and drawbacks, which can promote or impair successful measurements of valid and significant data results. The devices and techniques for measuring feeding behavior have been developed in various ways in accordance with their usability in practice and the measurement potential of feeding behavior data. However, it has not been possible to accomplish all requirements for the optimal observation of cow feeding behavior by the currently available methods and techniques.

For the accurate study of chewing and rumination behavior, longer time periods of feeding behavior with higher amounts of animals must be arranged (Kononoff et al., 2002; Schirmann et al., 2012). Thus, the low repeatability of generated data and their results is an essential drawback. Only through adequate numbers of sample sizes and reliable data analysis and with the consideration of inter- and intra-individual variations and deviations is it conceivable to derive resilient and, above all, reliable recommendations in the form of reference values.

The determination of applicable and transferable reference values is necessary to detect deviations in normal values for analyzing possible interferences in feeding behavior and to evaluate different chewing and rumination activities. Reference values can be regarded as widely undisturbed, physiological values. They should be determined under precisely defined conditions with an adequate number of sample sizes (Krejcie and Morgan, 1970; Bartlett et al., 2001; Kraft, 2005). Deviations in reference values or standard values denote disturbances of regular rumination behavior. Thereby, it is possible to apply these methods and techniques to use their potential as a rapid alert system for ruminants' health and well-being. The influence of different feeding rations on chewing and rumination behavior should be further researched and analyzed to increase the reliance into reference values. In addition, the extents of inter- and intra-individual variations of ruminants have not been comprehensively ascertained until now.

With the aid of five specified and applied scientific criteria, the different measurement methods and techniques can be qualitatively assessed in relation to various demand profiles. The defined criteria deal with most of the important requirements. To comply with these criteria, specifications have to be met and implemented. With regard to the varying advantages and disadvantages of the measurement methods and techniques, and the degree to which they meet the criteria, they are assessed as follows: restricted, reasonable, high or very high or, when the criteria are unrateable, they are recorded as absent. Subsequent, measurement methods and measurement techniques are comparatively assessed and evaluated due to scientific criteria.

3.4.4 Measurement methods

The first three assessed criteria (*accuracy, reproducibility, and sensitivity/specificity*) deal with the technology used for measurement of feeding behavior and explain the requirements regarding software functionality and software usage. In Table 4 an accumulated comparison of all five measurement methods is depicted referring to these scientific criteria, which is further explained in the following.

The first criterion a*ccuracy* conduces to verify the validity of different systems. The exact measurement of feeding behavior is essential for generating meaningful data, while the analysis software program should be reliable, interference-free and automatic. The accurate measurement of feeding behavior is possible using visual observance. The high correlation of results gained by two independent observers indicates that direct and continuous visual observance can be used as a suitable and valid measurement method (Schirmann et al., 2009; Burfeind et al., 2011). Higher numbers of observed animals influence the accordance of different observers adversely, while the human observer becomes the limiting factor regarding high precision. The pressure transducer system (Dado and Allen, 1993; Nydegger et al., 2011) and the method using electrical switches (Stobbs and Cowper, 1972; Law and Sudweeks, 1975; Nagel et al., 1975) have both been validated. Validation results showed a high correlation between automatic or computer-interpreted and manually determined variables. Therefore, when measuring jaw activities, accuracy appears on a very high level. The concordance between manual observation and automatic recording assumes equally satisfying results for most of the measurement tools involving electrical deformation sensors. Deformation sensors depend on their environmental conditions and can be influenced by external factors (Richter, 2010), why measurement reliability and accuracy is restricted and has to be critically appraised. Measuring single jaw movements with the acoustic biotelemetry is not possible, but accuracy during measurement of rumination phases is available and high, which is demonstrated by respectable validation results. Overall, accuracy of almost all of the five measurement methods described is on a very high level.

Reproducibility assesses resilience of generated data. Continuous and evaluable measurements should take place over several days to minimize the effects of day-to-day variations (Dado and Allen, 1994) in chewing and rumination activity. However, often only a small amount of reliable data of animals can be measured for just a few days and many of the methods have been developed for animals housed in tie-stalls or individual pens, not in loose-housing systems or on pasture (Deswysen and Ehrlein, 1981; Kennedy, 1985; Luginbuhl et al., 1987; De Boever et al., 1993; Schleisner et al., 1999). Studies of chewing activity are often conducted with a small number of animals as these recordings are time-consuming and require substantial technical equipment (Luginbuhl et al., 1987).

Therefore, transferable data for interpretation are rarely available and reproducibility of results is often restricted. With regard to the visual observance of feeding behavior, reproducibility of accurate results is reasonable for short monitoring durations and low sample sizes, which can reliably be observed by humans. However, repeatability is influenced negatively by the short duration of validation. Values of the pressure transducer measurement method with sample sizes of less than 30 dairy cows and monitoring durations of three days maximum (Dado and Allen, 1993; Schleisner et al., 1999; Nydegger et al., 2011) give rise to reasonable significance of repeatability and reproducibility. Monitoring durations of the electrical switches differ from 24 hours (Deswysen and Ehrlein, 1981) to 2500 hours (Luginbuhl et al., 1987) and numbers of measured animals are slight. The collection of meaningful data is therefore various, so that only reasonable levels of validity of reproducibility can be achieved. Additionally, low repeatability with high incidence of measuring errors can be expected due to the manual evaluation procedure. In the previous study, sample sizes of measurement methods of electrical deformation sensors are small and validation durations are very short, hence repeatability is restricted (Penning et al., 1984; Beauchemin et al., 1989). Measured data from acoustic biotelemetry during a first validation indicate reasonable repeatability due to ascertained results for the initial stages of acoustic recordings. Reproducibility of valid data is one of the most important aspects in improving and further developing all five measurement methods, but is only assessed as reasonable for all five methods.

The criterion *sensitivity* and *specificity* evaluate the benefits of the classification of different jaw movements into chewing, ruminating or other behaviors. By visual observance jaw activities can be differentiated into chewing, ruminating or other behaviors. Through this, sensitivity and specificity are on a high level, but no verification method for visual observance exists. The measurement methods of the pressure transducer and electrical deformation sensors enable the accurate assignment of jaw movements into correct behavioral patterns such as chewing, ruminating or other behaviors (Rutter, 2000; Nydegger et al., 2011). Sensitivity and specificity of these two methods reach a very high level. When using electrical switches, individual jaw movements can only be determined quantitatively with no regard for the size of opening of the cow's muzzle. Thus, sensitivity and specificity through differentiability of jaw movements into chewing, ruminating or other behaviors are absent. With regard to the acoustic measuring, only sounds generated during rumination are realized, and single jaw movements, like chewing behavior or other activities such as grooming activity cannot be measured. Therefore, differentiability of jaw activities into behavior patterns is not feasible. Correspondingly, sensitivity and specificity cannot to be assessed directly. Three of five of these different measurement methods are able to differentiate single jaw movements into corresponding behavior patterns regarding the used technology and their capabilities, whereby the criterion of sensitivity and specificity are fulfilled. The measurement methods of electrical switches and acoustic biotelemetry do not fulfill or are unable to be assessed by the criteria of sensitivity and specificity.

As a result and according to the criteria used, the pressure transducer measurement method met the requirements for a reliable and usable method for automatic measurement of feeding behavior to a higher degree than the other measurement methods.

Table 4. Comparison of all five measurement methods described; visual observance (1), pressure transducer (2), electrical switches (3), electrical deformation sensors (4) and acoustic biotelemetry (5) referring the applied criteria accuracy, reproducibility and sensitivity and specificity.

Criterion	1	2	3	4	5
Accuracy	++	+++	+++	(-)	++
Reproducibility	+	+	+	(-)	+
Sensitivity and Specificity	++	+++	-	+++	/

Meeting the criteria: + reasonable, ++ high, +++ very high, (-) restricted, - absent, / not able to be assessed

3.4.5 Measurement techniques

Within the following analysis of the measurement techniques, all five introduced scientific criteria are being used. First, the three criteria (*accuracy, reproducibility, and sensitivity/specificity*) which assess used technology and software functionality are applied. Additionally, the two criteria *functionality* and *applicability*, which assess robustness, usefulness, possible susceptibility and ease and feasibility of use are used. Table 5 illustrates an accumulated comparison of all three measurement techniques in reference to these five scientific criteria.

The criterion *accuracy* is on a very high level for all three mentioned techniques. For the IGER Behavior Recorder, the high overall index of concordance of measurements to record single jaw movements compared to visual observation (Champion et al., 1997;

Rutter et al., 1997; Rutter, 2000) demonstrates that the technique provides a high level of accuracy. Validation values of the Hi-Tag system show high agreements of results generated by visual observation and the electronic system (Schirmann et al., 2009; Burfeind et al., 2011), which also reveal high accuracy and reliability of this technique. However, assessment of accuracy concerning the measurement of single jaw movements is not possible; whereas accuracy and precision of measuring data regarding rumination behavior is assessed as high. Results of the validation of the latest device on the market for monitoring feeding behavior named RumiWatchSystem (Nydegger et al., 2011; Zehner et al., 2012), constitute a high accuracy for measurement of feeding behavior of dairy cows and demonstrate respectable concordance of visual and automatic measurement for ruminating and eating (Zehner et al., 2012).

Repeatability of results of generated data of all three of the measurement techniques described, namely the IGER Behavior Recorder, the Hi-Tag rumination monitoring system, and the RumiWatchSystem, is reasonable, but sample sizes of measured animals are too small and validation durations are much too short and should be increased to collect more comprehensive data.

The third criterion is different fulfilled by the three measurement techniques. The use of *sensitivity* and *specificity* to accurately distinguish different feeding behavior patterns is on a high level for the IGER Behavior Recorder, but has to be critically appraised because differentiability takes place subjectively by an experienced software user (Ultra Sound Advice, 2006; Ungar and Rutter, 2006). For the Hi-Tag rumination monitoring system, differentiability of jaw movements into different behavior patterns is not realizable, because only rumination behavior is measured. Therefore, assessment of the criterion of sensitivity and specificity is not possible. For the RumiWatchSystem, sensitivity and specificity through differentiability of jaw movements into ruminating, eating, drinking or other activities of each cow are very high, because each jaw movement corresponds to a specific deflection, which allows an exact allocation.

The two criteria for the assessment of measurement techniques further deal with direct usage of the hardware. F*unctionality* assesses, if the measurement system works without influencing animals' behavior, mobility or well-being. Unproblematic application under free-stall conditions should be possible. The techniques should cope with the current livestock conditions of dairy cows. Also resistance to mechanical interferences from the animals and to climatic influences is important. Functionality of the IGER Behavior recorder is reasonable, but offers ample room for improvement with respect to animal welfare.

Functionality of the other two techniques is assessed as high, but the Hi-Tag rumination monitoring system requires correct usage. For the RumiWatchSystem, the fixed halter might influence the animal's well-being. In comparison with other systems, the recording of feeding behavior by a device attached to a neck collar like the RumiWatchSystem, not to a halter, is new. The use of neck collars can be considered as advantageous, because many famers use neck collars for identifying their cows by numbers or by feeding stations. Thus, the use of this system would not require a changeover as the application of halters would. But ensuring the correct position of the incorporated microphone for measuring eating behavior will be more problematic than when using halters. It is possible that better positioning of neck collars can improve data generated from the system, especially for older animals (Burfeind et al., 2011). Another problem could be that the microphone attached to one cow might pick up grazing sounds from another cow (Ungar and Rutter, 2006). However, this potential problem was not discussed at further appraisals (Lindgren, 2009; Schirmann et al., 2009; Bar and Salomon, 2010; Burfeind et al., 2011).

The criterion *applicability* values the development of a technique, which allows reliable and uninterrupted recordings, preferably for a cow's lifetime. The ease of use should assess practicability, user-friendliness, cost-benefit-relationship, independency of other systems and possibility for integration in existing management systems. All three techniques are usable on pasture or in loose-housing systems, which is a fundamental advantage in comparison to other techniques or measurement methods. Ease of use of the IGER Behavior Recorder is restricted and offers lots of opportunities for improvements.

Table 5. Comparison of all three measurement techniques; IGER Behavior Recorder (IGER), Hi-Tag rumination monitoring system (Hi-Tag) and RumiWatchSystem (RumiWatch), with reference to the applied criteria accuracy, reproducibility, sensitivity and specificity, functionality and applicability.

Criterion	IGER	Hi-Tag	RumiWatch
Accuracy	++	++	+++
Reproducibility	+	+	+
Sensitivity and Specificity	++	/	+++
Functionality	+	++	++
Applicability	(-)	++	++

Meeting the criteria: + reasonable, ++ high, +++ very high, (-) restricted, - absent, / not able to be assessed

Furthermore, generated data of measured jaw movements have to be downloaded to a computer first, before being processed and analyzed. Continuous monitoring of feeding behavior of observed cows is not practicable. The Hi-Tag rumination monitoring system is able to transmit data via infrared communication almost continuously. However, a limited transmission range of only a few meters can affect the reliability of infrared data transfer. Live observation of feeding behavior by the RumiWatchSystem is possible. Thus, for the Hi-Tag rumination monitoring system and the RumiWatchSystem applicability is on a high level, easy and practicable.

As a result, the RumiWatchSystem achieved most of the demands, and is therefore still the most developed technique for reliable use in practice, and very suitable for purpose.

3.5 Conclusion

The different measurement methods and techniques show various possibilities but also drawbacks for the assessment of chewing and rumination activity of dairy cows in practice. The pressure transducer measurement method meets most of the requirements for the reliable and suitable measurement of feeding behavior of ruminants. The advantage is supported by the fact that the RumiWatchSystem measurement technique, which belongs to the pressure transducer method, complies with most of the five criteria for measurement techniques. Thus, the RumiWatchSystem achieved most of required demands, and is therefore the most developed technique for reliable use in practice.

Nevertheless, all three measurement techniques have the potential to be suitable for use in research work, but show ample room for improvements. In particular, the validation of generated data and their comparison to other techniques should be rectified and revised after long-time studies with an appropriate number of animals. Furthermore, chewing and rumination activity are not constant values, but multiple-influenced parameters. Reasons for deviations of feeding behavior should be interpreted individually for each animal by means of reference values.

Definitions of well-adapted reference values are complex and laborious. Thus, more attention should be given to reliable and transferable reference values, so that the potential of measurement systems for chewing and rumination activity can be used to identify dairy cows deemed to be in a critical situation. If it were possible to overcome those deficiencies, the assessment of chewing and rumination activity could become a useful means of supporting existing tools of Precision Dairy Farming. The earlier veterinary treatments or management changes are initiated during the disease process, the more effective they are.

This constitutes the increasing need for the development of an automatic measurement and appraisal technique to ascertain feeding behavior of ruminants.

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4 CHAPTER 2.

Technical note: Evaluation of a New System for Monitoring Feeding Behavior of Dairy Cows.

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4.1 Abstract

Feed intake, feeding and rumination time are important parameters in the identification of suboptimal feeding conditions and possible health disorders. The automatic recording of individual feeding behavior constitutes a reasonable tool for early detection of deviations in feeding behavior and feeding deficiencies. For this reason, a new system for measuring feeding behavior of dairy cows has been developed. The sensor-based system DairyCheck consists of a halter with two incorporated electrodes, a data logger, an accelerometer, power supply, and evaluation software. Measurement of feeding behavior ensues through electromyography (EMG), whereby electrical potential oscillations during jaw movements are recorded. Data are transmitted directly via radio transmission to a computer with automatic evaluation software. Automatic analysis software is based on an algorithm to identify single jaw movements and differentiate between active feeding phases and non-active dormant phases. For validation, feeding behavior of 14 cows as determined by both the EMG system and visual observation was analyzed. Results showed adequate agreement of the results of both assessments. The current system is therefore classified as a reliable and suitable tool for monitoring feeding behavior of dairy cows. Further progress and research are necessary for automatic data interpretation with a self-learning algorithm, to develop this EMG-based system into an appropriate management tool in the field of precision dairy farming.

Keywords: Electromyography, Precision Dairy Farming, Rumination time, Validation

4.2 Introduction

Increased milk performance per cow requires raised proportions of concentrate and energy (Krause and Combs, 2003) to compensate for limited physiological feed intake capacity (Allen, 1996; Grant and Albright, 2001; Harvatine and Allen, 2006). This practice results in feeding diets that are relatively low in dietary fiber and adequate particle size (Beauchemin et al., 2003; Beauchemin and Yang, 2005), thereby impairing optimal conditions for microbial activity in the rumen. Consequently, there may be disturbances of fermentation and of rumen activity as well as decreased feed intake, all of which can lead to subclinical and clinical metabolic disorders (Nocek, 1997; Maekawa et al., 2002). A well-adapted energy supply according to the individual requirements and an appropriate amount of fiber content in the diet are immensely important for the health, performance and reproduction of ruminants (Beauchemin and Yang, 2005; Zebeli et al., 2008).

The diurnal surveillance of feeding behavior, which is characterized by feed intake, feeding time (**FT**) and rumination time (**RT**) is essential with regard to its potential as an indicator of suboptimal feeding conditions and as a parameter to assess and construct feeding rations (Owens et al., 1998; Urton et al., 2005; De Vries et al., 2009). The daily observation and ascertainment of the feeding behavior of ruminants constitutes an obvious tool for monitoring health status (Hansen et al., 2003), considering the feeding situation of the whole herd as well as that of individual animals. However, the measurement systems available for monitoring feeding behavior do not meet all requirements for the optimal observation of cow feeding behavior (Büchel and Sundrum, 2013). Most of these systems are more or less inaccurate, unreliable, inadequately or inexplicable validated or are only able to gather RT (Kononoff et al., 2002; Schirmann et al., 2009). The inadequacies of these systems have led to the development of another system by which was intended to overcome most of the existing difficulties.

The overall objective of this study was to evaluate a new electromyography-based (**EMG**) system for monitoring feeding behavior in dairy cows. The objectives were (1) to determine the precision of EMG compared to direct visual observation and (2) to establish how accurately RT and FT are depicted by comparing this new system to visual observation.

4.3 Material & Methods

4.3.1 Measurement system

The system, labeled as DairyCheck is a non-invasive, sensor-based system for monitoring feeding behavior which works without further auxiliary means. It consists of a measurement halter with two incorporated electrodes, a data logger and a power supply, as shown in Figure 6. A three-dimensional accelerometer to determine movement activity and an evaluation software are also incorporated. To warrant an accurate and optimal positioning of the electrodes within the halter, the size and scatter ranges of the heads of more than 300 cows have been measured. These values have been utilized for creating an ideal halter. Consequently, the halters are individually adaptable for optimal attachment of the electrodes to the *M. masseter*, which is important for the accurate measurement of valid data. To comply with good functionality, the halter is soft padded and comfortable and does not affect the cow's well-being.

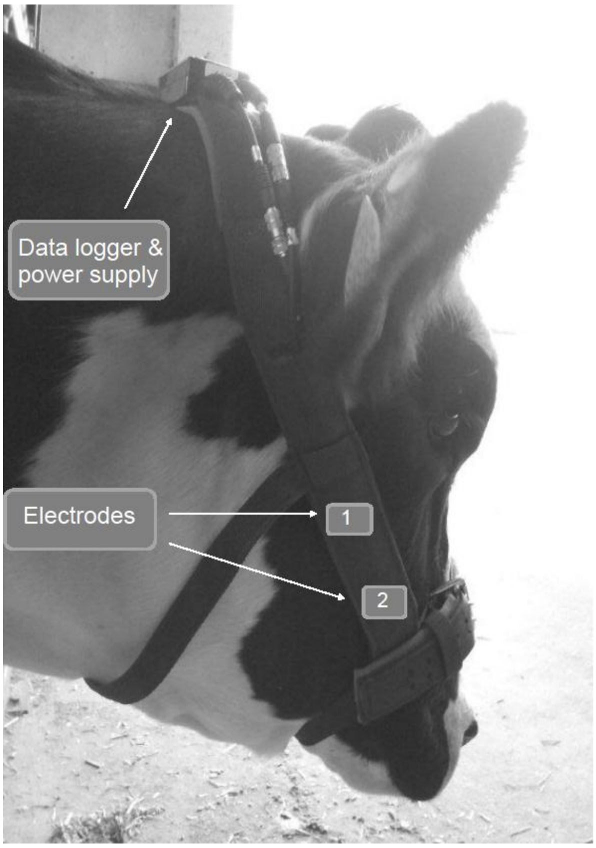

Figure 6. DairyCheck halter with data-logger, power supply and incorporated electrodes as fitted to cattle.

The whole system has been manufactured by BITSz engineering GmbH, Zwickau, Germany. Measurement of feeding behavior ensues through electromyography with modified electrodes, which are closely attached to the skin of the cow. When positioning the electrodes and measuring electrical impulses, the *M. masseter* was chosen because of its size and importance as well as its previous use in electromyographic studies (Griffin and Munro, 1971; Lewis et al., 2013). By means of two surface electrodes the electrical potential oscillations of the external masticatory muscle of the *M. masseter* during jaw movements are recorded with a resolution of 600 measuring points per minute. The myo-electrodes are connected to a data logger, which is integrated into a protective box. This box is placed on the top of the halter and is used for storing the power supply. The data logger registers the electrical impulses and saves them to a mobile central data processing unit for up to 11 hours, after which the first recorded minute is overwritten. If the connection between the data logger and the computer is disconnected, data can be saved for up to 11 hours. Direct raw data transmission (BITSz engineering GmbH, Zwickau, Germany) takes place via bi-directional radio transmission at a frequency of 2.4 GHz. Thereby, live observation and constant monitoring of feeding behavior in real time is possible. The system is powered by a rechargeable 3.7 V, 2.7 Ah lithium-ion battery which allows up to three weeks of uninterrupted recordings.

4.3.2 Working principle

The system enables the automatic and continuous measurement of individual jaw movements. Generated data are automatically evaluated in terms of graphs, where a plot of the amplitude of the signal from the electrodes against time is displayed. The software program, which is based on an algorithm with animal specific values, then identifies single jaw movements, and uses the frequency, amplitude and shape of the jaw movement waveform to discriminate between active feeding and rumination phases and non-active dormant phases. Thus, the algorithm for analysis is based on classification of data in different time sections on the basis of their specific graphic profiles. Rumination behavior is characterized by regular pauses between jaw movements. In these short pauses during regular chewing motions, illustrated in Figure 7, the cow swallows and regurgitates the cud. The pauses are used by the algorithm for recognition. In contrast, jaw movements during feed intake follow an irregular and constant sequence of chewing motions (Figure 8).

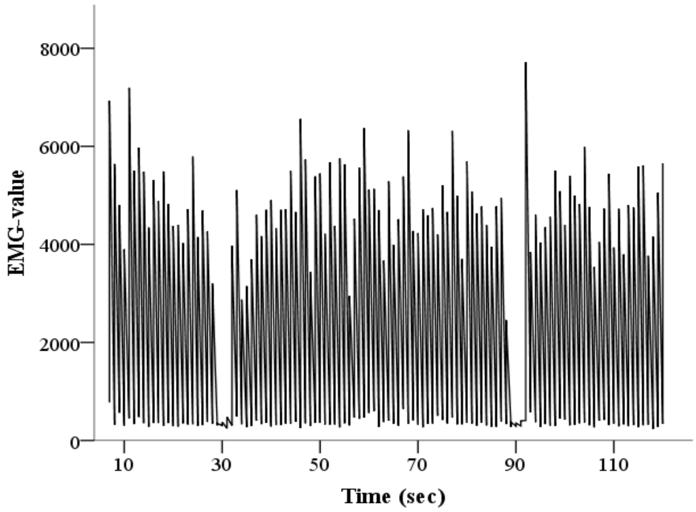

Figure 7. Rumination phase

Non-active dormant phases generate no graphic deflection, which facilitates their detection and classification by the algorithm. The categorization of jaw movements into different behavior patterns by the algorithm is carried out in accordance to the *Graze* software program developed by Rutter et al. (1997). The analysis software and the algorithm are still under development with regard to achieving an automatic classification of feeding behavior and to still improve the full system. Further details of the discrimination algorithm and its validation will be published in the future. For this reason feeding behavior data are up to now processed manually by visual assessment of their specific graphic profiles by the researchers themselves.

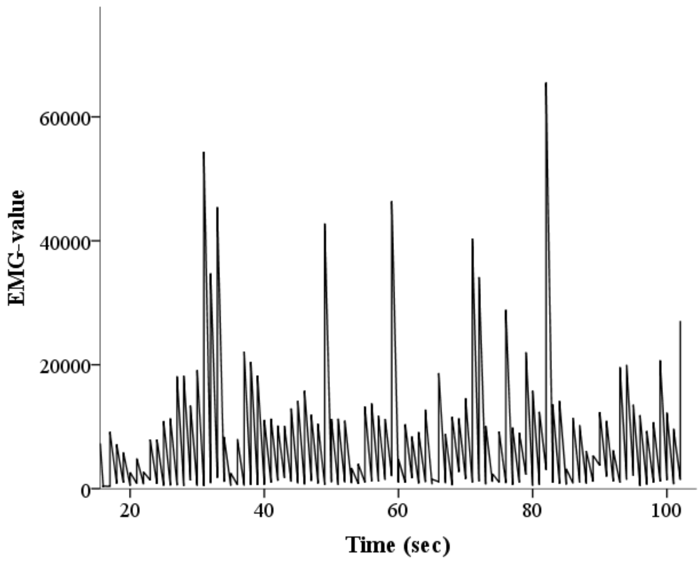

Figure 8. Feed intake

4.3.3 Study Design

A field validation was carried out to test the ability of the automatic measurement system to record feeding and rumination time of dairy cows. This validation has been carried out in accordance with the EU Directive 2010/63/EU (2010) for animal experiments. The experiment was conducted on a commercial farm under conditions of practice in February 2013. The dairy cows were held in tie-stalls, which made visual observation easier. A total of 14 lactating Holstein Friesians were used, divided into seven multiparous (mean milk performance of 24.4 ± 6.4 kg) and seven primiparous cows (mean milk performance of 25.7 ± 6.3 kg). Dairy cows were given a mixed feed once a day (at approximately 17:00 h) comprising 39.4% grass silage, 37.0% corn silage and 23.6% concentrate and mineral mix on a basis of 29.3% dry matter. Feed was pushed up at 07:00, 10:00 and 14:00 h. The validation consisted of two days, during which the RT and FT of the cows were recorded. On each day seven randomly selected cows were fitted with the EMG halter. Feeding behavior was measured and recorded by visual observation and electronically with the EMG system on the first day from 09:00 h to 16:00 h and on the second day from 09:15 h to 16:00 h. Visual observation was arranged in a time-interval of 1-minute scan samplings by one trained human observer, using a stop-watch. Feeding behavior was determined by individually and accurately defined details, for which one observer was sufficient (Schirmann et al., 2009; Burfeind et al., 2010). As they were kept in tethered housing, the identification, measurement and observation of the cows were feasible and reliable to perform.

4.3.4 Statistical Data Analysis

Statistical data analysis was accomplished with the SPSS program (Version 19.0.0.1, IBM Company Inc., USA). The data were normally distributed assessed by the Kolmogorov-Smirnov test. The relationship between FT and RT measured electronically with the EMG system and the measurements form direct observation were assessed using Pearson's correlation coefficient (Pearson, 1920). Used data were summarized for each of 14 cows and for each minute of the validation days. The agreement between measurements of direct visual observation and measurements generated electronically by EMG was assessed for the total time spent ruminating within the observed periods of 311 to 422 minutes using linear regression (Figure 9) and the Bland and Altman plot (Bland and Altman, 1986) in Figure 10. The Bland and Altman method included plotting the average of paired measurements (x-axis) achieved by direct visual observation and by the EMG system against their difference (y-axis). The 95% confidence interval of the mean of the difference was calculated and covered on the plot.

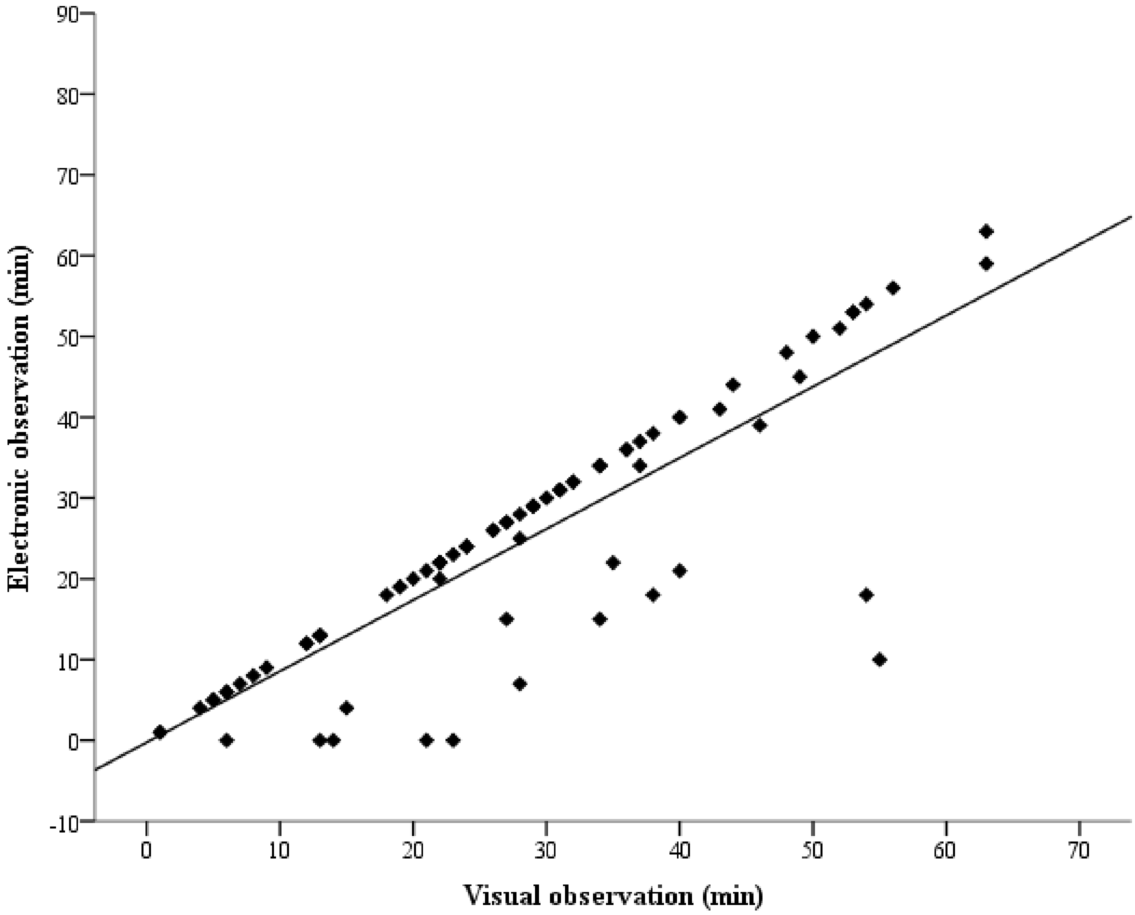

Figure 9. Linear regression of rumination time (min) measured visual and electronically. Regression equation: y = -0.247 + 0.881x

4.4 Results

The EMG system provided estimates of feeding behavior that were similar to those detected by visual observation. Base data of feeding behavior recorded by visual observation were summarized for each of the 14 cows and for each minute of the validation days and vary from 311 minutes (n=1) and 407 minutes (n=8) to 422 minutes (n=5). For the validation, correlation coefficients (r) and coefficients of determination (R^2) between rumination times measured electronically with the EMG system (24.3 min ± 15.6 min) and by direct observation (27.8 min ± 15.2 min) were high ($r = 0.86$, $R^2 = 0.74$, $n = 14$, $P < 0.001$). Correlation coefficients and coefficients of determination between feeding times measured electronically with EMG (2.8 min ± 2.9 min) and by direct observation (3.3 min ± 3.2 min) were also high (r = 0.87, $R^2 = 0.75$, $P < 0.001$). The total number of agreements (a) and disagreements (d) for electronic recording and visual observation of FT and RT were used to calculate an index of concordance i.e. a/(a+d) (Martin and Bateson, 1986). The overall index of concordance was 87%.

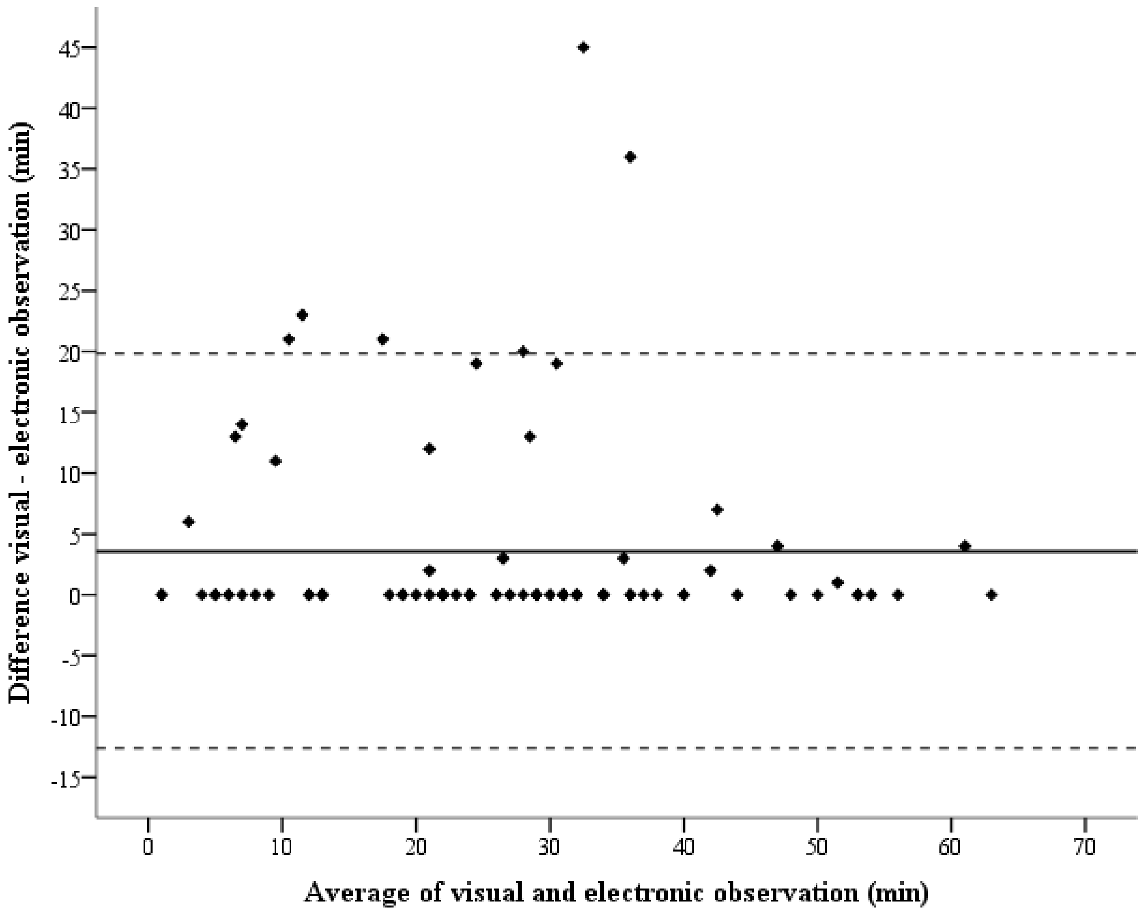

Figure 10. Differences between rumination times measured electronically with the EMG and by direct visual observation (visual – electronic) against the mean of both estimates. Data are shown for 83 rumination periods from 14 cows (mean difference = 3.56, 95% confidence interval: -12.6 to 19.8).

Plotting the difference between estimations of RT measured electronically and by visual observation against the mean of these two assessments showed that disagreements between both methods were unevenly distributed across the range. Disagreements of measuring RT were only underestimated, not overrated by EMG usage. The mean difference of 3.56 minutes indicated that the EMG system stated rumination times that were 3.56 minutes shorter than the values determined by direct visual observation. The 95% confidence interval for the point estimates of the mean difference was -12.6 minutes and 19.8 minutes.

About 95% of data points were within the upper and lower limits of agreement by using the Bland and Altman (1986) plot. The maximum variation between rumination estimates in an individual case was 10 minutes measured with EMG and 55 minutes measured by direct visual observation. By using the Bland and Altman plot for FT, the EMG system stated a mean difference of 0.46 minutes with a 95% confidence interval which ranged from -2.67 minutes to 3.59 minutes. Disagreements of measuring FT were underestimated, not overrated by measurement with EMG.

4.5 Discussion

The comparison of RT and FT measured by visual observation and electronic recording systems like the DairyCheck system is a reliable method for evaluating and validating new technical observation tools (Law and Sudweeks, 1975; Penning et al., 1984). Compared to direct visual observation, the EMG-based system is accurate and convincing with respect to accordance of generated data. Statistical calculations signify repeatable and reliable values. Compliance of measured values of feeding behavior by comparing the system to visual observation expresses a strong positive correlation (Cohen, 1969). However, the overall index of concordance of 87% to reflect the actual feeding behavior accurately shows room for improvement. The usage of the Bland and Altman (1986) plot indicates that disagreements of measuring RT and FT were only underestimated. Incorrectly positioned or loose electrodes may have contributed to this underestimation of RT and FT by the EMG system. Errors associated with visual observation may be slight. Precisely defined criteria were used for observation and recording of feeding behavior. Furthermore, Rutter et al. (1997) reported high concordance (92.2%) between estimates of two different observers for feeding behavior, wherefore significance of one trained human was sufficient.

In comparison to current commercially available systems, validation results are resilient and show good and acceptable data values. The EMG system measures single jaw movements during chewing the cud and chewing feed and has essential advantages over the Hi-Tag rumination monitoring system. This Hi-Tag system can only determine the sound of regurgitation during rumination (Burfeind et al., 2010; Schirmann et al., 2009); measurement of feeding time is not recorded. Regarding quantity of used sample size and validation duration, validation results of the EMG system are more resilient and repeatable than the IGER behavior recorder (Rutter et al., 1997) and the RumiWatch health monitoring system (Zehner et al., 2012). A clearly description of validation results of all these systems are not published and therefore not transparent.

One disadvantage of the EMG system is the limitation of the analysis software for automatic classification of feeding behavior, which is still under development. Furthermore, battery lifetime should be increased. Considering that two electrodes are incorporated into the halter, compensation of one electrode can be ensured in case of damage to the second electrode. The system enables continuous measurement of individual jaw movements. This permits the detection of individual boli during ruminating and feeding and offers therefore more information about the individual animal. Thus, the system provides contingencies for problems which may occur as a result of the cows' behavior.

4.6 Conclusion

In its current stage of development the EMG system is a reliable and suitable tool for monitoring rumination and feeding time of individual dairy cows. Feeding behavior can be recorded as reliably and precisely with this system as it can with visual observance during this study. However, further research and development of this system is necessary. The implementation of automatic analysis software with a self-learning algorithm for data interpretation of feeding behavior is one of the next steps.

Chewing and rumination activity are multiple-influenced parameters, therefore interpretation of data generated from individual animals is essential. By means of well-adapted, reliable and transferable reference values, the potential of the EMG system can be used to recognize suboptimal feeding conditions and possible impairments to health. The earlier veterinary treatments or management changes are initiated during the disease process, the more effective they are. This indicates the increased necessity for the advancement of the automatic analysis software and the determination of reference values to ascertain feeding behavior of ruminants. All in all, data of this validation provide evidence that the EMG system offers reasonable measurements of RT and FT and is evaluated as an appropriate and helpful management tool in the current research field of Precision Dairy Farming.

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5 CHAPTER 3.

Comparison of Systems for Measuring Rumination Time of Dairy Cows

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5.1 Abstract

The use of automatic systems facilitates the monitoring of the health and nutritional status of individual cows. Measurement of the daily rumination time (RT) constitutes a suitable parameter for individual monitoring of dairy cows with respect to deviations from normal conditions that might indicate disturbances. In the past, different systems for automatic measurement of feeding behavior of ruminants have been developed. Three systems: The Lely Qwes HR (HR) sensor, the DairyCheck (DC) system and the RumiWatchSystem (RW), all of which are based on diverse measurement methods, have achieved market maturity. The aim of this study was to investigate the reliability and validity of the measurement systems and to compare their results. For this study, the rumination time of nine dairy cows was recorded in two trials. In trial 1, RT was determined by both the DC system and by the HR sensor. In trial 2, RT was determined by both the RW system and by the HR sensor. Results indicated that data generated by both the DC system in trial 1 (total mean of RT per 24h for all cows of 530 ± 60 min) and the RW system in trial 2 (total mean of RT per 24h for all cows of 546 ± 54 min) were clearly different in comparison to those detected by the HR sensor in trial 1 (total mean of RT per 24h about all cows of 399 ± 148 min) and in trial 2 (total mean of RT per 24h for all cows of 413 ± 148 min). RT during one day deviated an average of 131 (DC) and 133 (RW) minutes from those detected by the HR sensor. Results of the measurements with DC and RW demonstrated a high concordance. Thus, these results are clearly more consistent than those detected by the HR

sensor and indicate that the DC and RW systems are the most common and useful tools for reliably recording rumination behavior. However, all three measurement systems are in need of further development to reduce their individual disadvantages and to achieve a high level of applicability for reliable usage in practice.

Key words: feeding behavior, measurement systems, validation

5.2 Introduction

The use of automated measurement systems to support health management has gained increasing importance in livestock production (Hogeveen et al., 2010; Rutten et al., 2013). Due to larger herd sizes, manual labor is increasingly being replaced by the use of technology. Automated measurement systems enable dairy farmers to manage larger herds with less time needed for surveillance, therefore reducing labor costs (Svennersten-Sjaunja and Pettersson, 2008; de Koning, 2010). Thus, automatic systems within Precision Dairy Farming will become of greater relevance in the future.

The development of automatic systems to measure feeding behavior of ruminants has engaged many scientists for several decades (Nagel et al., 1975; Penning, 1983; Rutter et al., 1997; Kononoff et al., 2002). Further technical developments have led to innovative and new options for the automatic recording and interpretation of chewing and rumination activity of dairy cows to facilitate farm management (Rutten et al., 2013). These measurements are now a high priority and are considered to be a reasonable and helpful indicator in gaining relevant information about the individual animal and its ability to cope with farm-specific feeding situations (Owens et al., 1998; DeVries et al., 2009). For example, the daily observation of individual rumination time (**RT**) provides information about the fiber content and composition of the ration and its benefit for rumen health function (Murphy et al., 1983; Leonardi et al., 2005) and is strongly associated with dry matter intake (Metz, 1975; Yang and Beauchemin, 2006). Data concerning rumination time are suitable for the early detection of deviations from normal conditions of feeding behavior and diseases in dairy cows deriving thereof (Hansen et al., 2003; Krause and Oetzel, 2006).

Many different devices for recording rumination behavior with automatic measurement systems have been developed. Some of these devices are in use in practice or in research work and are commercially available or will be available in the near future. However, the reliability of such devices has not been proven in a comparative analysis, until now. The overall objective of the current study was to test three different measurement systems in regard to their reliability and to the validity of generated data when measuring RT of dairy cows. The objectives were (1) to assess the concordance of measuring RT of a measurement system already implemented in practice compared to two systems so far used primarily in research work and (2) to determine the extent to which generated RT of both research systems are comparable to each other.

5.3 Materials & Methods

5.3.1 Measuring Techniques

The measurement of RT was conducted by using three different systems which varied in terms of their area of application and use of technology. They corresponded to acoustic biotelemetry, pressure transducer and electromyography systems. For each system one representative device was chosen. For the acoustic biotelemetry system, the Lely Qwes HR (**HR**) sensor was selected, for the pressure transducer, the RumiWatchSystem (**RW**) was used, and for electromyography, the chosen device was the DairyCheck (**DC**) system. These three devices were selected for their stage of development and applicability**.** The HR sensor has already been applied in practical use, while both of the other systems have been primarily used in research.

Lely Qwes HR

The first prototype of the acoustic biotelemetry system was developed by Israeli scientists and is labeled as Vocal Tag, RuminAct™ or HR-Tag (SCR Engineers Ltd., Netanya, Israel used by Lely Ltd., Maassluis, the Netherlands). The HR sensor consists of a neck collar with a tag which incorporates a touch-sensitive microphone and data logger. Rumination activity is recorded through the sound of regurgitation of boluses during a rumination phase. To ensure the right position of this tag, a counterweight is fixed to the collar ventrally. Rumination is recorded with a resolution of two minutes, which results in 60 possible agreements or disagreements per two-hour interval (Burfeind et al., 2011). The technology is set up for the collection of data from eleven two-hour intervals. Consequently, a maximum of 22 hours can be recorded, whereupon the first interval is overwritten and the results of data are lost if they are not downloaded in time. Data are infrared transferred and downloaded either by antennas, positioned at highly frequented positions within the barn, such as above the water trough or in the milking parlor, or by a handheld reader to a receiver and transmitted by wire connection to a computer (Lindgren, 2009; Schirmann et al., 2009; Burfeind et al., 2011). The battery lifetime is three to four years (VocalTag, 2008). RT is analyzed by an algorithm which considers rumination events if successive regurgitations were separated. The different automatic analysis software program generates graphs which reflect the rumination activity during the course of a day of each documented cow.

RumiWatchSystem

The RW system is a pressure transducer for recording feeding behavior of dairy cows. The technique consists of a halter with a noseband sensor comprising a vegetable oil-filled silicon tube with a built-in pressure sensor, a data logger, power supply, and the corresponding evaluation software (Itin + Hoch GmbH, Liestal, Switzerland). The data logger registers the pressure during chewing and ruminating at a frequency of 10 Hz, saves the raw data to an SD Memory Card and stores them for up to four months. Under laboratory conditions the battery lifetime is up to three years. Data are transmitted wirelessly or via an SD Memory Card to a computer (Zehner et al., 2012). For automatic measurement, a generic algorithm without animal specific learning data divides individual jaw movements of different amplitudes and chewing bout pauses into ruminating, eating, drinking or other activities (Zehner et al., 2012).

DairyCheck

The DC system is a sensor-based system for monitoring rumination and chewing behavior of dairy cows by electromyography (Büchel and Sundrum, 2013a). The system comprises a measurement halter with two incorporated electrodes, a data logger, a power supply, and evaluation software (BITSz engineering GmbH, Zwickau, Germany). The myoelectrodes are closely attached to the skin of the cow for measuring electrical impulses of the *M. masseter*. They are connected to a data logger, which registers the electrical impulses with a resolution of 600 measuring points per minute and saves them to a mobile central data processing unit for up to 11 hours, after which the first recorded minute is overwritten. If the connection between the data logger and the computer is disconnected, data can be saved for up to 11 hours. Direct data transmission takes place via bi-directional radio transmission at a frequency of 2.4 GHz. Thereby, live observation and constant monitoring of feeding behavior in real time is possible. The system is powered by a rechargeable 3.7 V, 2.7 Ah lithium-ion battery, which allows up to three weeks of uninterrupted recordings. Data are evaluated in terms of graphs. Data analysis is based on an algorithm with animal specific values. Differentiation of generated data into active feeding and rumination phases and into non-active dormant phases is possible. Since the analysis software for achieving an automatic classification of feeding behavior is still under development, these data are processed manually by the researchers themselves.

5.3.2 Study Design

The study was carried out to test different measurement systems for measuring RT of dairy cows. The experiment was divided into two trials. They were conducted on a commercial dairy farm under practical conditions in April 2013. A total of nine randomly selected lactating Holstein Friesians were used: four primiparous (mean milk performance of 30.0 ± 2.6 kg) and five multiparous cows (mean milk performance of 42.2 ± 4.8 kg). The cows were kept in free-stall barns with a free cow traffic routine that meant that all parts of the stable areas, such as the cubicles, the feed alley, and the automatic milking system could be adjusted in every situation at any time. The dairy cows were fed a total mixed ration once a day (at approximately 18:00 h) comprising 42.1% grass silage, 17.0% corn silage, and 40.9% concentrate and mineral mix on a basis of 44.5% dry matter. Feed was pushed up at 07:30, 10:00, 14:00 and 22:30 h. The study consisted of two weeks during which the RT was recorded. In trial 1, nine cows were used. The RT of each cow was recorded by both the DC system and the HR sensor simultaneously over a time period of six days. Trial 2 used the same nine cows. The RT of each cow was recorded by both the RW system and the HR sensor simultaneously over six days, too. The DC system and the RW system were integrated into a halter; the HR sensor was incorporated into a head collar, which enabled the comparison of this combination. With regard to RT, a direct comparison of both halter-fitted systems was not practicable because it was not possible to guarantee that the functionality of one halter would not be influenced by the other halter.

5.3.3 Statistical Analysis

Statistical data analysis was achieved with the SPSS program (Version 20.0.0, IBM Company Inc., USA). The program calculated values for the Cohen’s kappa coefficient (Cohen, 1960) and the asymptotic standard deviation and Pearson’s correlation coefficient

(Pearson, 1920), together with the coefficient of determination. Data were summarized for all nine measured cows and for all of the experimental days. The kappa coefficient was used because it reveals agreement for nominal scales and assumes that the events are independent (Alexopoulos, et al., 1988; Viera et al., 2005). The Mann Whitney U test was used to determine whether two sampled groups were from a single population with no specific distribution (Wilcoxon, 1945; Mann and Whitney, 1947).

5.4 Results

The DC system provided estimates of RT that were very different to those detected by the HR sensor. Moreover, the RW system delivered estimates of RT that were dissimilar to those measured by the HR sensor. Rumination activity per day for all nine cows ranged from 410 to 666 minutes with a mean of 530 ± 60 minutes for the DC system, from 382 to 643 minutes with a mean of 546 ± 54 minutes for the RW system and from 75 to 635 minutes with a mean of 413 ± 148 minutes for the HR sensor. Base data of rumination activity recorded by the three different systems were summarized for each cow and for each day of the study and resulted in n = 51 data sets for trial 1 and in n = 54 for trial 2. Mean deviation of recorded RT in trial 1 was -131 minutes when comparing the DC to the HR. In trial 2, mean deviation of recorded RT was -133 minutes when comparing RW to HR. Discrepancies of measuring RT were distinctly underestimated by the HR sensor in comparison to both of the other systems. Mean and standard deviation of recorded RT for each of the nine cows measured for both trials is given in Table 6.

For trial 1, correlation coefficients (r) and coefficients of determination (R^2) between rumination times measured with the DC system and with the HR sensor were low ($r = 0.30$, $R^2 = 0.09$, $n = 14$, $P < 0.05$). For trial 2, correlation coefficients and coefficients of determination between rumination times measured with the RW system and with the HR sensor were also low ($r = 0.14$, $R^2 = 0.02$, $P < 0.10$). Values of the Cohen's kappa coefficient (κ) and asymptotic standard deviation (σ) were correspondingly very low for trial 1 ($\kappa = -0.001$, $\sigma = 0.001$, $P < 0.10$) and for trial 2 ($\kappa = -0.004$, $\sigma = 0.002$, $P < 0.10$).

Within the two trials, no significant differences in individual rumination activity and no significant effect between cows wearing halters or wearing the head collar were detected. The Mann-Whitney U test confirmed that the rumination times measured in trial 1 in the first week by the DC halter and the HR head collar were equal with respect to trial 2 in the second experimental week, in which the cows wore the RW halter and the HR head collar. Asymptotic significance was 0.401 by comparing RT measured by both halters, each used in one trial. By comparing RT measured by the HR head collar in both trials, asymptotic significance was 0.508. Thus, generated data were similar for the same cows over the two weeks in which both halter-related systems (DC, RW) were worn consecutively, and the neck collar system (HR) was worn continuously.

Table 6. Mean and standard deviation of recorded rumination time in minutes per cow when comparing the DC system to the HR sensor (trial 1) and the RW system to the HR sensor (trial 2).

Cow	DairyCheck	Lely Qwes HR	RumiWatch	LelyQwes HR
	trial 1		trial 2	
1	471 ± 32	413 ± 53	567 ± 26	469 ± 47
2	499 ± 31	132 ± 43	555 ± 33	181 ± 39
3	461 ± 48	223 ± 38	541 ± 27	218 ± 18
4	572 ± 38	367 ± 73	568 ± 63	545 ± 29
5	590 ± 65	453 ± 31	538 ± 83	475 ± 34
6	511 ± 32	524 ± 51	537 ± 39	539 ± 39
7	529 ±27	501 ± 15	555 ± 47	517 ± 36
8	546 ± 43	198 ± 59	533 ± 63	264 ± 91
9	561 ± 45	590 ± 51	522 ± 57	506 ± 76
Total mean[1]	530 ± 60	399 ± 148	546 ± 54	413 ± 148
Mean dev.[2]	-131		-133	

[1]Mean and standard deviation of all data recorded for all cows for each comparison.
[2]Mean deviation between DC and HR, and between RW and HR.

5.5 Discussion

The data presented represent the results of a comparative study of three different measurement systems. Due to technical reasons, it was not possible to assess feeding behavior simultaneously by visual observation, which is generally accepted as the gold standard for validating the classification of feeding behavior into feeding, ruminating or idling (Büchel and Sundrum, 2013b). Moreover, recording feeding behavior during a whole day over several consecutive days is not possible using this method. However, every single one of the three measurement systems has been independently validated through visual observance. The HR sensor was validated by external scientists in several trials under various conditions (Lindgren, 2009; Schirmann et al., 2009; Burfeind et al., 2011). The other two systems were validated by the developing scientists themselves (Nydegger et al., 2011; Zehner et al., 2012; Büchel and Sundrum, 2013a). All previous validation trials were realized under different practical conditions, varying also in sample sizes and lengths of monitoring duration. The current trials were accomplished under equal practical conditions for all three systems, enabling a direct comparison, instead of a comparison of different validation results.

The results of this study demonstrate that the recorded RT varied significantly between the HR sensor and the DC system within trial 1 and between the HR sensor and the RW system in trial 2. On average, RT during one day was 131 and 133 minutes lower than that detected by the HR sensor (Table 6). RT was therefore obviously underestimated by the HR sensor. The underestimation of RT was similar to those results obtained by Pahl et al. (2012). They compared the ART-MSR pressure transducer, which was the preceding model of the RW system (Nydegger et al., 2011), to RuminAct™, which also includes the tag of the HR sensor. RT determined by this RuminAct™ sensor was underestimated compared to direct observation and correlated only moderately with the ART-MSR pressure transducer ($r = 0.58$, $n = 527$, $P < 0.01$). Thus, the HR sensor does not fulfill the demands of precision and reliability required during measurements. Technical deficiencies of the HR sensor must be further improved so that the significance of results of the automatic analysis software can be trusted. In combination with other parameters which can be recorded by this device (Lely, 2013; SCR, 2013), the HR sensor seems to be more suitable for practical use. Its restrictions in terms of the valid and suitable recording of RT are compensated by measurements of physical activity or lying time and other measurement parameters. When more information is achievable, better concrete statements about the condition of individual animals can be made. This additional information provides suitable opportunities for successful usage in practical trials, which have been reported by Lindgren (2009) and Bar and Solomon (2010). But due to the lack of precise measurement results generated within this study, the HR sensor is only of limited use for research trials and casts doubt on the significance of RT data already generated during practical trials.

Data recorded by the DC system are comparable to those detected by the RW system, which is confirmed by the asymptotic significances of the Mann Whitney U test. In the represented trials a comparison between the halter-fitted systems, DC and RW, to HR, which is fitted to a neck collar, were viable. The reason for the considerable deviation of the HR sensor to both of the other systems might be due to the positioning of the neck collar with its incorporated touch-sensitive microphone. Considering that cows are different sizes, weights and shapes, it was not possible to maintain the correct position of the neck collar for every cow. That's why the individual cow had a crucial influence on the absolute difference of RT of the HR sensor compared to the other research systems (Pahl et al., 2012). Burfeind et al. (2011) also stated the significance of the exact positioning of the neck collar and the data logger fixed behind the left ear, which should be ensured by a counterweight, because incorrect positioning of the microphone might impair the recording of rumination activity. Ungar and Rutter (2006) recognized the problem that the microphone attached to one cow might pick up grazing sounds from another cow. During this study an increase of measured rumination minutes could not be observed by the HR sensor in comparison to the DC system and the RW system. Burfeind et al. (2011) highlighted the slight resolution of two minutes within one two-hour interval, which can affect precise recordings and might be another explanation for the significant deviation. A further disadvantage could be the indirect measurement of the neck collar by acoustic biotelemetry of the HR sensor (Soriani et al., 2012), instead of direct measurement using halters with the other two systems. Direct measurement of rumination activity by electromyography and by a built-in pressure sensor, which are both attached closely to the area of jaw movements to be analyzed, offers the possibility of more exact recordings and reduces the amount of disturbing external influences. This advantage is reflected in the results presented. On the other hand, using a neck collar is an advantage because many dairy farmers make use of neck collars for identifying their cows with fixed number tags or for identifying them by feeding stations. Thus, unlike with halters, the use of neck collars requires no changeover for the cows.

However, both halter-fitted systems are not free from certain problems. During this study, the application of the RW halter caused injuries to the area of the muzzle of some cows. The material used for the halter should be improved to ensure animal health and welfare. Two crucial disadvantages of the DC system are the missing automatic analysis software, which is still under development, and the short battery lifetime compared to both of the other systems.

5.6 Conclusion

It is apparent that the DC system and the RW system are useful tools for the recording of RT of dairy cows. Rumination time recorded by the tag of the HR sensor is of limited use for measuring reliable and convincing data due to restricted accuracy and reproducibility. This study has demonstrated that the DC system and the RW system are clearly more consistent with regard to measurement of rumination behavior than the HR sensor. Their measured data are reliable and usable for the surveillance of feeding behavior. However, to achieve most of the demands required for reliable usage in practice, further research and development of all three systems is necessary. Thus, the implementation of analysis software for automatic data interpretation should be one of the next steps of the DC system. To increase the comfort of the RW halter for the cows, the material used should be adapted. For the HR sensor, the major challenge is to ensure optimal positioning of the acoustic tag on the neck collar.

The recent development of three new measurement systems provides evidence that the recording of rumination time is a particularly suitable method for monitoring the feeding behavior of dairy cows. Each of the systems has different drawbacks which should be overcome, thus enabling them to develop into appropriate and helpful management tools in the field of Precision Dairy Farming.

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6 CHAPTER 4.

Decrease in Rumination Time as an Indicator of the Onset of Calving

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6.1 Abstract

The aim of this study was to investigate whether rumination time (RT) is affected by the onset of calving. The relationship between both feeding time and dry matter intake (DMI) to the onset of calving was also examined. In addition, the correlation between feeding behavior characteristics, described here as RT, feeding time and DMI, was evaluated. Under test conditions, the feeding behavior of pregnant Holstein cows was recorded from the time when they were moved into calving pens (usually 7-5 days prepartum) until the onset of calving. Feeding time and DMI were recorded by automatic feed bins; RT was measured by a measuring halter based on electromyography (DairyCheck, BITSz engineering GmbH, Zwickau, Germany). Data analysis relates to the final 72h before the onset of calving, which are divided into twelve 6h-blocks. The last 6h (one 6h-block) before calving were compared to the 72-7h time frame (eleven times 6h-blocks) before calving, which is defined as the reference period. For this time period, feeding behavior data for 17 cows was fully available, which was the precondition for data analysis. In the final 6h before imminent birth, RT was significantly reduced. During this time, it was found that the mean minimum RT was 69.9 ± 28.5 min/6h compared to the mean RT of 95.5 ± 30.8 min/6h in the reference period. The average decrease in RT was 27% (25.6 min/6h). In addition, feeding time and DMI were significantly reduced. The average decrease in feeding time was 57% (20.8 min/6h), and in DMI it was 56% (1.9 kg/6h). High correlation coefficients between feeding behavior characteristics were only found between feeding time and DMI. Values of feeding behavior among cows were characterized by a high variability. Recording RT can serve as a useful tool for predicting the timing of birth for dairy cows, but further research is necessary.

Key words: birth, feeding behavior, management support, measurement system

6.2 Introduction

The process of calving constitutes a critical stage for both, dam and calf (Schuenemann et al., 2013). Prolonged calving, delayed parturition or severe assisted extraction of the calf at birth can result in a difficult birth which has been defined as dystocia (Mee, 2004, Lombard et al. 2007). Primary causes of dystocia are fetal-maternal size mismatch (Berger et al., 1992), fetal malpresentation (Meijering, 1984), dam-related causes such as uterine torsion (Frazer et al., 1996) and hypocalcemia (Curtis et al., 1983). Dystocia can lead to a range of consequences for the dairy cow and the calf, including the increased incidence of stillbirth (Meyer et al. 2000), calf mortality within 30 d post calving (Lombard et al., 2007; Mee, 2008), the increased likelihood of both cow and calf respiratory and digestive disorders, and retained placenta and uterine disease of the cow (Lombard et al., 2003; Sheldon et al., 2009). Dystocia is also associated with economic losses due to a possible decrease in milk yield, decline in reproductive performance and the risks for an increase in cow and calf morbidity and mortality (Dematawewa and Berger, 1997; Rajala and Gröhn, 1998). Prevention of dystocia in dairy cows should therefore be a high priority in farm management. Calving management practices for dairy personnel need to be adjusted to create optimal surveillance and care of the cow and calf during parturition. Recognition of benchmarks and reference times for normal births as well as for difficult births is essential for determining the appropriate time for intervention under field conditions (Schuenemann et al., 2013). This requires, if possible, an exact knowledge about the onset of birth. Thus, identification of the onset of birth is a crucial parameter for the prevention of dystocia.

Generally, the onset of birth is recognized by monitoring behavior changes or external changes in the dam, either visually or by video observation. Birth can also be monitored by measuring feeding behavior, like feeding time and dry matter intake (**DMI**). Feeding time and DMI are reasonable and helpful indicators in the early recognition of animals which have deviated from their normal conditions (Beauchemin and Yang, 2005; De Vries et al., 2009; Burfeind et al., 2010). In dairy cows, a gradual depression in feeding time and DMI usually happens from a few days until less hours before calving (Grant and Albright, 1995; Maekawa et al., 2002; Hansen et al., 2003). Measuring feeding time and DMI on commercial dairy farms is laborious, dependent on human observation and is susceptible to human error (Lukas et al., 2008). In contrast, the measurement of individual rumination time

(**RT**), which also belongs to feeding behavior characteristics, is more suitable for automatic, sensor-based recording. RT is strongly associated with feeding time and DMI (Welch, 1982; Dado and Allen, 1994; Yang and Beauchemin, 2006), and is simpler to record than feeding behavior and therefore easier to use for monitoring dairy cows. As a result, numerous methods for automatically measuring, assessing and analyzing individual RT of dairy cows have been developed up to now (Ungar and Rutter, 2006; Burfeind et al., 2011; Zehner et al. 2012).

The overall objective of this study was to investigate whether there is an obvious decrease in RT shortly before calving. The aims were (1) to measure the individual RT in the last 72 hours before calving and (2) to determine if RT might be a useful indicator for predicting the timing of birth. Furthermore, feeding time and DMI were recorded in order to assess their relationship to calving time and to RT.

6.3 Materials & Methods

6.3.1 Study Design

The study was conducted under test conditions at the State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt in Iden, Germany from June to August 2013. A total of 55 multiparous Holstein cows were tested. From 7-5 days before the expected date of calving, the cows were held in a straw-bedded calving pen with free access at any time to five feed bins. When a cow approached the feed bin, an antenna detected its unique neck collar-mounted transponder and lowered the barrier, allowing the cow access to the feed. Dairy cows were given a TMR ad libitum once a day at approximately 10:00 h comprising 34.0% lucerne grass silage, 44.2% corn silage and 21.8% concentrate and mineral mix on a basis of 45.0% DM. Feeding time and DMI were recorded by using automatic feed bins from the day of being moved into the calving pen, until the onset of calving. The RT of each cow was measured by a measuring halter (DairyCheck, BITSz engineering GmbH, Zwickau, Germany). When the cows were turned over into the calving pen once or twice a week, measurement halters were applied. After calving, measurement halters were removed. RT was recorded from the day of halter application until a few hours after calving. The onset of calving was recognized by human observation of changes in the cows' behavior and/or on the basis of external changes. From this point, the amount of feed intake and duration of feeding time and RT were analyzed for the previous 72h. During analysis, measurement values recorded within these 72h were divided into twelve 6h-blocks. The reference period is defined as the last 66 hours (11 times 6h-blocks) before the last 6 hours (one 6h-block) before the onset of calving. And the onset of calving was defined as the hour when the first stage of the expulsion period was detected by visual observation. Data relating to 17 of the 55 cows tested were available for this study. Only fully generated data sets of feeding behavior could be considered for the analysis. The main reason of the lack of data from 38 of the dairy cows was the incidence of premature delivery after being moved into the calving pen, which meant that it was not always possible to use the measuring halter for the three days necessary for this study. A further reason was due to the fact that some of the rumination and feed bin data was missing.

6.3.2 Measuring Technique

For the automatic recording of RT, an electromyography-based system labeled as DairyCheck (BITSz engineering GmbH, Zwickau, Germany) was used. It is a sensor-based system for monitoring rumination and feeding time of dairy cows (Büchel and Sundrum, 2013, unpublished data). The system comprises a measurement halter with two incorporated electrodes, a data logger, a power supply, and evaluation software. The myo-electrodes are closely attached to the skin of the cow for measuring electrical impulses of the *M. masseter*. They are connected to a data logger, which registers the electrical impulses with a resolution of 600 measuring points per minute and saves them to a mobile central data processing unit for up to 11 hours. Direct data transmission takes place via bi-directional radio transmission (BITSz engineering GmbH, Zwickau, Germany) at a frequency of 2.4 GHz. Thereby, live observation and constant monitoring of feeding behavior in real time is possible. The system is powered by a rechargeable 3.7 V, 2.7 Ah lithium-ion battery, which allows up to three weeks of uninterrupted recordings. Data are evaluated in terms of graphs. The generated data can be used for distinguishing between active feeding and rumination phases and non-active dormant phases. Since the analysis software for achieving the automatic classification of feeding behavior is still under development, data are processed manually by the researcher themselves.

6.3.3 Statistical Analysis

Statistical data analysis was accomplished with the SPSS program (Version 20.0.0, IBM Company Inc., USA). Data were summarized for each cow and at 6h-intervals. Hours with incomplete data due to technical problems or premature calving were discarded. Only dairy cows with at least 72h of data until calving time (n = 17 cows) were included in the final analysis. Descriptive statistics were used for all variables. The data were normally distributed and assessed by the Kolmogorov-Smirnov test. Means of the reference period against the 6h period before calving were tested by using the univariate analysis of variance (ANOVA) with repeated measurements. The relationship between feeding behavior characteristics was assessed using Pearson's correlation coefficient (Pearson, 1920). A level of confidence of 95% was applied.

6.4 Results

The duration of rumination time of dairy cows was influenced by calving time (Figure 11). 15 out of 17 (88%) of the dairy cows analyzed showed reduced RT during the last 6h before calving. In the reference period, cows spent on average 95.5 ± 30.8 min/6h ruminating. During the last 6h before the onset of calving, RT averaged 69.9 ± 28.5 min/6h. RT was significantly reduced ($P < 0.01$) by a mean of 27% (25.6 min/6h) in the last 6h before the onset of calving compared to the reference period.

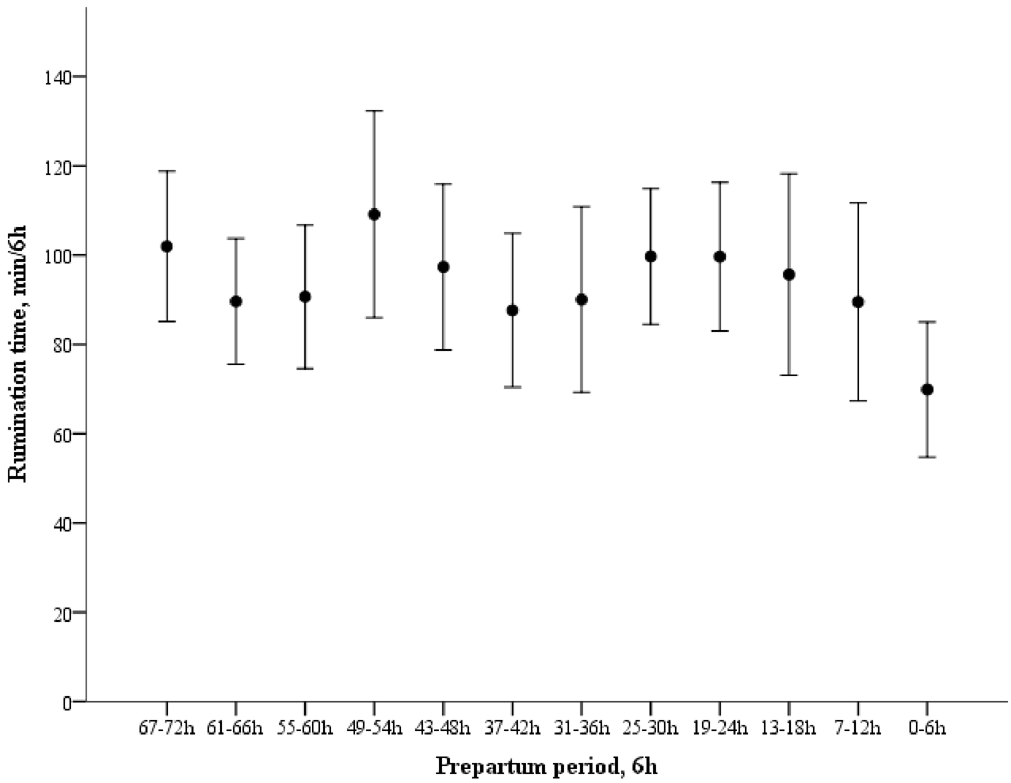

Figure 11. Variance of rumination time of dairy cows in min/6h during the last 72h before the onset of calving (mean; standard deviation). (n=17)

With respect to all 17 cows, the variance of RT within the reference period ranged from a maximum of 210.5 min/6h to 0 min/6h. Within the last 6h before the onset of calving, the variance of RT ranged from a maximum of 114.8 min/6h to 0 min/6h.

Feeding time (Figure 12) and DMI (Figure 13) were considerably influenced by calving time. 16 out of 17 cows (94%) clearly spent less time feeding and all 17 (100%) cows reduced DMI in the last 6h before the onset of calving. Cows spent an average of 36.4 ± 18.6 min/6h feeding and had a mean DMI of 3.5 ± 1.8 kg/6h within the reference period. During the last 6h before the onset of calving feeding time was 15.6 ± 12.6 min/6h and DMI 1.6 ± 1.1 kg/6h, respectively. Both, feeding time and DMI were significantly reduced ($P < 0.001$) by on average 57% (20.8 min/6h) and by a mean of 56% (1.9 kg/6h) within the last 6h before the onset of calving compared to the reference period.

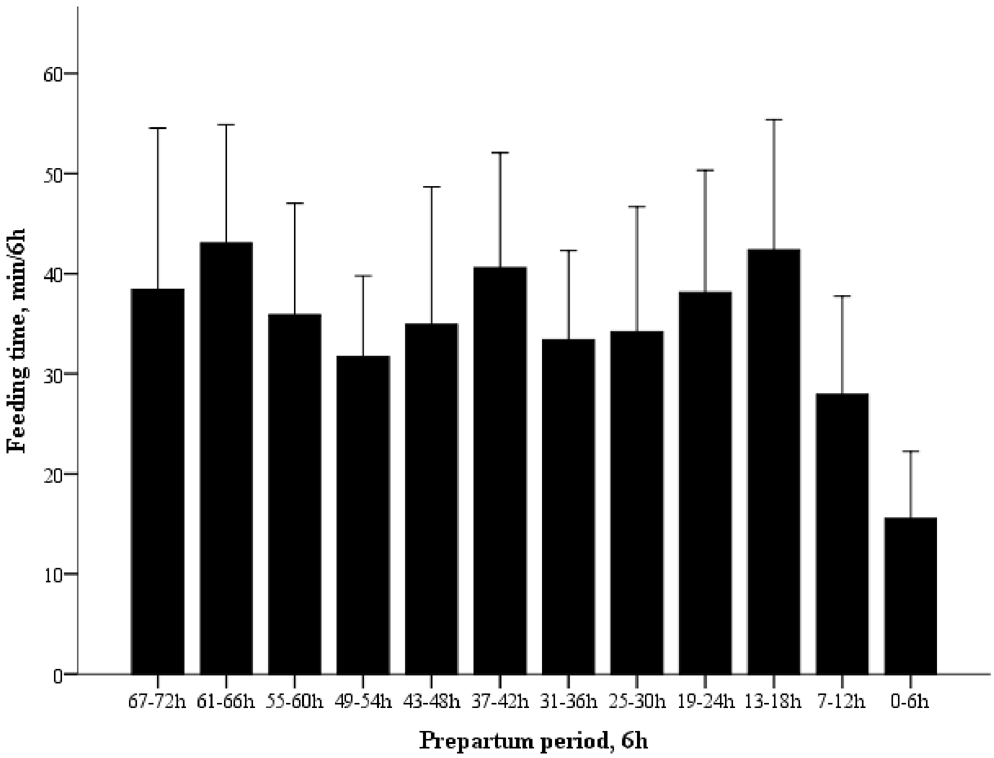

Figure 12. Variance of feeding time of dairy cows in min/6h during the last 72h before the onset of calving (mean; standard deviation). (n=17)

Variance of all 17 cows ranged from 115.5 min/6h to 0 min/6h for feeding time and from 11.9 kg/6h to 0 kg/6h for DMI within the reference period. For the last 6h before the onset of calving, variance ranged from 49.5 min/6h to 0 min/6h for feeding time and from 3.8 kg/6h to 0 kg/6h for DMI.

Associations between parameters of feeding behavior were different. Correlation coefficients (r) and coefficients of determination (R^2) between feeding time and DMI were on a high level (r = 0.81, R^2 = 0.66, n = 17, $P < 0.01$). However, between feeding time and RT, the correlation was weak (r = -0.085, R^2 = 0.007, $P > 0.05$) and not significant. Even between RT and DMI there was only a slight relationship in terms of a low, but significant negative correlation (r= -0.186, R^2 = 0.035, $P < 0.01$).

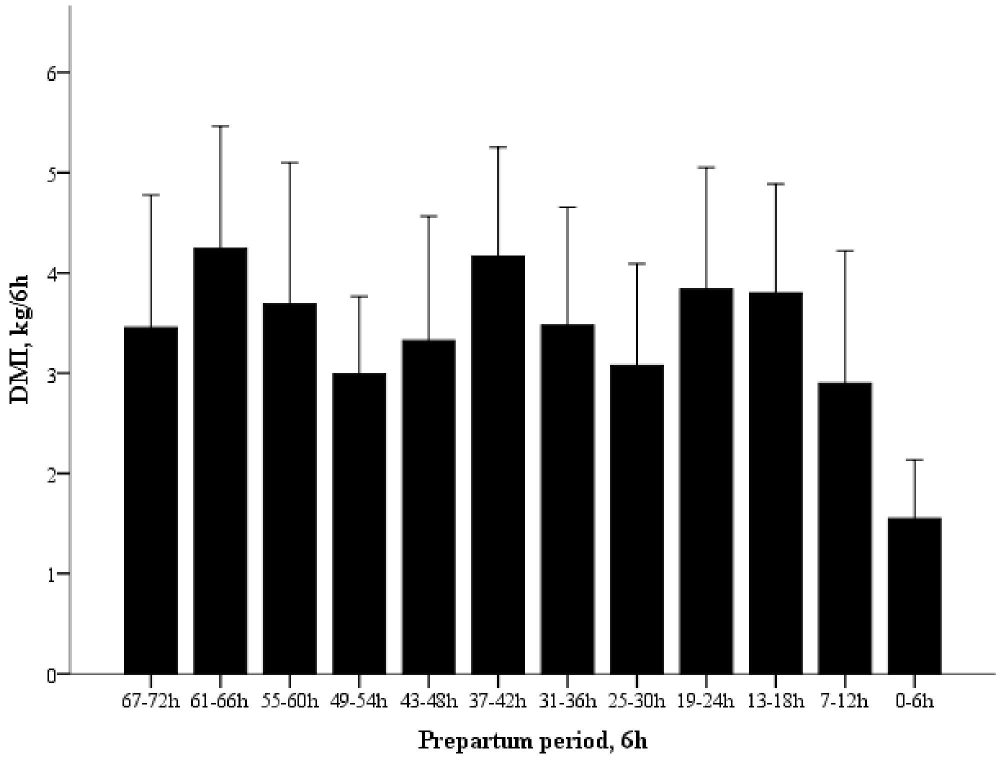

Figure 13. Variance of DMI of dairy cows in kg/6h during the last 72h before the onset of calving (mean; standard deviation). (n=17)

6.5 Discussion

To our knowledge, the current results of the relationship between rumination time and calving time have not been reported in previous studies. They demonstrate that RT was significantly influenced by the onset of calving. Exact classification of the onset of calving is difficult, because behavioral changes vary considerably, wherefore comprehensive training in calving management practices is necessary (Schuenemann et al., 2013). This fact may lead to the imprecise determination of the exact onset of calving and explains a possible shift of the last 6h before calving.

In the current study also feeding time and DMI were significantly influenced by the onset of calving. Reduction in feeding time and DMI is consistent with results of other studies. Bertics et al. (1992) recorded a reduction of 30% in DMI during the final week before calving. Journet and Remond (1976) observed a decrease of 0.2 kg voluntary DMI per week during the last six weeks of pregnancy. During the last week of pregnancy, the days of lowest DMI were the day before calving and the actual day of calving. Lukas et al. (2008) observed a decrease in DMI and water intake, which was associated with time of calving. According to Dado and Allen (1994), feeding time is strongly associated to DMI, which accords to the previous results. Urton et al. (2005) observed a decrease in time spent feeding of 35% over the final 2 weeks before calving. In the study of Huzzy et al. (2007), cows decreased feeding time in the last two weeks before calving.

The prepartum reduction in feeding time and DMI may be due to physical limitations related to pregnancy, as mentioned by Oetzel and Berger (1985), or to the hormonal status of the cow (Hansen et al., 2003). RT may also be affected by these factors, although there are currently no physiological explanations. Considering that feeding time and DMI are strongly associated to RT (Welch, 1982; Dado and Allen, 1994; Yang and Beauchemin, 2006), the demand for chewing the cud is reduced when feed intake decreases. However, due to the low correlation between DMI and RT, a reduced feed intake is not adequately explaining the reduced RT. On the other hand, RT may be reduced by endocrine changes shortly before calving. The estrogen concentration constitutes a diverse indicator for altered behavioral changes. A positive correlation between estrus behavior and total estrogen concentration ($r = 0.66$; $P < 0.0019$) has been observed by Mondal et al. (2006). This raised estrogen concentration during estrus affects feed intake and activity behavior (Phillips and Schofield et al., 1990; Arney et al., 1994), which are both negatively correlated to RT (Mondal et al., 2006). Besides decreased feed intake and increased activity behavior, there is, in addition, an increase in estrogen levels (Falter, 1999) shortly before calving, whereby RT might be affected.

There was not a decrease in RT and feeding time in all cows towards the onset of birth. DMI, however, was affected in all dairy cows. Variability of feeding behavior between cows was high. RT varied from +31% to -100%, feeding time from +24% to -100% and DMI varied from -15% to -100% among dairy cows. These results indicate a high, within-cow variability as well as a high variability between different cows. In addition, dairy cattle follow a specific diurnal pattern of feeding behavior (DeVries et al., 2003, Hosseinkhani et al. 2008).

Between RT and feeding time and between RT and DMI a weak negative correlation was observed. These results are comparable to those found by Schirmann et al. (2012). A negative relationship between RT and feeding time and DMI confirms the assumption that cows which ruminate more spend less time feeding, and that cows are not able to consume feed and ruminate at the same time (Schirmann et al., 2012). Statements of Welch (1982), Dado and Allen (1994), and Yang and Beauchemin (2006) about the strong positive relationship between feeding time and DMI to RT could not be confirmed by the previous results.

6.6 Conclusion

Within the last 6h before the onset of calving RT was significantly reduced compared to the reference period, which includes the 72-7h period before calving. Feeding time and DMI were also, on average, significantly reduced shortly before calving compared to the reference period. Thus, RT can be used as an early indicator for predicting the timing of birth. While feeding time and DMI are also indicate an approaching birth, they require extended equipment for the assessment of changes in cow behavior due to imminent delivery. Overall, the results of the relationship between RT and calving time constitute a new opportunity for predicting the timing of calving. However, further research is necessary to define accuracy, repeatability, sensitivity, and specificity of generated data with a higher number of dairy cows kept under various conditions to determine suitable, animal-individual reference values for RT decrease before the onset of calving.

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7 CONCLUSION

The measurement and consideration of feeding behavior of dairy cows offer a suitable and informative opportunity to observe the nutritional condition and health status of individual animals. Because impairments or changes in the normal condition are promptly reflected by altered feeding behavior, the continuous monitoring of chewing and rumination activity enables timely intervention with a focused response to the problem. Thus, the acquisition of feeding behavior data has gained a high priority.

In the comparison of different measurement tools for recording the feeding behavior of dairy cows in the special evaluation study, only the RumiWatchSystem achieved most of the required demands for reliable use in practice. Furthermore, the additional measurement systems, which have been developed up to now, show different inadequacies. This has led to the development of another system, which was intended to overcome most of the existing difficulties. The newly developed system named “DairyCheck” is based on electromyography, whereby measurement of single jaw movements is possible. This clear recording offers a wide range of opportunities for dairy management and is competitive in relation to the RumiWatchSystem and other measurement tools. The validation results show good and acceptable data values, but the limited automatic analysis software still indicates that there is ample room for improvement. In comparison to other measurement systems, the validation results of the DairyCheck system are described in detail and are, therefore, fully transparent and resilient. When compared with two additional measurement systems, the Lely Qwes HR sensor and the RumiWatchSystem, rumination data generated by DairyCheck are highly comparable to those detected by the RumiWatchSystem and are more reliable and valid than those measured by the Lely Qwes HR sensor. Thus, in relation to results formulated within the evaluation of different measurement methods, it may be inferred that DairyCheck also meets a lot of the required demands for the reliable measurement of valid feeding behavior data, as does the RumiWatchSystem. But user-friendly application in practice with this system has been restricted, until now. The analysis software and the algorithm are still not mature enough for commercial use, wherefore feeding behavior data are processed manually through visual assessment by the users themselves. Thus, suitable usage in practice depends upon further technical development with regard to achieve an automatic classification of feeding behavior by a reliable, viable and resilient algorithm.

The results of the application of DairyCheck when recording data for a specific question demonstrate suitable and appropriate scope in practice. The generated data demonstrate that rumination time was significantly influenced by the onset of calving and therefore might be an early indicator for prediction of the timing of birth. Even feeding time and feed intake were significantly influenced by the onset of birth and can be used for the detection of imminent delivery. But due to manual analysis by visual assessment, the system is far from ready to be successfully and easily applied in the facilitation of dairy farm management. The benefits of using this system do not outweigh the cost of it which confirms the necessity for further technical development. The findings of this study also encourage the assumption that feeding behavior can be useful for the early identification of changes in individual animals.

All trials show that feeding behavior is a considerable indicator for the detection of changes in cow behavior. But for successful recognition, data have to be analyzed individually per animal with the aid of corresponding reference values. Critical values have to be defined for rumination time, feeding time, and feed intake. These values facilitate the premature recognition of deviations in normal values which enables the analysis of possible interferences in feeding behavior, like an early warning system. Thus, a profound database has to be established, consisting of feeding behavior data representing healthy animals or animals at different stages of health impairments. But the determination of resilient reference values, alongside future technical development, is one of the most challenging tasks when striving to elevate DairyCheck into an appropriate and helpful management system within Precision Dairy Farming.

8 SUMMARY

The measurement of feed intake, feeding time and rumination time, summarized by the term feeding behavior, are helpful indicators for early recognition of animals which show deviations in their behavior. Impairments or changes in the normal condition are promptly reflected by altered feeding behavior, which may enable the identification of cows with suboptimal feeding conditions and possible health disorders. But, measurement systems which are available for cow monitoring do not meet all of the requirements for optimal observation of cow feeding behavior. The inadequacies of different systems and the importance of measuring feeding behavior brought about the development of a new measurement system, called DairyCheck. The overall objective of this work was the development of an early warning system for inadequate feeding rations and digestive and metabolic disorders, which prevention constitutes the basis for health, performance, and reproduction.

In a literature review, the current state of the art and the suitability of different measurement tools to determine feeding behavior of ruminants was discussed. There are a various measurement devices with different stages of development and practical usage, but their reliability is variable. Five measurement methods based on different methodological approaches (visual observance, pressure transducer, electrical switches, electrical deformation sensors and acoustic biotelemetry), and three selected measurement techniques[1] (the IGER Behavior Recorder, the Hi-Tag rumination monitoring system and RumiWatch-System) were described, assessed and compared to each other within this review. The three selected techniques are currently commercially available, and for this reason they were commented on and assessed more specifically in regard to their applicability and functionality. Evaluation of measurement methods and techniques took place through assessment based on the following defined scientific criteria: accuracy, reproducibility, sensitivity and specificity, applicability and functionality. Within the evaluation and according to the specifically defined criteria, the pressure transducer measurement method met the requirements for a reliable and usable method for automatic measurement of feeding behavior to a higher degree than the others. Within the evaluation of measurement techniques, the RumiWatchSystem achieved most of the demands and is, therefore, the most developed technique for reliable use in practice. The different methods and techniques showed a number

[1] Within the first study of this work, measurement systems are consistently designated as measurement techniques, due to better contextual unification.

of options, but also some disadvantages with regard to the reliable observation of the chewing and rumination activity of dairy cows. Above all, the definition of individual reference values for each animal so that deviations from normal feeding behavior conditions can be more easily detected should be further researched.

In the second study, the new system for measuring feeding behavior of dairy cows was evaluated. The sensor-based system DairyCheck consists of a halter with two incorporated electrodes, a data logger, power supply, and evaluation software. The measurement of feeding behavior ensues through electromyography (EMG), whereby electrical potential oscillations during jaw movements are recorded. Generated data are transmitted directly via radio transmission to a computer with automatic evaluation software. The analysis software and the algorithm are still under development with regard to achieving an automatic classification of feeding behavior, for what reason data are up to now processed manually by visual assessment of their specific graphic profiles by the researchers themselves. For validation, the feeding behavior of 14 cows was determined by both the EMG system and by visual observation. Results of the correlation between rumination times measured electronically and by visual observation were high (r = 0.86, R^2 = 0.74, $P < 0.001$), even results of the correlation between feeding time measured electronically and by visual observation were high (r = 0.87, R^2 = 0.75, $P < 0.001$). The results indicate that the current system is a reliable and suitable tool for monitoring the feeding behavior of dairy cows. But further progress and research are necessary, especially for automatic data interpretation with a self-learning algorithm.

The aim of a further study was to compare the DairyCheck (DC) system and two additional measurement systems for measuring feeding behavior in relation to efficiency, reliability and reproducibility, with respect to each other. The two additional systems were selected as a consequence of the market maturity they have achieved, their respective application, and their usability for research or practice. They were labeled as the Lely Qwes HR (HR) sensor, and the RumiWatchSystem (RW). Rumination time of nine dairy cows was recorded in two trials. In trial 1, rumination time as determined by both the DC system and by the HR sensor was analyzed. In trial 2, rumination time as determined by both the RW system and by the HR sensor was examined. Results indicated that data generated by both the DC system in trial 1 (total mean of RT per 24h for all cows of 530 ± 60 min) and the RW system in trial 2 (total mean of RT per 24h for all cows of 546 ± 54 min) were clearly different in comparison to those detected by the HR sensor in trial 1 (total mean of RT per 24h about all cows of 399 ± 148 min) and in trial 2 (total mean of RT per 24h for all cows of 413 ± 148 min). Rumination time during one day deviated an average of 131 (DC) and 133 (RW) minutes from those detected by the HR sensor. Results of accordance of RW and DC to each other were high. These results are clearly more consistent than those detected with the HR sensor and indicate that the DC and RW systems are the most common and useful tools for reliably recording rumination behavior. But for all three of the systems mentioned, further progress and research are necessary to reduce their individual disadvantages. For the DC system the implementation of analysis software for automatic data interpretation should be one of the next steps. To increase the comfort of the RW halter for the cows, the material used should be adapted. The major challenge for the HR sensor is to ensure optimal positioning of the acoustic tag on the neck collar, to generate valid data.

The last study examined whether rumination time (RT) is affected by the onset of calving and if it might be a useful indicator for the prediction of imminent birth. In addition, the relationship between feeding time and dry matter intake (DMI) to imminent birth was assessed. Under test conditions, feeding behavior of 55 non-lactating dairy cows was recorded from the time they were moved into the calving pen (usually 7-5 days prepartum) until initial calving. Feeding time and DMI were recorded by automatic feed bins; rumination time was measured by the DairyCheck system. Data analysis referred to the final 72h before the onset of calving, which were divided into twelve 6h-blocks. The last 6h (one 6h-block) before calving were compared to the time period 72-7h (eleven times 6h-blocks) before calving, which was defined as the reference period. Primarily, premature deliveries after moving into the calving pen which enabled the application of the measuring halter for less than 3 days, beside data losses with the feed bins and the measuring halters, were the reasons why only 17 data sets of feeding behavior of dairy cows were available. The results showed that RT was significantly reduced in the final 6h before imminent birth. During this time, mean minimum RT of 69.9 ± 28.5 min/6h compared to mean minimum RT of 95.5 ± 30.8 min/6h in the reference period was found. The average decrease was 27% (25.6 min/6h). Feeding time and DMI were also significantly reduced. The average decrease of feeding time was 57% (20.8 min/6h), and of DMI 56% (1.9 kg/6h). High correlation coefficients between characteristics of feeding behavior were found only between feeding time and DMI. Values of feeding behavior among cows were characterized by a high variability. Thus, recording RT can serve as a useful tool for the prediction of the timing of birth for dairy cows. The next step of further development should be to define accuracy, repeatability, sensitivity, and specificity of generated data with a higher number of dairy cows kept under various conditions. This would enable the determination of suitable, animal-individual reference factors for RT decrease before the onset of calving.

Overall, the DairyCheck system is suitable for monitoring the feeding behavior of dairy cows. The clear acquisition of data by the EMG system through the recording of single jaw movements offers a wide spectrum of surveillance methods of individual animals. But this requires accurate automatic analysis software for successful application in practice. Furthermore, corresponding reference values for the safe identification of changes in the condition of cows have to be initiated. These critical values have to be defined for rumination time, feeding time, and feed intake to facilitate the identification of deviations in normal values to recognize possible decreases in nutritional condition or impairments to health status. Both aspects mentioned, require further research to improve and develop DairyCheck into an appropriate and helpful management system within the field of Precision Dairy Farming.

9 ZUSAMMENFASSUNG

Die Erfassung der Futteraufnahme, der Fresszeit und der Wiederkäuzeit, welche als Fressverhalten charakterisiert werden, sind hilfreiche Indikatoren für die frühzeitige Erkennung von Tieren mit Verhaltensveränderungen. Beeinträchtigungen oder Veränderungen des Normalzustandes werden direkt durch ein geändertes Fressverhalten reflektiert, welches die Identifikation von Kühen mit suboptimalem Fressverhalten und möglichen Gesundheitsstörungen ermöglicht. Jedoch erfüllen Messsysteme, welche für ein optimales Kuh-Monitoring des Fressverhaltens einsetzbar sind, nicht alle erforderlichen Voraussetzungen dessen. Diese Unzulänglichkeiten verschiedener Systeme und die Bedeutung der Erfassung des Fressverhaltens führten zu der Entwicklung eines neuen Messsystems welches als DairyCheck bezeichnet wird. Das Gesamtziel dieser Arbeit war die Entwicklung eines Frühwarn-Systems für inadäquate Futterrationen und Verdauungs- sowie Stoffwechselstörungen, dessen Prävention die Basis für Gesundheit, Leistung und Reproduktion bildet.

In einer Literaturstudie wurden der aktuelle Stand der Technik und die Eignung verschiedener Messinstrumente zur Bestimmung des Fressverhaltens von Wiederkäuern diskutiert. Es gibt eine Vielzahl von Messmöglichkeiten, die sich in unterschiedlichen Stufen der Entwicklung und der Praktikabilität befinden und deren Zuverlässigkeit sehr verschieden ist. Fünf Messmethoden, die unterschiedlichen methodischen Ansätzen unterliegen (Visuelle Erfassung, Druck-Transducer, Elektrische Schalter, Elektrische Deformationssensoren und Akustische Biotelemetrie) und drei aus diesen ausgewählte Messtechniken[2] (Der IGER Behavior Recorder, das Hi-Tag Wiederkäu-Erfassungssystem und das RumiWatchSystem) wurden innerhalb der Studie beschrieben, bewertet und miteinander verglichen. Die drei ausgewählten Messtechniken sind bereits kommerziell erwerblich, aus welchem Grund diese hinsichtlich ihrer Funktionalität und Verwendbarkeit genauer erläutert und bewertet wurden. Die Beurteilung der Messsysteme und –techniken erfolgte durch die Bewertung anhand folgender definierter wissenschaftlicher Kriterien: Genauigkeit, Reproduzierbarkeit, Sensitivität und Spezifität, Verwendbarkeit und Funktionalität. Innerhalb dieser Bewertung und übereinstimmend mit den eigens definierten Kriterien, erfüllte die Messmethode der Druck-Trancducer hinsichtlich einer zuverlässigen und anwendbaren Methode zur automatischen Erfassung des Fressverhaltens, diese zu einem höheren Grad

[2] Innerhalb der ersten Studie dieser Arbeit werden Messsysteme aufgrund einer besseren kontextualen Zuordnung durchgehend als Messtechniken bezeichnet.

als andere. Innerhalb der Evaluation der Messtechniken erfüllte das RumiWatchSystem den größten Teil der Anforderungen und ist demnach die am weitesten entwickelte Technik für einen zuverlässigen Gebrauch in der Praxis. Die verschiedenen Methoden und Techniken zeigten eine Vielzahl von Optionen, jedoch auch einige Nachteile hinsichtlich einer zuverlässigen Erfassung des Kau- und Wiederkäuverhaltens von Milchkühen. Insbesondere die Definition individueller Referenzwerte für Einzeltiere zur einfacheren Erkennung von Abweichungen vom normalen Fressverhalten sollten weiterhin Gegenstand der Forschung sein.

In der zweiten Studie wurde ein neues Messsystem zur Erfassung des Fressverhaltens von Milchkühen evaluiert. Das Sensor-basierende System DairyCheck besteht aus einem Halfter mit zwei integrierten Elektroden, einem Datenlogger, einer Energieversorgung und einer Auswertungssoftware. Die Erfassung des Fressverhaltens erfolgt durch Elektromyografie (EMG), wobei elektrische Potentialschwankungen während der Kaubewegungen erfasst werden. Generierte Daten werden umgehend via Funkübermittlung an einen Computer mit einer automatischen Auswertungssoftware übermittelt. Die Auswertungs-Software und der Algorithmus befinden sich derzeit in der Entwicklung hinsichtlich einer automatischen Klassifizierung des Fressverhaltens, weshalb Daten bisher manuell durch eine visuelle Bewertung anhand des jeweiligen grafischen Profils durch die Anwender selbst ausgewertet werden. Für die Validierung wurde das Fressverhalten von 14 Milchkühen sowohl durch das EMG-System als auch durch visuelle Beobachtung bestimmt. Die Ergebnisse bezeugen eine starke Korrelation zwischen der elektronisch und visuell erfassten Wiederkäuzeit ($r = 0.86$, $R^2 = 0.74$, $P < 0.001$); auch die Ergebnisse der Fresszeiten, welche elektronisch und visuell erfasst wurden, bescheinigen eine enge Korrelation beider Erfassungsmethoden zueinander ($r = 0.87$, $R^2 = 0.75$, $P < 0.001$). Die Ergebnisse indizieren, dass das aktuelle System ein zuverlässiges und zweckmäßiges Hilfsmittel zur Erfassung des Fressverhaltens von Milchkühen ist. Jedoch bedarf es weiterer Entwicklung und Forschung, insbesondere für die automatische Interpretation von Daten mit Hilfe eines selbstlernenden Algorithmus.

Das Ziel einer weiteren Studie war der Vergleich des DairyCheck (DC) Systems mit zwei weiteren Messsystemen zur Erfassung des Fressverhaltens hinsichtlich Effizienz, Zuverlässigkeit und Reproduzierbarkeit. Die zwei weiteren Systeme wurden als Konsequenz ihrer erreichten Marktfähigkeit, der jeweiligen Anwendbarkeit und Brauchbarkeit für Forschung und Praxis ausgewählt. Die Systeme waren der Lely Qwes HR (HR) Sensor und das RumiWatchSystem (RW). Die Wiederkäuzeit von neun Milchkühen wurde innerhalb von zwei Versuchen aufgezeichnet. Im ersten Versuch wurde die Wiederkäuzeit gleichzeitig sowohl vom DC System als auch vom HR Sensor erfasst. Im zweiten Versuch wurde die Wiederkäuzeit gleichzeitig sowohl vom RW System als auch vom HR Sensor aufgezeichnet. Die Ergebnisse deuteten darauf hin, dass sich die Daten, welche im Versuch 1 mit dem DC System (mittlere tägliche Wiederkäuzeit aller Kühe von 530 ± 60 Min.) und im Versuch 2 mit dem RW System (mittlere tägliche Wiederkäuzeit aller Kühe von 546 ± 54 Min.) erfasst wurden, deutlich von denen unterscheiden, welche im Versuch 1 (mittlere tägliche Wiederkäuzeit aller Kühe von 399 ± 148 Min.) und im Versuch 2 (mittlere tägliche Wiederkäuzeit aller Kühe von 413 ± 148 Min.) mit dem HR Sensor erfasst wurden. Die Wiederkäuzeit pro Tag wich im Mittel um 131 (DC) und 133 (RW) Minuten von den Tageswerten, welche mit dem HR Sensor generiert wurden ab. Die Übereinstimmung zwischen den Ergebnissen von RW und DC waren hoch. Diese Ergebnisse sind daher deutlich konsistenter als jene, welche mit dem HR Sensor erfasst wurden und indizieren diese Systeme auch als deutlich gebräuchlichere und nutzbarere Hilfsmittel für eine zuverlässige Überwachung des Wiederkäuverhaltens. Jedoch bedarf es zur Reduzierung individueller Schwachstellen aller drei genannten Systeme weiterer Entwicklung und Forschung. Für das DC System sollte die Implementierung einer automatischen Analyse-Software zur Datenauswertung einer der nächsten Schritte sein. Um den Komfort des RW Halfter hinsichtlich der Kühe zu verbessern, sollte das eingesetzte Material dementsprechend angepasst werden. Die größte Herausforderung für den HR Sensor stellt die Gewährleistung einer optimalen Positionierung des Akustik-Tags am Halsband zur Generierung valider Daten dar.

In der letzten Studie wurde untersucht ob die Wiederkäuzeit durch den Beginn der Abkalbung beeinträchtigt wird und somit als Indikator zur Vorhersage der unmittelbar bevorstehenden Geburt genutzt werden kann. Zusätzlich wurde die Beziehung zwischen der Fresszeit und der Trockenmasse (TM) -Aufnahme zur bevorstehenden Abkalbung untersucht. Unter standardisierten Bedingungen wurde das Fressverhalten von 55 hochtragenden Milchkühen, vom Zeitpunkt an welchem sie in den Abkalbestall gebracht wurden (normalerweise 7-5 Tage prepartum) bis zum Beginn der Abkalbung, erfasst. Die Fresszeit und die TM-Aufnahme wurden durch automatische Fresswiegetröge ermittelt; die Wiederkäuzeit wurde durch das DairyCheck System erfasst. Die Datenanalyse bezog sich auf die letzten 72h vor dem Beginn der Abkalbung, welche in zwölf 6h-Blöcke unterteilt wurden. Die letzten 6h (ein 6h-Block) vor der Kalbung wurden mit der Zeitperiode von 72-7h (elf 6h-Blöcke) vor der Kalbung, welche als Referenzzeit bezeichnet wurde, verglichen. Hauptsächlich führten verfrühte Abkalbungen von Tieren die in den Abkalbestall verbracht wurden, so dass eine Applikation des Messhalfters von weniger als drei Tagen umsetzbar war, neben Datenverlusten der Fresswiegetröge und Messhalfter dazu, dass insgesamt nur 17 vollständige Datensätze des Fressverhaltens von Milchkühen zur Verfügung standen. Die Ergebnisse zeigten, dass die Wiederkäuzeit in den letzten 6h vor dem Beginn der Abkalbung signifikant reduziert war. Während dieser Zeit lag die mittlere Wiederkäuzeit bei 69.9 ± 28.5 min/6h verglichen zu einer mittleren Wiederkäuzeit von 95.5 ± 30.8 min/6h innerhalb der Referenzzeit. Der durchschnittliche Rückgang lag bei 27% (25.6 min/6h). Auch die Fresszeit und die TM-Aufnahme waren signifikant reduziert. Der mittlere Rückgang der Fresszeit lag bei 57% (20.8 min/6h), der der TM-Aufnahme im Mittel bei 56% (1.9 kg/6h). Hohe Korrelationskoeffizienten zwischen Charakteren des Fressverhaltens wurden nur zwischen der Fresszeit und der TM-Aufnahme gefunden. Zwischen den Kühen waren die Werte des Fressverhaltens durch eine hohe Variabilität gekennzeichnet. Die Erfassung der Wiederkäuzeit kann demnach als nützliches Hilfsinstrument zur Vorhersage der unmittelbar bevorstehenden Abkalbung von Milchkühen genutzt werden. Im nächsten Schritt der Entwicklung sollten Genauigkeit, Reproduzierbarkeit, Sensitivität und Spezifität der ermittelten Daten mit Hilfe einer größeren Anzahl von Tieren unter unterschiedlichen Bedingungen definiert werden. Dies wiederum ermöglicht dann die Bestimmung angemessener, tier-individueller Referenzwerte für einen Rückgang der Wiederkäuzeit unmittelbar vor der Abkalbung.

Generell ist DairyCheck ein geeignetes System zur Überwachung des Fressverhaltens von Milchkühen. Die eindeutige Erfassung von Daten des EMG Systems durch die Aufzeichnung einzelner Kaubewegungen ermöglicht ein weites Spektrum an Kontrollmöglichkeiten für das Einzeltieres. Dies erfordert jedoch eine exakte automatische Auswertungssoftware für eine erfolgreiche Anwendung innerhalb der Praxis. Weiterhin sollten entsprechende Referenzwerte für eine zuverlässige Identifizierung von Zustandsveränderungen von Kühen eingeführt werden. Diese kritischen Werte sollten sowohl für Wiederkäuzeiten, Fresszeiten als auch für Futteraufnahmen definiert werden, wodurch eine Erkennung von Abweichungen vom Normalzustand, die auf verschlechterte Ernährungszustände oder Gesundheitsbeeinträchtigungen hindeuten, erleichtert wird. Beide genannten Aspekte erfordern weitere Untersuchungen zur Verbesserung und um DairyCheck in ein angemessenes und hilfreiches Managementsystem des Precision Dairy Farming zu entwickeln.

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I herewith give assurance that I completed this dissertation independently without prohibited assistance of third parties or aids other than those identified in this dissertation. All passages that are drawn from published or unpublished writings, either word-for-word in paraphrase, have been clearly identified as such. Third parties were not involved in the drafting of the material content of this dissertation; most specifically I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.

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Witzenhausen, October 2013

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