Bachelor thesis

Validation of measurement system, 'EquiWatch', for automatic measurement of equine chewing activity in horses: a pilot study

Author Iris Buiting

Date 29 June, 2015

Bachelor thesis

Validation of measurement system, 'EquiWatch', for automatic measurement of equine chewing activity in horses: a pilot study

Author:	Iris Buiting	iris.buiting@wur.nl
Student number:	940917001	
Educational institute:	Hogeschool van Hall Larenstein	
Major:	Equine, Leisure and Sports	
School year:	2014-2015	
Commissioned by:	Pavo	
Supervisor VHL:	Sandra van Iwaarden	sandra.vaniwaarden@wur.nl
Supervisor Pavo:	Rob Krabbenborg	rob.krabbenborg@pavo.net
Date:	29 June, 2015	

Preface

You are now starting to read my bachelor thesis, about the validation of the EquiWatch, which was commissioned by the equine feed company Pavo. This thesis was written as part of my education Equine, Leisure and sports, which is a major of the bachelor study Animal Husbandry at the Hogeschool Van Hall Larenstein in Wageningen.

During my graduation project I researched the validation of the measurement system, EquiWatch, developed for the measurement of chewing activity in horses. After a period of performing test measurements I found out that the tool was not as far in its development as we had expected and that it was not, yet, suitable for the research that we had planned to do. After a couple consultations with my supervisors a new research was born to help the developers optimize the tool. This all caused a little delay but I have still experienced it as a good and interesting period.

Therefore, I would like to thank my supervisor Rob Krabbenborg, from Pavo, for giving me the opportunity to work with the EquiWatch and perform this research. I also would like thank him for this supervision and support during the entire period.

Secondly I would like to thank my thesis coach, Sandra van Iwaarden, for her help, support and thinking along during my graduation period.

Also many thanks go to thank family Boelsma having me at their riding school, Manege & ponykamp de Burght.

I also would like to thank Wim and Gerry Hoksbergen for letting me perform my first trials and test of the research on their horses.

Last but not least I would like to thank my family and friends for their unconditional support.

I hope you enjoy reading my bachelor thesis as much as I enjoyed performing this research.

Iris Buiting

Groessen, 29 June, 2015.

Summary

In comparison to feral horses which spend 12-16 hours with feed intake behaviour (Zeitler-Freicht, 2008) and travel up to 28 km a day (Hampson et al., 2010), nowadays management of the horse by humans has shortened its feeding time and introduced unfamiliar feed types, especially cereals containing a large amount of starch, protein concentrates and dried forages (Frape, 2010). The lack of chewing activity in horses can cause many health and welfare related problems in horses like stomach ulcers, colic, development of stereotypical behaviour and dental problems. Therefore, chewing activity of horses is an important parameter for health and welfare monitoring in horses (Werner et al., 2014)

Research into the registration of equine chewing activity was performed by Werner et al. (2014) with an originally developed, sensor-based automatic measurement system for cattle called RumiWatch (developed by Research centre Agroscope and Itin+Hoch) to determine the feasibility to use this system for horses. The results of this research have shown that it is feasible to use this system for horses but that it needs to be refined in further research projects in order to be used as a reliable monitoring tool.

An additional research with an adapted version of the RumiWatch, named EquiWatch, was performed by Zehner et al. (2014). The EquiWatch is an adapted version of the RumiWatch, but the halter is only adapted in its form and shape so that is suites the horse better and prevents the horse from getting wounds during long periods of wearing the halter. This research was performed to test the fundamental suitability of the EquiWatch for the registration of chewing activity in horses in a preliminary research.

In the first instance a study was set up, commissioned by the Dutch Equine feed company Pavo, to look for differences in chewing activity in horses housed in different housing situations, according to 48 hour measurements with the EquiWatchSystem. However, according to the results of the research performed by Zehner et al. (2014) who stated that a comprehensive development and validation of analysis algorithms and the development of analysis software were required and according to several test measurements performed by the investigator performing this study, it was decided to do not perform this research in this setting because the reliability of the results of this research would be low.

As a follow up of the two investigations (by Werner et al., 2014 and Zehner et al. (2014) mention before, the following study was set up, instead of the research into differences in chewing activity in horses housed in different housing situations, to validate the measurement system EquiWatch, which is the adapted version of the, in 2013 for cattle developed, RumiWatch. The RumiWatch halter has

been adapted in its form and shape so that it suits the horse better and prevents the horse from getting wounds on its head while wearing the halter for longer periods of time. This new formed and shaped halter is named the EquiWatch. Furthermore, the evaluation software (RumiWatchManager and RumiWatchConverter) that has to be used, to analyse the registered data, is still the same and still classifies eating, drinking, other activities and ruminating. As horses do not ruminate and differ from cattle in their chewing and eating behaviour the EquiWatch needed to be further validated to find out whether the tool is suitable for the registration of chewing activity in horses

The aim of this research was to validate the EquiWatch as is a suitable tool for measuring equine chewing activity.

This study has been set up in two separate trials to validate the EquiWatch system in two different settings. In the first trial the number of chewing movements (CM) registered by the EquiWatchSystem were compared with the number of chewing movements (CM) counted by visual observation to investigate the reliability of the counted chewing movements (CM). The chewing movements (CM) of horses were counted visually by an observer during 5 periods of 10 minutes in 3 horses. These visually counted chewing movements (CM) were later on compared to the number of chewing movements registered within the observed 10-minute periods by the EquiWatch system. In the second trial the oral behaviour of the horses has been observed and videotaped to investigate if the classification of the oral movements of horses is comparable with the classifications made by the software used to analyse the data. The oral behaviour of 5 horses was filmed for 15 to 30 minutes. The videos were analysed and the performed behaviour of the horses was compared with the raw data output of the EquiWatch. After this was done it was calculated in how often the observations of the oral behaviour of the horses was identical classified by the evaluation software, RumiWatchConverter, of the EquiWatch.

The results of the first trial indicate that there were movements of the horse its jaw registered automatically as chewing movements, which were not counted as chewing movements by visual observation. These movements of mandibular motion could be other oral behaviours such as licking, biting or cribbing.

The results of the second trial demonstrate that more than half of the observations of the oral behaviour of horses are classified differently by the RumiWatchConverter. The classification ''eating'' by the RumiWatchConverter was given for 147 observations, when in 48 of the cases the horses were actually showing eating behaviour. This substantiate that there are oral behaviours performed by the horses that cause jaw movements, which are registered as chewing movements, which are actually not chewing movements.

In conclusion, based on the outcome of this study, further research with the EquiWatch is necessary to develop a more suitable and reliable measurement system for the registration of equine chewing activity. To increase the reliability of the EquiWatch, the registration of chewing activity needs to be optimized and the evaluation software needs to be changed to make it more suitable for horses. The analysing algorithm, developed for cattle, needs to be adapted to consider the specific eating and chewing behaviour of horses.

Table of content

Abbreviations

%	per cent
&	and
<	Less than
Am	morning
aut	automatic
BW	body weight
BCS	Body condition Score
CM	Chewing Movements
Cm	centimetre
Cm^3	cubic centimetre
Csv-file	Comma separated values file
DM	dry matter
e. g.	For instance
EO	essential oil
et al	and others
fig	figure
g	gram
GmbH	Company with limited liability
H	hour
Hz	Hertz (1/Second)
I.e.	that is
JM	Jaw Movements
Km	kilometre
L	litter
Mg	milligram
Mm	millimetre
KWPN	Royal Dutch Sport Horse
N	number
NDF	neutral Detergent Fibre
P	P is a value of significance
PH	power of hydrogen
Pm	Afternoon
RWU	RumiWatchUnit
RWU-ID	RumiWatch Unit-number
RWU-file	RumiWatchUnit- file with raw data output
Sum	summary
V	volt
vis	Visual
vs.	Versus
WM	wet matter

List of tables

List of figures

1. Introduction

Chewing activity of horses is an important parameter for health and welfare monitoring (Werner et al., 2014). A lack of chewing activity in horses can cause many health and welfare problems like stomach ulcers, colic, stereotypical behaviour and dental problems. The chewing activity in horses is depending on several different factors, for instance the amount and the type of nutrition they get but also the amount of feeding bouts per day and their housing situation are important factors that influence the chewing activity in horses (Ellis, 2004; Houpt et al., 2004;Meyer et al, 1975)

From an evolutionary point of view wild horses have evolved and adapted to a grazing and browsing existence, in which they select juicy forages containing relatively large amounts of water, soluble proteins, lipids, sugars and structural carbohydrates, but little starch. Short feeding periods occur throughout day and night (Frape, 2010). This results in a continuous intake of low energy and high fibre feed during different feeding bouts. During the evolution of the horse its body is well adjusted to these feeding conditions, including its gastro intestinal tract.

In comparison to feral horses which spend 12-16 hours with feed intake behaviour (Zeitler-Freicht, 2008) and travel up to 28 km a day (Hampson et al., 2010), nowadays management of the modern horse by humans has shortened its feeding time and introduced unfamiliar feed types, particularly cereals with a starchy content, protein concentrates and dried forages (Frape, 2010). Shortened feed intake time and missing activity in their feeding behaviour may lead to physiological and ethological problems in equine health and welfare (Werner et al., 2014).

Research was performed by Werner et al. (2014) with an originally developed, sensor-based automatic measurement system for cattle called RumiWatch (developed by Research centre Agroscope and Itin+Hoch) to determine the feasibility of this system for registration of equine chewing activity. The results of this research have shown that it is feasible to use this system for horses but that it needs to be refined in further research projects in order to be used as a reliable monitoring tool.

The RumiWatch system consist out of a pedometer, noseband sensor and evaluation software and is an appropriate tool for the recording of ruminating, eating, drinking and motion behaviour in dairy cows. The first version of the RumiWatch was developed in 2010. Zehner et al. (2012) did research to the validation of the RumiWatch. The results of this research have shown that the RumiWatch is suitable for research and advisory purposes in dairy cows and that further research is necessary to ad threshold values (“alert values”) and for the detection of health condition changes (“healthy”, “affected”, “sick”) so that the system is able to warn the owner about the health state of the animal.

The research performed by Werner et al. (2014) was done with the noseband sensor of the RumiWatch used on horses to identify the differences between horses and cattle in chewing activity with the purpose to adapt the RumiWatch system to horses. Under the same conditions 10 horses were observed visually, six times for a period of 10 minutes, to evaluate the precision of the automatic measurement system. The results of direct observation were compared to the automatic evaluation of eating times and number of eating chewing movements generated by the noseband sensor. The direct visual observations were carried out while horses where eating roughage. The results of this study by Werner et al. (2014) have shown that it is feasible to use the automated measurement system RumiWatch for horses. The average deviation between visual and automatic observations is approximately 8% in total. This is highly encouraging regarding the fact that the system was developed for cows. Nevertheless, the system needs to be refined in further research projects in order to be used as a reliable monitoring tool.

An additional research with an adapted version of the RumiWatch, named EquiWatch, was performed by Zehner et al. (2014). The EquiWatch is an adapted version of the RumiWatch, but the halter is only adapted in its form and shape so that is suites the horse better and prevents the horse from getting wounds during long periods of wearing the halter. This research was performed to test the fundamental suitability of the EquiWatch for the registration of chewing activity in horses in a preliminary research.

In the first instance a study was set up, commissioned by the Dutch Equine feed company Pavo, with the aim to look for differences in chewing activity in horses housed in different housing situations, according to 48 hour measurements with the EquiWatchSystem. However, according to the results of the research performed by Zehner et al. (2014) who stated that a comprehensive development and validation of analysis algorithms and the development of analysis software were required and according to several test measurements performed by the investigator performing this study, it was decided to do not perform this research in this setting.

As a follow up of the two investigations (by Werner et al., 2014 and Zehner et al. (2014) mention before, the following study was set up, instead of the research into differences in chewing activity in horses housed in different housing situations, to validate the measurement system EquiWatch, which is the adapted version of the, in 2013 for cattle developed, RumiWatch. This was done because Pavo aims to do more research in equine chewing activity with the use of this system. The overall final goal of Pavo is to be able to perform measurements on equine chewing activity of a period of 24 hours or longer. The RumiWatch halter has been adapted in its form and shape so that it suits the horse better and prevents the horse from getting wounds on its head while wearing the halter for longer periods of time. This new formed and shaped halter is named the EquiWatch. Furthermore, the evaluation software (RumiWatchManager and RumiWatchConverter) that is available, to analyse the registered data, is still the same and still classifies eating, drinking, other activities and ruminating. As horses do not ruminate and differ from cattle in their chewing and eating behaviour the EquiWatch needed to be further validated to find out whether the tool is suitable for the registration of chewing activity in horses. In this way the EquiWatch can be further developed and adapted if necessary so it becomes a reliable to for health and welfare monitoring in horse for Pavo, but also for other interested parties such as for instance equine scientists, equine veterinarians and equine dentists.

1.1 Problem definition and research objective

The problem that is investigated in this study is the fact that little knowledge is present about the fact if the EquiWatch is suitable for measuring equine chewing activity.

The aim of this research is to validate the EquiWatch as is a suitable and reliable tool for measuring equine chewing activity.

Research questions:

1. Is the EquiWatch a suitable tool for measuring equine chewing activity?

2. Do visually counted chewing movements in horses correspond to the automatic registered chewing movements by the EquiWatch?

3. Are the oral behaviours performed, according to visual observation, by the horse classified in the identical category by the evaluation software, RumiWatchConverterer?

2. Literature review

2.1 Evolution of the modern horse: from *Eohippus* to *Equus Caballus*

The first horses are traced back about 50 to 60 million years ago. These ancestors of the horse were known as *hyracotherium* (also known as eohippus, or 'dawn horse') and looked like a small fox like animal. It was an herbivore that lived in the tropical forests of North America and was 14 inches high at the shoulder (Davies, 2005).

The defining moment in the evolution of the horse occurred approximately 27 million years ago. The horse's ancestors had to move onto the plains, adapting to the new environment in a number of ways (Davies, 2005). Changes in global climate produced drier grasslands and pains and changes in their genetic makeup helped these ancestors of the horse to adapt to their new diets. Grass plant cells contain a complex carbohydrate named cellulose which is basically indigestible to all mammals also for horses unless they develop some way of breaking down cellulose to unlock the nutrients contained within.

Grass also contains a hard substance named silica and therefore grazing horses needed to evolve teeth which were able to grind the herbage containing silica. To be able to house the longer grinding teeth the head of the horses became bigger and the depth of the jaw increased to house more powerful muscles for 'grinding' as well. Additionally, the jaws became sideways moving to create a more efficient break down of the fibrous food. The teeth became higher crowded and coated with cement and later on they started to continuously grow. To allow the animal to reach down and graze its neck became longer as well as its limbs allowing them to run faster away from predators (Davies, 2009).

These modern horse's ancestors, known as *merychippus and parahippus*, stood firmly on a single middle toe with toes on the side that were semi-functional. These ancestors were approximately 42 inches high (Davies, 2005).

Not only the exterior of the horses adapted to its habitat but the digestive system also evolved in different ways to adapt to its new diet. A symbiotic arrangement with millions of microbes has arisen in the hindguts of most herbivores. These microbes are able to produce an enzyme which breaks down cellulose that is contained in plant cell walls and cannot be otherwise digested.

In turn the horse provides an environment in which the microbes can live in a specialized digestive area. These large areas for fermentation where evolved by most herbivores within the gut in which the bacteria live and ferment the plant material anaerobically (i.e. in the absence of oxygen) which is ingested by the horse.

The ruminant stomach in cows has developed into a large multi-compartmented section of the digestive tract known as the fore stomachs. The most well-known stomach of these is the rumen, but also the reticulum, omasum and abomasum support fermentation in cows. The four stomachs of a cow are situated between the oesophagus and the small intestine (Davies, 2009).

However, horses have developed a large fermentation area, named the caecum, within the hindgut. Therefore, horses are known as hindgut caudal fermenters. Instead of ruminants who are consequently known as foregut cardinal fermenters (Davies, 2009).

2.2 Anatomy and physiology of the chewing horses

At this point it might be clear that the anatomy and physiology of the horse has adapted in many ways over the years and so does the anatomy of its head and mouth due to the changes in their living circumstances. In this part of the literature review in depth information about the anatomy and the physiology of the eating modern horse will be given to give an impression about the way horses eat and chew nowadays compared to other animals.

2.2.1 Mouth

The teeth, but also the lips and tongue of the horse, are suitable for the ingestion of feed and give horses the ability to be highly selective in the feed intake. The horse's upper lip is strong, mobile and sensitive and is used while grazing to place forage between the front teeth. Cows do use their tongue for this purpose. The horse's tongue moves ingested food to the cheeks, where the check teeth are housed, for grinding.

The lips of a horse are also used as a crater though which water is sucked into the mouth (frape, 2010). Water, but also milk enters the mouth through suction caused by a negative pressure in the mouth which is created by the actin of the tongue (Davies, 2009). As a distinct from cows, the horse has upper and lower incisors to graze. This enables the horse to graze closely by shearing of forage.

2.2.2 Teeth

A horse its teeth differ from other animal's teeth in that they grow continuously throughout its life time. This is due to the constant grinding action that wears down the molars. During its life time a horse has two sets of teeth, temporary and permanent teeth (Davies, 2009). The temporary teeth appear soon after birth and are replaced by the growth of the permanent teeth. The permanent incisors and cheek teeth of a horse grow continuously to compensate the wear, and their changing form creates the basis for assessing the horse's age (Frape, 2010).

From the age of 2,5 years the temporary teeth of a horse are replaced and most horses have a set of permanent teeth by about the age of five. These permanent teeth last the lifetime of the horse. An adult horse has three sorts of teeth: incisors, molars and canines (Davies, 2009). A horse has a total of 40 or 42 permanent teeth consisting out of the molars; a horse has twelve molars and twelve premolars, incisors, twelve in total and the canines. The canines appear only in stallions or geldings at the age of about 48 months and do not erupt. The wolf teeth are present in the upper jaw of about 30% of fillies and about 65% of colts. These wolf teeth are often extracted because, when using a snaffle bit, their sharp tips can injure the cheeks of a horse. In figure 1 the configuration of the teeth in the upper or lower jaw of a horse is presented.

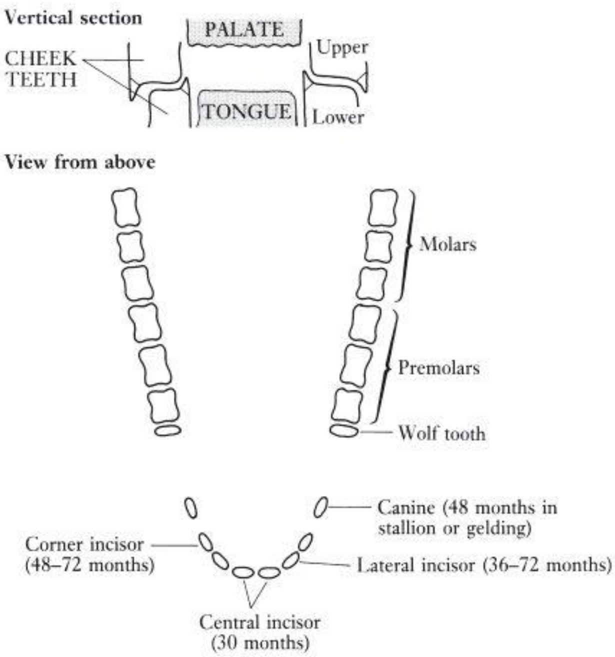


Figure 1: The configuration of the teeth in the upper or lower jaw of a horse (Source: Frape, 2010).

The lower teeth of the horse are implanted in the jaw in two straight rows that diverge towards the back of the jaw. The space between the two rows of cheek teeth in the lower jaw is less than the space between the two rows of the cheek teeth in the upper jaw. This accommodates a sideways movement of the jaws that shears the feed more effectively. This action leads to a characteristic pattern of the wear of the biting surface of the teeth (Frape, 2010).

In horses only a small part of the crown is visible above the gum line but the teeth grow continuously upwards to compensate for wear caused by the grinding action while chewing. This grinding action of the horse its teeth is essential to break down the fibrous food, but it can also create sharp edges and hooks over time, which must be filed to prevent the mouth becoming sore and damaged from the sharp teeth because a sore mouth can keep a horses from eating.

Horses with poor quality teeth may be quidding, i.e. dropping not completely chewed food out of the mouth while eating. The teeth of elderly horses can become loose and weak and this might result in a reduced intake of food. The care of an old horse's teeth is very important and if these horses are no longer able to chew long fibrous roughage efficiently, feed should be soaked with short, soft chaffs to provide a mixture (Davies, 2009).

2.2.3 Chewing

As mentioned before a horse its teeth are important for its health and welfare and are vital for its well-being. A horse uses its teeth to chew different sorts of feed, the one easier to digest than the other. Therefore, healthy teeth are important so that it is able to chew its food efficiently to make it easier to digest the feed stuff.

Horses give the impression that they chew their food quite thoroughly. This reduces the particle size of the ingested food and provides a higher digestion rate from enzymatic and microbial enzymes (Ellis & Hill, 2005). However, horses actually chew their food less thoroughly than do ruminants, based upon minutes of chewing per kg of dry matter (DM) of food ingested (Duphy et al, 1997).

As a distinct from cows, a horse has upper and lower incisors enabling it to graze closely by shearing off forage. More intensive chewing by the horse means that the ingestion rate of long hay, per Kg of metabolic body weight (BW), is three to four times as fast in cattle and sheep than it is in ponies and horses, although the number of chews per minute is similar, according to published observations (73-92 for horses and 73-115 for sheep) for long hays. Compared to sheep,5,6-6,9 mg, the DM intake per Kg of metabolic BW for each chew is 2,5 mg in horses (frape, 2010).

Bonin et al. (2007) described the three phases, opening, closing and power stroke, of the equine chewing cycle. Bonin et al. (2007) described the opening phase as a downward pivotal movement together with a rolling motion around the rostrocaudal axis that separates upper and lower rows with teeth on the chewing side. At the same time a yaw motion around the dorsoventral axis turns the jawbone away from the chewing side. The closing phase was described by Bonin et al. (2007) as a small amount of roll that brings the upper and lower teeth rows into apposition on the chewing side, while the yaw turns the jawbone across the midline. For the power stroke, the lower dental row slides across the upper row in a lateral to medial direction (Geor et al., 2013).

These lateral and vertical movements of the horse's jaws enable the cheek teeth, with the presence of saliva, to reduce the particle size of long hay mostly and the small particles covered with mucus are suitable for swallowing. Strong and healthy teeth reduce hay and grass particles to less than 1.6 mm in length.

The number of chewing movements a horse makes when chewing roughage is considerably greater than that required for chewing concentrates (Frape, 2010). Horses chew between 800 and 1200 times on 1 kg concentrates, whereas 1 kg long hay needs between 3000 and 3500 chewing movements. Ponies chew even more, namely 5000-8000 times on 1 kg concentrates and very many more for hay according to Meyer et al. (1975). This partly corresponds to the following numbers according to Ellis (2004): eating 1 kg hay takes about 40 minutes and requires 2200 to 2500 chewing movements compared to 1 kg concentrates which takes about 10 minutes and requires 600 chewing movements. Horses fed a hay diet chewed 40,000 times per day. This is four times more than horses fed a pellet diet, which chewed 10,000 times per day pellets according to the research of Houpt et al. (2004).

Clayton et al. (2003) concluded in their research that the emergence of sharp enamel points is more likely when fed a high concentrate diet. The addition of 35% short chaff (<2 cm) to a sweet concentrate mix slowed the rate of consumption and doubled the eating time, but increased the eating rate (Harris et al., 2005) while the addition of chopped straw, either 2.5 or 4 cm in length at rates of 10-30% of a pelleted diet mixed with chopped alfalfa, increased the time to eat 1 kg wet matter (WM) (Ellis et al., 2005). These observations are important for an understanding of healthy digestion (Frape, 2010).

2.2.4 Production, function and composition of equine saliva

The eating time and chewing activity of a horse is important because when a horse is chewing saliva is produced by three sets of salivary glands situated on the sides of the face. The horse has the following three main salivary glands, parotid, mandibular (submandibular), and sublingual, named according to their anatomical location. The parotid glands are about 20 cm long and 2 cm wide with an average weight of about 200g (Davies, 2009). The mandibular gland lies underneath the ventral portion of the parotid gland. The sublingual gland, which is the smallest, is located just under the mucous membrane in the mouth of the horse between the body of the tongue and jaw (Sisson & Grossman, 1959). Each gland ends into the cavity of the mouth where saliva is secreted (Davies, 2009).

Equine saliva consists for more than 99% out of water (Alexander, 1966). In general equine saliva contains more calcium and chloride and less bicarbonate and sodium, than the saliva of ruminants and is therefore more similar in composition to saliva found in carnivora and omnivora (Alexander & Hickson, 1970; Stick et al., 1981). Resting electrolyte concentrations are present in saliva from the parotid gland in different concentrates.

In saliva the concentrations of NA+, Cl- and HCO3- increase in a linear relationship to the rate of saliva secretion. Adult horses secrete 35 to 40 litres saliva per day. This saliva has an PH level of 8,6 to 9,1. The largest amount this saliva is secreted by the parotid gland (Meyer et al., 1985; Moeller et al., 2008; Stick et al., 1981). Saliva secretion in the horse is stimulated by the intake of food and chewing activity. The saliva secretion of the horse is depending on the amount of dry matter within the food it is eating. So the greater the amount of dry matter within the food the horse is eating, the greater the amount of saliva secreted. The rate of saliva secretion is partly depending partly on the physical composition of the food and partly to the time needed to chew it (Meyer et al., 1985, 1986).

As a distinct from carnivore and omnivore, equine saliva contains virtually no digestive enzymes. The results of a study by Varloud (2006) reported a level of be 0.44U/ml of amylase in horses vs. the average data 77 U/ml in humans and 98 U/ml in swine. Amylase is an enzyme which starts the digestion of starch. The mucus content of saliva enables it to function as an efficient lubricant to prevent a horse from 'choke'. The bicarbonate content of saliva provides a buffering capacity. The production of bicarbonate and sodium chloride in the saliva is proportional to the rate of saliva secretion. As earlier described, saliva is continuously secreted while a horse is eating. This buffers the digesta in the proximal region of the stomach. Besides that, it is permitting some microbial fermentation with the production of lactate (Frape, 2010).

2.3 Physiological and behavioural problems in horses based on chewing activity

As described the chewing activity in horses is an important factor for health and welfare monitoring. A lack of chewing activity can cause different health and welfare related problems. But there might also be related problems that make it difficult for horse and manager to create enough chewing for instance in older horses and horses with dental problems. Other problems that might occur because of a lack of chewing activity are behaviour related problems. In this chapter of the literature review a couple of these problems are lined out to give an impression about the impact of these health related problems.

2.3.1 Dental problems in horses

First of all the impact of dental problems in horses are described. A horse its teeth are important to its well-being. Research has shown that primary disorders the cheek teeth of horses represented a large amount, namely 87%, of the dental disorders in 400 horses (Dixon et al., 2000). The disorders in this research included abnormalities of wear, traumatic damage, and fractures form which the response to treatment was good.

Horses with dental and head pain show specific behavioural indicators such as anorexia, altered eating patterns, quidding and feed refusal (Ashley et al., 2005) and it causes digestive disturbances and colic. Dental disease is associated with a poor body condition score (BCS) but also with previous episodes of colic, diastemata (a gap between adjacent teeth) and wave-, smooth- and step-mouth (Du Toit et al., 2009).

Horses with badly worn and diseased teeth might be limited in their ability to chew roughage which is important for its general health. Cheek teeth infections in horses are not uncommon and Dixon et al. (2000) found out that nasal discharge was more frequent with infections of caudal than with rostral maxillary teeth.

2.3.2 The elderly horse

One important group of horses that struggle more often with dental problems are elderly horses. Dental disease and dental abnormalities are a common problem in older horses and might lead to difficulties with chewing food (Lowder & Mueller, 1998). Examination of the oral cavity is an important part of the clinical evaluation of old horses. McGowan (2009) reported that while owners of aged horses reported only 0,5% dental disease, veterinary evaluation confirmed that moderate to severe dental disease occurred in 46% of the horses that were examined. This shows that dental disease in horses is often not noticed by the horse owners. Therefore, observation of ingestive and masticatory behaviour of horses is important and can provide useful information for the owner (e.g., evidence of quidding that suggests a dental/oral cavity abnormality). The oral cavity and the teeth of old horses should be thoroughly evaluated using a mouth speculum so that the condition of even the most caudal molars can be adequately assessed. Dental abnormalities which are correctable such as hooks, sharp points (fig 2) and infected or broken molars should be addressed. However, over-correction or aggressive rasping of the teeth should be avoided (Ralston, 2006). Changes in the horse its diet may be necessary when dental abnormalities are not correctable. In figure 2 a picture is shown of a horse with a large sharp point at its molar.

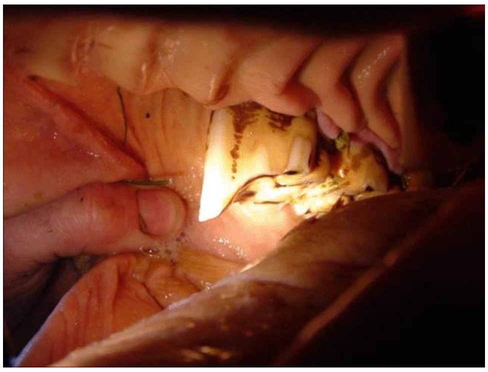


Figure 2: Horse with a large sharp point at its molar. (Source: www.paarden-tandarts.nl)

For owners who's horse has un-correctable dental problems, for instance multiple missing teeth, it might be a challenge to make sure their horse receives enough, at least 1,5 % body weight of, roughage/forage-based feed per day because these animals may not be able to properly masticate long stem hays. If laminitis is not a problem turnout on grassland may be the best solution for these horses because this might be the most appropriate forage source for these animals, as grass appears to require less chewing than dried long stem roughages and it is usually a good source of most nutrients required by healthy adult horses. Horses with severe dental abnormalities should not be fed whole grains and even texture grains because they might not be able to properly chew these feedstuffs. A modified diet is therefore very important for these horses.

2.3.3 Effect of different types of feed on the chewing activity and behaviour of the horse

Besides the fact that healthy teeth might become a problem due to lack of chewing activity such as sharp tips and hooks (fig 2), unhealthy teeth might cause this lack of chewing in horses. This concludes that it affects each other and is therefore even more important because it has in impact on the general health of the horse. Besides the effect of chewing on the health of a horse its teeth, the time of chewing and the feed types also affects the behaviour of the horse.

Modern horses nowadays are maintained in conditions very different from those in which they evolved (McFadden, 1994). The diet of feral horses consisted out of many grasses and browse species (Hansen, 1976, Putman et al., 1987); however, most horse nowadays are stabled individually and maintained on relatively indigestible straw bedding and provided a single forage (Greet and Rossdale, 1987).

The lack of foraging opportunity decreases the amount of time a horse is chewing, which results in consequent negative impacts on the digestive system (including reduced passage rates, increased risk of colic, greater risk of stomach ulcers) and might lead to increased coprophagy, bedding eating and it the increases the risk for developing stereotypies (Ellis et al, 2010; Boswinkel et al., 2007). In this part of the literature review the effects of chewing activity on behaviour of the horse will be described with the use of previous research that has been done to the behaviour of horses.

Elia et al. (2010) researched to the motivation for hay in horses. The aim of this study was to determine the motivation for hay in horses fed a low roughage diet. Their motivation could be used to determine if low roughage diets accommodate the welfare of horses. The secondary objectives of this research were: to determine the effect of diet on behaviour of the horses and to determine the chewing rate and total chewing movements per day while consuming diets differing in fibre content. The results of this study by Elia et al. (2010) have shown that horses did not work for hay when hay was available but when horses where provided with pellets there was an increased motivation for hay. Over a period of 24 hours, horses spent 10% of their time consuming pellets compared to 64% of their time consuming hay. While eating a pellet diet the horses spent 58% of their time standing. When the horses where eating a hay diet only 36,6% of their time was spent standing. Searching behaviour in the stall (i.e., sifting through wood shaving bedding for food particles) took up about 11.5% of the horse's day while eating a pellet diet compared to only 1,2 % of the horse's daily time while eating a day diet. The rate of chewing pellets was significantly faster than the rate of chewing hay. In this research horses chewed fewer times per minute while consuming a hay diet compared to the number of chews per minute while consuming a pellet diet. However the horses had spent more time each day chewing a hay diet than chewing a pellet diet. The results of this study conclude that a reduction in fibre diets has an impact on the physiology and behaviour of horses. This research has shown that horses are motivated to work for hay (higher fibre), using operant conditioning, only when fed a low fibre diet. This indicates that the horse has a behavioural need for chewable fibre.

Goodwin et al. (2002) looked into the effect of foraging enrichment for stabled horses on the selection and behaviour of the horse. Restricted access to pasture has been linked to the performing of stereotypic behaviour and redirected behaviour patterns in horses. It has been suggested that racehorses provided with multiple sources of forages have a smaller chance to express and develop these behavioural patterns. To investigate this, the same trials where performed 4 times. Up to 12 horses were introduced into each of two identical stables one stall containing single forage and the other one containing six forages for five minutes. To detect the effects of novelty, in the first and third trials the single forage was hay. In the second and fourth trial the single forage was the preferred forage from the previous trial. The results of this study by Goodwin et al. (2002) show that when hay was presented as the single forage (Trials 1 and 3), all recorded behaviour patterns were significantly different between the two stalls e.g. during Trial 3 in the 'Single ' stable, horses looked over the stall door more frequently ($P<0.001$), foraged on straw bedding for longer ($P<0.001$), moved for longer ($P<0.001$), and they exhibited behaviour indicative of motivation to search for alternative resources ($P<0.001$) more frequently. When the horses where presented with a previously preferred forage as the single forage (Trials 2 and 4) the behaviour was also significantly different between stalls, e.g in Trial 4 horses foraged for longer in their straw bedding ($P<0.005$) and looked out over the stable door more frequently ($P<0.005$). To determine whether these effects persist over longer periods of time further research is required. The trials from this research indicate that enrichment of the stable environment through the feeding of multiple forages may have benefits for the welfare of horses, in reducing the consumption of straw and facilitating the expression of highly motivated foraging behaviour

2.3.4 Five freedoms in equine welfare

Above named research show that horses do show a highly need for chewable fibre and that providing more than one single forage might improve its welfare. The welfare of horses can be assessed based on what animal welfare agencies call the five freedoms. These five freedoms consist out of the following five basic rights that all animals should have (Brambell, 1965):

1. Freedom from hunger and thirst
2. Freedom from discomfort
3. Freedom from pain, injury and disease
4. Freedom to express normal behaviour
5. Freedom from fear and distress.

2.3.5 Freedom to express normal behaviour and developing stereotypies

The freedom to express normal behaviour is an important factor for equine welfare because modern horses nowadays are managed by humans in a very different way than how horses lived free in nature when they evolved. Therefore, the management of the horse by the owner or stable manager has an effect on the horse its freedom to express its normal, natural, behaviour. Due to these management conditions horses might for instance be limited in their movement and eating time and therefore also in their chewing activity but horses might also be restricted from social contact with congeners.

When horses do not get the opportunity to meet their behaviour needs all different defects in its behaviour might occur such as restlessness, nervousness and passivity. Restricting a horse in its freedom to express normal behaviour might even have a bigger impact on the horse which might cause the development of stereotypic behaviour in the horse.

According to Ellis et al. (2010) and Boswinkel et al. (2007) the lack of feeding opportunity increases the risk for the development of stereotypies in horses. Other management factors that were associated with an increased reported risk of developing stereotypies by McGreevy et al. (1995b) are: feeding less than 6,8 kg of forage per day, housing horses on other type of bedding than straw, housing horses on a yard with less than 75 horses, housing horses in boxes which minimises social contact between neighbouring horses and the absence of a paddock on the yard (Mills & Nankervis, 1999).

2.3.6 Stereotypies and the effects

Stereotypies are described by Mills & Nankervis (1999) as 'repetitive behaviours which do not seem to vary much but have no obvious function'. According to Hothersall & Casey (2011) executing stereotypic behaviour is a strategy to cope with an environment that is not optimal for the animal and it may serve to improve the situation for the animal.

Stereotypies that include oral behaviours:

Cribbing or crib-biting: Horses performs this behaviour when it repeatedly grabs something with its front teeth, and arched its neck and usually grunts as it pulls back and let's go.

Windsucking: Is performed by the horse as it appears to gulp air repetitively. A grunt usually accompanies the effort, but recent research suggests very little air, if any, is actually swallowed. Cribbing often occurs in the same horses.

This list could also include licking, tongue movements, wood-chewing, nodding and other unusual oral behaviours like tongue-lolling.

In domestic animals stereotypic behaviours are common performed behaviours but stereotypic behaviours have not been reported in animals that have never been kept in captivity. It seems that between 5% and 20% of horses on any given yard may show one or even more of above named behaviours (McGreevy et al., 1995a). Therefore, stereotypic behaviour is a fairly common behaviour performed by horses in captivity which is not performed when horses live in the wild (Mills & Nankervis, 1999).

The effect of performing a stereotypic behaviour differs per behaviour. Windsucking and cribbing are is for instance associated with a risk of colic. The results of a study performed by Malmed et al. (2010) stated that 'animals at higher risk for colic may be identified based on history of cribbing or windsucking behaviour' but this behaviour was not associated with increased risk for a particular category or severity of colic'. Besides the association from cribbing with colic also dental problems are associated with cribbing in horses because the front teeth of cribbing horses wear quicker and not equally. In figure 3 the wear down of the teeth of a cribbing horse is presented.

Figure 3: Wear down teeth of cribbing horse.

(Source: www. paardentandartsslob.nl)

Horse owners refer to stereotypic behaviour as stable vices, as if the horse is at fault (Cooper & Albentosa, 2005). These 'stable vices' are often treated because they are considered undesirable for economic reasons, and not because the activity has an effect on the horse's quality of life. An understanding of the causes and the effects of the certain behaviour is necessary to assess the costs and benefits of treatment. The stereotypic behaviour performed by the horse is a sign of poor welfare, such as inadequate living circumstances. Treatment of these behaviours can best be achieved by removing the underlying causal. Preventing the behaviour without addressing the cause may result in its perseverance in a modified form. It also might disrupt the animals' ability to adapt to its environment (Cooper & Mason, 1998). Therefore, it is important to find the original cause of the stereotypic behaviour so that to original problem can be solved.

Preventing the horse from expressing the stereotypic behaviour is used quite a lot in the management of the behavioural problem. This can be done in many ways such as: isolating the horse that is aggressive to others and muzzling the cribbing horse. The effectiveness of these techniques vary, e. g. many horses still weave behind weaving bars. Preventing these stereotypic behaviours does not address the underlying cause and therefore it only makes the psychological situation worse (Mills & Nankervis, 1999).

2.4 Previous research on equine chewing activity

Previous research on equine chewing activity has been done by several scientists (e.g. Müller, 2009 and Ellis et al.,2005,) in different settings over the years. Most research has been done to determine differences in chewing activity and feeding behaviour in horses eating different types of feed. These researches have been done by counting chewing movements by visual observations but also with the use of special designed tools for measuring chewing activity and eating time.

2.4.1 Research on chewing activity by visual observation

Research on chewing activity in Long-stemmed vs. cut haylage

Müller (2009) did research to the differences in chewing activity between in horses eating long-stemmed haylage and horses eating chopped haylage in bales. The experimental design of the feeding experiment was a cross-over with 10 horses divided into two groups in two periods, with each period taking four weeks. The feed ratio of the horses was spread over four times per day. During the meals the horses were observed, and number of chewing movements and swallowing per minute was counted for each individual horse. With this research Müller found out that the eating time (min/kgDM) was similar when horses were fed cut haylage compared to long-stemmed haylage. The chewing rate in chews per minute was slightly higher and the number of chews per kg DM was lower when horses were fed chopped haylage. Very small differences were found but the impact of these differences over period of 24 hours or longer periods are not known. Further research is required to investigate the long term effects.

The effect of adding chopped straw to concentrate feed

A couple years earlier a study was performed by Ellis et al. (2005) to investigate the effect of adding chopped straw to concentrate feed. In this research the effect of the inclusion rate and the particle length on the intake behaviour in horses was investigated. Dulphy et al. (1997) observed that the intake rates (Dry matter per minute = DM/min) almost halved when hay and straw where compared (14 g and 7.9 g DM/min, respectively). The purpose of the study by Ellis et al. (2005) was to investigate the effects of increasing the amount of straw chaff to concentrate pellets within a meal on such behaviour of horses. In six horses the feed intake behaviour was measured during the morning and evening and the chewing movements per minute and the intake time per kg WM where calculated. Before the feeding at morning (7.00 am) and evening (17.00 pm) horses had not received any other feed for at least 3 hours. The chews per minute were measured by direct observation and the left overs of the removed feed was weighted so that the amount of feed eaten by the horse could be calculated. The intake rate in gram per minute and the chewing rate in chews per kg were calculated according to the results of the direct observation. The results of this study show a clear 120% increase in feed intake time and chewing activity per kg was observed when straw chaff was added to a high DM concentrate feed. Such an increase is likely to lead to a beneficial increase in saliva production.

2.4.2 Research on chewing activity with automatic measurement systems

Chewing activity and particularly jaw movements, is a measureable parameter in the registration process of feed intake behaviour in horses, but also in other animals. Different scientists (e.g. Brøkner et al., 2006; and Vervuert et al., 2012) worked with automatic measurement systems for measuring chewing activity in horses and the development of automatic measurement systems still continues.

The effect of grain type and processing on equine chewing time

Brøkner et al. (2006) investigated the effect of grain type and the processing of the grain type on equine chewing time with the use of a special chewing halter. This experiment was conducted to find out if increased grain Neutral Detergent Fibre (NDF) and feed particle size results in increased chewing time in horses. Therefore, three adult Standardbred horses (Group I) and 3 adult Icelandic horses (Group II) were fed 3 daily meals during 3 consecutive day in two 3 x 3 completely randomized block design experiments. The meals of contained oats, barley and wheat that were fed whole, rolled and ground during three times per day. Time the horses spend eating was visually observed. Chewing activity was recorded using a special chewing halter. The results show that the chewing rate and chewing regularity did not differ between the two groups of horses. The efficient chewing time for whole grain was 18 min per kg DM but it was not systematically shorter than for ground grain (20 min per kg DM). In conclusion, the presumed hypothesis that increased grain NDF and feed particle size results in increased chewing time in horses was rejected. The results from this study indicate that the regularity of jaw movements during eating provide a new method for quantifying cereal grain characteristics. This result, that feed particle size increases chewing time, corresponds to the result of the research by Müller et al. (2009) who stated that there was nog significant difference in eating time and chewing activity between horses eating long-stemmed and horses eating chopped haylage.

The effect of feed type and essential oil product on equine chewing activity

Besides the research on the effect of grain type and processing on equine chewing time, Brøkner et al. (2009) did also research to the effect of feed type and essential oil product (EO) on equine chewing activity using the special chewing halter. The results of this study have shown that all chewing characteristics, measured in this research, were significantly affected by roughage type ($p < 0.001$) and concentrate type ($p < 0.01$). No significant ($p < 0.05$) effect of adding EO was found for any chewing characteristic measured. In conclusion, effect of the type of roughage and concentrate was more significant than potential effects of essential oils.

As the results of this research describe, roughage type effects the chewing activity in horses and as earlier described in this report horses do chew much more on roughage than on concentrates. According to Meyer et al. (1975) horses chew between 800 and 1200 times on 1 kg concentrates, whereas 1 kg long hay requires between 3000 and 3500 chewing movements (Meyer et al., 1975). The speed of intake varies between ~10 min per kg for concentrates and ~45 min per kg for roughage. The rapid ingestion of concentrates per unit of time is associated with the limited production of saliva (<3kg per kg feed) whilst the consumption of roughage encourages a profuse production of saliva (~5kg per kg feed) (Meyer et al. 1975, 1986b).

Investigation of the effect of the order of feeding oats and alfalfa to horses

Before Brøkner et al. (2005, 2009) studied the effect of feed type and essential oil product on equine chewing activity, a study was performed by Brüssow et al. (2005) to investigate the effect of the order of feeding oats and chopped alfalfa to horses on the rate of feed intake and the chewing activity. The objectives of the this study were to clarify the effects of feeding oats alone, before or after feeding chopped alfalfa or, feeding oats in admixture with the alfalfa on the intake of feed and the chewing activity of healthy horses. Four horses were used in a changeover experiment. The animals were kept in individually in boxes on wood shavings and had free access to water. The diets, two meals per day, consisted of chopped alfalfa and unprocessed oats. The two diets were offered in three ways; a) first alfalfa and immediately thereafter oats, b) first oats followed by alfalfa or c), a mixture of alfalfa and oats. The time it took the horse to consume the feed was recorded for each horse. Special types of halters were used to measure chewing activity. The results of this study have shown that the quickest feed intake time was recorded while eating the alfalfa-oats mixture. The rate of the intake of both oats and alfalfa was not influence by the feeding order. The chewing activity, measured in chews per 100 gram, was similar for the alfalfa oats mix and oats at about 90. During alfalfa ingestion, more chewing was required independent of the order of feed. There were no differences present between the chews per minute between the alfalfa -oats mix or the roughage and oats. The mean duration of a chewing cycle was 0,2 sec with no influence of the type of feed or the feeding order.

Electromyographic evaluation of masseter muscle activity in horses

Besides research on chewing activity and chewing behaviour, research has also been done on the activity of the masseter muscle by Vervuert et al. (2012). The researcher of this study investigated the elcotromyographic evaluation of masseter muscle activity in horses fed different types of roughage and maize after different hay allocations. The results of this study conclude that the consumption of hay, haylage or straw/alfalfa chaff was associated with intensive masseter muscle activity which was likely to stimulate the rate of salivary flow. As a contrast to roughage, concentrates, like cracked maize, are consumed rapidly with less intensive masseter muscle activity. This is associated with a low rate of salivary flow that may have an adverse effect on gastric function. In addition, it might be concluded that feeding different allocations of hay before feeding maize did not affect chewing intensity. Besides that, the extension of maize feeding times was only achieved when feeding hay ad libitum. These results partly correspond to the results of the research done by Brøkner et al. (2009).

3. Methodology

This research has been set up in two separate trials to validate the EquiWatch system in two different settings. In the first trial the number of chewing movements, registered by the EquiWatch system, were compared with the number of chewing movements counted by visual observation to investigate the reliability of the registered chewing movements. In the second trial the oral behaviour of the horses has been observed and videotaped to investigate if the classification of the oral movements of horses is comparable with the classifications made by the software used evaluate the data. This study was set up as a pilot study. It was an experiment to validate the system and the results were analysed based on descriptive research.

3.1 Measurement system EquiWatch

The EquiWatch system is an adapted version of the RumiWatch system developed by the firm Itin + Hoch GmbH, Switzerland. The EquiWatch system incorporates a noseband sensor, data logger with online data analysis, and evaluation software (RumiWatchManager and RumiWatchConverter). The noseband sensor is similar to the method developed by Nydegger et al. (2011). In this study the reliability of noseband sensor of the EquiWatch system is tested with the use of the associated evaluation software.

3.1.1 Functioning of the noseband sensor

The noseband sensor of the RumiWatchHalter, which was the halter developed for cattle, was originally integrated in the noseband of a normal, for horses used halter. The RumiWatch halter has been adapted into the EquiWatch halter for horses. Its form and shape have been adapted so that it suites the horse better. The halter consists of a vegetable oil-filled silicone tube with a built-in pressure sensor at the end of the tube placed in the casing of the halter over the bridge of the horse's nose. A picture of the build-up of an EquiWatchHalter with a build in pressure sensor is present in figure 4.

Figure 4: The build-up of an EquiWatchHalter with integrated sensor technology.

The bending of the noseband is altered by the jaw movement of the horse's, which causes a pressure change in the fluid-filled silicone tube. The pressure sensor is connected to a data logger. This data logger is placed in a protective casing on the right side of the halter. A battery is placed in a second casing on the left side of the halter which serves as power supplier.

The data logger registers the pressure in the noseband sensor at a logging rate of 10 Hz (10 movements per second) and saves the raw data to a SD memory card. Selectable formatting of the memory card allows a recording period up to four months. The data are transmitted wireless or using a SD memory card to a computer as raw data in a rwu-file (Zehner et al., 2012). Later on man can export the data into a csv- file with the use of the evaluation software (RumiWatchConverter). In figure 5 a csv-file of the raw data output with all evaluation parameters is presented. These evaluation parameters include the date and time of the measurement, the measured pressure, the values of the three axes of the position sensor, the temperature and the recording time of pressure peaks.

K49239 fx

	A	B	C	D	E	F	G	H	I
1	time	pressure	move_x	move_y	move_z	temperature	peak_time	classification	
49198	07.04.2015 09:59:55.6	2655	48	26	7	1685	60163	2	
49199	07.04.2015 09:59:55.7	3218	48	28	-2	1685	60163	2	
49200	07.04.2015 09:59:55.8	2557	47	29	-8	1685	60163	2	
49201	07.04.2015 09:59:55.9	2219	47	23	-3	1685	60163	2	
49202	07.04.2015 09:59:56.0	2023	48	22	0	1685	60560	2	
49203	07.04.2015 09:59:56.1	1929	49	25	-3	1685	60560	2	
49204	07.04.2015 09:59:56.2	1955	49	24	-2	1685	60560	2	
49205	07.04.2015 09:59:56.3	1981	48	25	0	1685	60560	2	
49206	07.04.2015 09:59:56.4	2130	49	26	-3	1685	60560	2	

Figure 5: Example of a csv-file of a raw data output.

In addition to the raw data output, the data is classified into different categories when the data is exported into a csv-file. This classification is provided by a defined algorithm. As this system was originally developed for cattle this algorithm has been developed for ruminants. This result in the following four possible categories: eating, ruminating, drinking and other activity, which are shown in table one.

Table 1: Four possible classifications by evaluation software RumiWatchConverter.

Classification number	Classification
0	Other activity
1	Ruminating
2	Eating
4	Drinking

With the use of the evaluation software (RumiWatch Converter) the pressure peaks which are above a certain threshold are filtered and counted together. Thus, for the evaluation of the number of chews the height of the peaks doesn't have an effect, only the frequency and the occurrence of a peak are taken into account.

The power supply is a 3.6V battery (Tadiran Batteries , Juice Group , Bagnolet , France) , which is installed in a second protective box at the other end of the nose band. The low-energy system has a focus on long-term (months to several years) operating time at minimized energy consumption. Due to ultra-low power components predicted battery lifetime is up to three years under laboratory conditions. However, the SD-memory card is a limiting factor because it can be formatted to a maximum of 4 months data log of 10 Hz. With the use of an ANT-antenna a wireless connection can be made between a computer, laptop or tablet and the EquiWatch halter. With the use of this wireless connection 1 hour summaries can be transferred to the respective media (e.g. pc, laptop, tablet). These one hour summaries are saved on the internal memory of the data-logger for 48 hours.

3.1.2 Evaluation software

The software that supports the EquiWatch system consist out of two programs the so called ''RumiWatchManager'' (version 2.1.0.1) and the ''RumiWatchConverter'' (version 0.7.3.2) with the integrated ''RumiWatchViewer''.

The management of an individual halter can be controlled in the stable with the use of a laptop of tablet. With the use of an ANT antenna the data can be transferred wirelessly to a used medium (computer, laptop, tablet or smartphone). Each individual EquiWatchHalter has a so called RumiWatchUnit-number (RWU-ID). With the use of the evaluation software RumiWatchManager these numbers are used to attach is specific halter to an individual horse. This creates the possibility to control the data recording; this includes starting and stopping recording but also synchronizes the time settings from the halter with the computer, of each individual horse. In addition, one hour summaries of the raw data can be transferred to the used medium (computer, laptop, tablet or smartphone). To read the raw data of the memory card of a specific RumiWatchUnit the RumiWatchManager is used.. Another important function of the RumiWatchManager is to control the activity of the functioning halter. This can be done with the software to check the status of recording as well as the battery state of charge.

For data analysis the RumiWatchConverter is used. After transferring the raw data from the RumiWatchUnits to the used medium (computer, laptop, tablet or smartphone) the RumiWatchConverter can visualize the data in the RumiWatchViewer, this shows on the one hand a detailed view of a certain period and on the other hand over the complete recording time of the data of each file as shown in figure 6. This provides an initial overview of the classification and the completeness of the records. Additionally, the different classifications are displayed using different colours. The values of the position sensor of the different axes can be represented graphically as well.

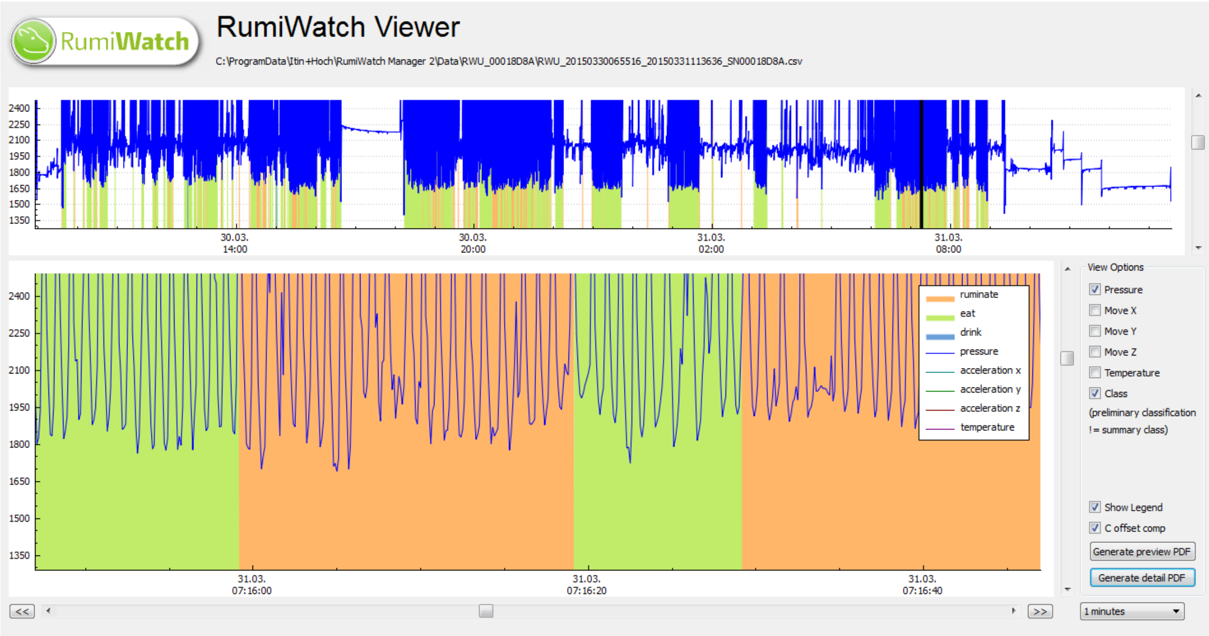


Figure 6: Example of a visual representation of a rwu- file in RumiWatchViewer.

Another additional function of the RumiWatchConverter is the ability to convert the raw data into summaries of various periods of time. The 10 Hz raw data can be shown in a csv-file format in different temporal resolutions (1 minute; 10, 30, 60 minutes; 3, 6, 12 or 24 hours). The definitions of a start and end point can therefore be used to filter exact periods out of the large amount of raw data. Because of the special RumiWatch-algorithm for cattle, the data are divided into various categories by the RumiWatchConverter (table 1). Because of the position sensor in the EquiWatchHalter the amount of time the horse has held its head in a specific position is also measured. However, this information is not validated in this research.

3.2 Trial 1: Comparing visually counted chewing movements with chewing movements registered by the EquiWatchHalter

In the first trial of this research a comparison between the numbers visual observed chewing movements (CM) and the numbers of chews registered by the EquiWatchHalter was made to find out if there was a difference and the deviation was calculated. Werner et al. (2014) did an experiment to compare visually counted chewing movements with the registered number of chewing movements by the RumiWatchHalter on horses, when the horses were fed roughage to find out if this corresponds with each other. Based on her research this research was set up when horses had no food available to find out if there was a difference between the visually counted chews and the chews registered by the EquiWatchHalter and to find out how much of a deviation there is between the two when no feed is available for the horse.

3.2.1 Animals

In the first trial three KWPN (Royal Dutch Sport Horses) horses from the age of 17, 19 and 23, two mares and one gelding, were used. These horses were stabled individually on straw bedding, were turned out on grassland for about 4 to 6 hours per day and were fed with hay and concentrates twice per day. During the observational period the horses got their usual diet and the horses were ridden as usual, 4 to 6 times per week about for one hour and trained in dressage up to medium level or ridden outside for a hack.

One of the horses is showing the stereotypical behaviour cribbing when it is in the stall. This stereotypical behaviour was never mentioned when the horse was outside on grassland. This horse was included in the research to get an impression if the EquiWatchsystem is able to distinguish these cribbing movements from chewing movements or not.

3.2.2 EquiWatch halters

For this research three EquiWatchHalters, developed by the firm Itin+Hoch, were provided by the Dutch equine feed company Pavo. The halters are equipped with buckles on the headband as well as on the part that runs under the chin of the horse and the two parts that run over the cheek of the horse as shown in figure 7, so that the halter could be adapted to the size of the horses's head. Before the observations took place the horses were already introduced to the halters and had been wearing the halters for about half a day, or even a longer period of time, so that the horses could get used to the weight on their head and nose.

Figure 7: Example of a KWPN gelding wearing an EquiWatchHalter.

The halters where put on the hoses as described in the RumiWatch User Guide which can be downloaded in the download centre on the website www.Rumiwatch.ch. The correct position of the halter was checked through the following technique. There should be enough space left between the noseband and the bridge of the nose, to allow the four fingers of a hand to fit in it easily.

3.2.3 Experimental design

When the horses, stabled on straw bedding, had no food available periods of 10 minutes were visually observed and chewing movements were counted with the use of a tally counting device as shown in figure 8. Only chews and bites, which led to the intake of the straw bedding, were counted. This research was set up in this setting because with the final goal from Pavo, to perform measurements of 24 hours or longer with the EquiWatch, it was necessary to test the reliability of the system when horses are left without food. This was done because of the fact that, within these longer measurement periods, there are periods when horses have no food available. The observer relied mainly on the sound of grinding teeth for data collection. Each horse was observed for three periods of ten minutes. These observational periods took place in the morning after the horses finished their morning feed an before they were turned out in the field so between 8.30 and 13.00 hours. In this study the visual observations were set as the gold standard, because it is feasible to differentiate between chewing movements and other jaw movements. This referencing method was already established for the evaluation of automatic measurement systems in other studies (Nydegger et al., 2011; Zehner et al., 2012).

Figure 8: Tally counting device used for counting chewing movements.

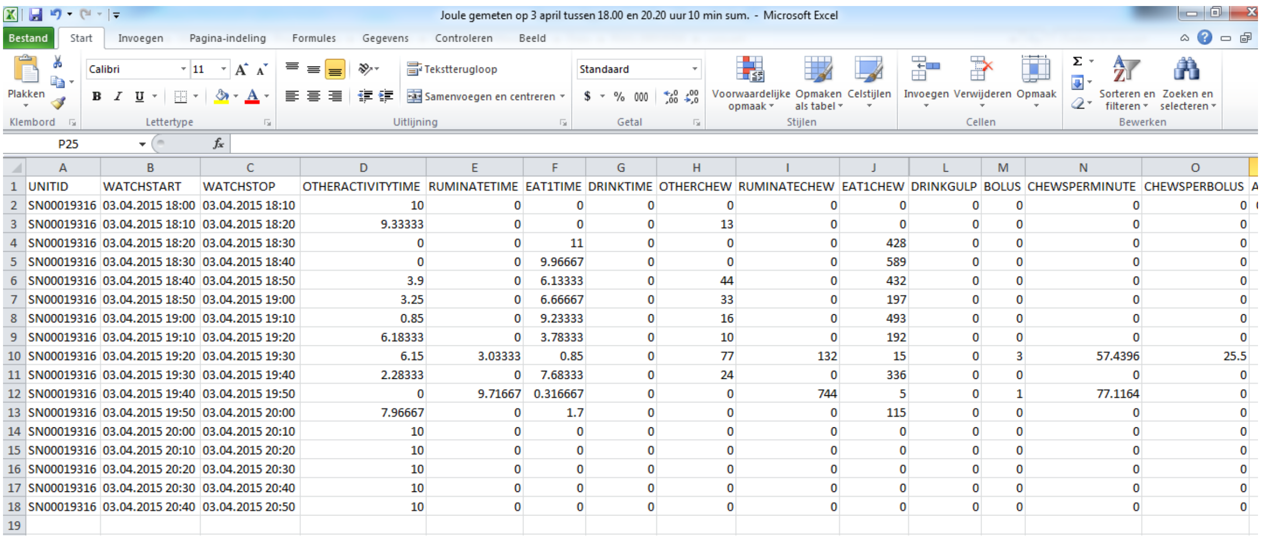
Source: www.conrad.com

Table 2: Experimental design for visual observations of three horses during periods without feed.

Number of horses	**Observational period (min)**	**N observations per horse in total**	**Total number of observations**
3	10	5	15

The alarm of a smartphone was used to set the time on 10 min for each period. The time of the alarm on the smartphone was set at the same time as the time on the laptop that was used for the research so that the time was set equal. The counting was started every time on 10,20,30, 40 or 50 minutes after the whole hour. After ten minutes the alarm went off and the counting stopped and the number of observed chews counted where noted.

These visually counted chewing movements were compared with the number of registered chews by the EquiWatchHalter. To compare the visual counted chews with the automatic registered chews, the raw data of the halter were transferred to a laptop and converted with the use of the RumiWatchConverter in to 10 minute summaries as show in figure 9.



UNITID	WATCHSTART	WATCHSTOP	OTHERACTIVITYTIME	RUMINATETIME	EAT1TIME	DRINKTIME	OTHERCHEW	RUMINATECHEW	EAT1CHEW	DRINKGULP	BOLUS	CHEWSPERMINUTE	CHEWSPERBOLUS
SN00019316	03.04.2015 18:00	03.04.2015 18:10	10	0	0	0	0	0	0	0	0	0	0
SN00019316	03.04.2015 18:10	03.04.2015 18:20	9.33333	0	0	0	13	0	0	0	0	0	0
SN00019316	03.04.2015 18:20	03.04.2015 18:30	0	0	11	0	0	0	428	0	0	0	0
SN00019316	03.04.2015 18:30	03.04.2015 18:40	0	0	9.96667	0	0	0	589	0	0	0	0
SN00019316	03.04.2015 18:40	03.04.2015 18:50	3.9	0	6.13333	0	44	0	432	0	0	0	0
SN00019316	03.04.2015 18:50	03.04.2015 19:00	3.25	0	6.66667	0	33	0	197	0	0	0	0
SN00019316	03.04.2015 19:00	03.04.2015 19:10	0.85	0	9.23333	0	16	0	493	0	0	0	0
SN00019316	03.04.2015 19:10	03.04.2015 19:20	6.18333	0	3.78333	0	10	0	192	0	0	0	0
SN00019316	03.04.2015 19:20	03.04.2015 19:30	6.15	3.03333	0.85	0	77	132	15	0	3	57.4396	25.5
SN00019316	03.04.2015 19:30	03.04.2015 19:40	2.28333	0	7.68333	0	24	0	336	0	0	0	0
SN00019316	03.04.2015 19:40	03.04.2015 19:50	0	9.71667	0.316667	0	0	744	5	0	1	77.1164	0
SN00019316	03.04.2015 19:50	03.04.2015 20:00	7.96667	0	1.7	0	0	0	115	0	0	0	0
SN00019316	03.04.2015 20:00	03.04.2015 20:10	10	0	0	0	0	0	0	0	0	0	0
SN00019316	03.04.2015 20:10	03.04.2015 20:20	10	0	0	0	0	0	0	0	0	0	0
SN00019316	03.04.2015 20:20	03.04.2015 20:30	10	0	0	0	0	0	0	0	0	0	0
SN00019316	03.04.2015 20:30	03.04.2015 20:40	10	0	0	0	0	0	0	0	0	0	0
SN00019316	03.04.2015 20:40	03.04.2015 20:50	10	0	0	0	0	0	0	0	0	0	0

Figure 9: Csv-file of raw data output converted into 10 min summary.

3.2.4 Data analysis

Because the RumiWatch was developed for cattle it makes a distinction between ruminating chews and eating chews. Because of the fact that horses do not ruminate, in this research, the numbers in the column 'ruminate chew' and the number in the column 'eat chew' are counted together to get the number of chewing movements registered by the EquiWatchHalter within the period of 10 minutes. An example based on the numbers out of the table in figure 9 of the amount of chews registered by the EquiWatchHalter between 18.50 and 19.00 hours the outcome is 197, zero and 197 counted together and between 19.20 and 19.30 hours it is 147, so 132 and 15 counted together.

Firstly, to compare the visual counted chewing movements with the number of chewing movements registered by the EquiWatchHalter, the average number of visual counted chews and the average number of automatically registered chews was calculated for each horse over the five measurement 10-min periods.

Secondly, the deviation between the average numbers was calculated for each horse. This provides an indication how much of a difference there is between the visual counted chewing movements and the automatic registered chewing movements.

3.3 Trial 2: Comparing visual observed movements with classification by RumiWatchManager

In the second trial of this investigation visually observed oral behaviour of the horse was observed and compared to the classification of the evaluation software to find out if there were non-chewing movements registered as chewing movements and the other way around.

3.3.1 Animals

The animals that were used in this second trial were the same three horses as used in the first trial including the one that shows the stereotypical behaviour so that also these movements were visually observed to find out if these were classified as chewing or not. Additionally five other horses were observed in this research. These horses were five riding school horses that are housed in a group housing stable on concrete and straw during the day and at night individually in boxes with straw bedding. These horses are aged between 8 and 20 are used for riding school lessons about 10 hours per week. In annex 1 an overview of all horses used for this investigation is presented with information about each horse.

3.3.2 EquiWatchHalters

In this second trial the same EquiWatchHalters were used as in the first trial. The three horses that were used in the first trial were already introduced to the halters the other horses were all introduced to the halter for about 2 to 3 hours, so that they could get used to the weight on the head and nose, before the observation took place.

3.3.2 Experimental design

In this second trial the oral behaviour of eight horses was filmed in the stall for about 15 to 30 minutes per horse. Filming was performed to get as much different oral behaviours on video as possible so that these behaviours could be compared with the classification by the evaluation software, RumiWatchConverter. The horses were filmed by hand, and not using a tripod, so that the mouth of the moving horse could be followed with the camera as good as possible and as much oral behaviours as possible could be captured on camera. Filming was started at the whole minute based on the time set on the laptop because the time of the evaluation software and the EquiWatchHalters was synchronised with the time of the laptop. Every time a new film was made the starting time and the end time was written down to be able to analyse the videos later on.

In total nine oral behaviours have been observed and filmed, spread over 165 minutes of video. The following nine behaviours were filmed and observed:

1. Foraging behaviour: The horse is moving its lips in the straw and showing searching behaviour selecting roughage to eat.

2. Chewing roughage: The horse is chewing while ingesting roughage. This can be hay of silage but also the ingestion of straw is classified as chewing roughage in this research.

3. Chewing concentrates: The horse is chewing while ingesting a concentrate feed.

4. Drinking: The horse sucks water into its mouth and swallows it.

5. Licking: Horse is putting its tongue out of its mouth and is licking an object.

6. Tongue movements: Horse putting its tongue out of its mouth but does not lick an object.

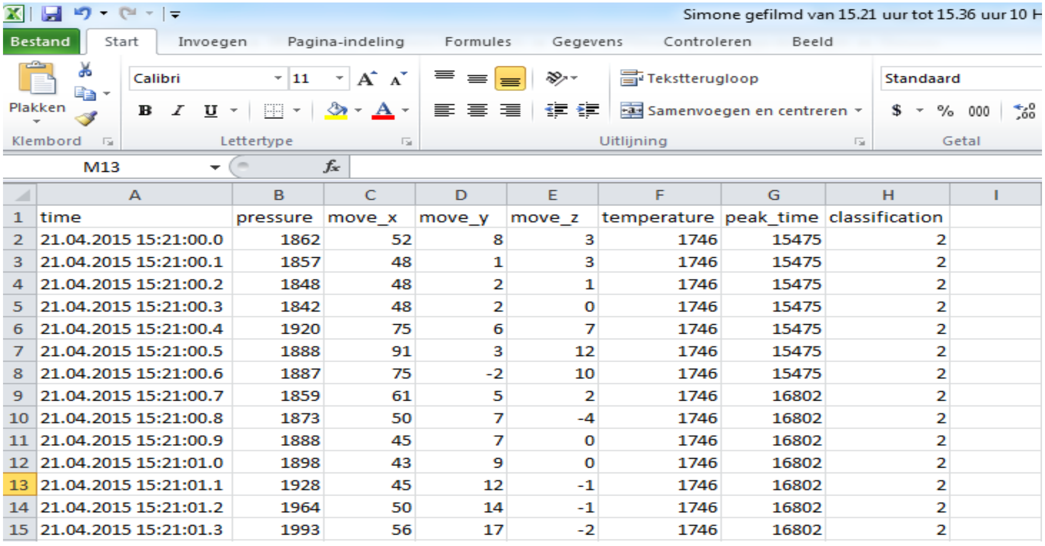
7. Cribbing: The horse grabs an object with its front teeth, arched its neck and grunts as it pulls back and let's go.

8. Flehmen response: The horse is curling the upper lip and puts its nose high in the air.

9. Scratching: The horse is scratching itself with its own teeth or biting himself to get rid of itch.

0. Other behaviour: The behaviour captured on camera which where none of above named oral behaviours where all classified as other behaviour.

After filming of the horses was finished the data registered by the EquiWatchHalters was transferred to a laptop and the period of observation was converted by the evaluation software, RumiWatchConverter, in 10 Hz resolution as shown in figure 10.



	A	B	C	D	E	F	G	H
1	time	pressure	move_x	move_y	move_z	temperature	peak_time	classification
2	21.04.2015 15:21:00.0	1862	52	8	3	1746	15475	2
3	21.04.2015 15:21:00.1	1857	48	1	3	1746	15475	2
4	21.04.2015 15:21:00.2	1848	48	2	1	1746	15475	2
5	21.04.2015 15:21:00.3	1842	48	2	0	1746	15475	2
6	21.04.2015 15:21:00.4	1920	75	6	7	1746	15475	2
7	21.04.2015 15:21:00.5	1888	91	3	12	1746	15475	2
8	21.04.2015 15:21:00.6	1887	75	-2	10	1746	15475	2
9	21.04.2015 15:21:00.7	1859	61	5	2	1746	16802	2
10	21.04.2015 15:21:00.8	1873	50	7	-4	1746	16802	2
11	21.04.2015 15:21:00.9	1888	45	7	0	1746	16802	2
12	21.04.2015 15:21:01.0	1898	43	9	0	1746	16802	2
13	21.04.2015 15:21:01.1	1928	45	12	-1	1746	16802	2
14	21.04.2015 15:21:01.2	1964	50	14	-1	1746	16802	2
15	21.04.2015 15:21:01.3	1993	56	17	-2	1746	16802	2

Figure 10: Csv file of raw data output in 10 Hz resolution.

3.3.3 Data analysis

After the raw data had been put on de laptop the videos were analysed from one minute to the other in Microsoft Excel. The time a horse started performing one of the oral behaviours was noted and when it started performing another behaviour the time was noted again. Each time a horse changed from oral behaviour was interpreted as one observation. Then the data output of the EquiWatchHalter was analysed and the classification made by the evaluation software was added in a column behind the observed behaviour as shown in table 3.

Table 3: Example of the analysed videos. Three minutes of filming horse 7.

Time	Oral behaviour	Classification by evaluation software
9.27.00	Other	2
9.27.04	Foraging	2
9.27.15	Chewing roughage	2
9.27.33	Chewing concentrates	2,1
9.29.02	Licking	1
9.29.13	Other	1
9.29.25	Licking	1,2
9.29.37	Other	2
9.29.45	Foraging	2
9.29.57	Other	2
9.30.04	Licking	2

After analysing the videos each change in behaviour was interpreted as a new observation and the data was sorted on behaviour instead of time. The observations were numbered so that a clear overview of the amount of observations per oral behaviour was present. The observations of behaviour that were classified with more than one classification by the evaluation software were interpreted as a new observation. So a period of an oral behaviour that was classified with two classifications became two observations and a period of an oral behaviour that was classified with three classifications became three observations. After this was finished for each observation there was searched for agreements between the oral behaviour in the videos and the data output.

The behaviours where compared with the classification by the RumiWatchConverter and coded with a 0 or a 1 as shown in table 4. If the behaviours were coded with 0 it meant that is was classified identical by the evaluation software and if coded with 1 it was given a different classification. In Table 5 the, in this research interpreted as identical, classification per behaviour is given based on the classification of the evaluation software as shown in table 1.

Table 4: Example of comparing the oral behaviour drinking with the classification by the evaluation software RumiWatchConverter.

Observation	Horse	Oral behaviour	Classification by evaluation software	Agreement
1	7	Drinking	2	1
2	7	Drinking	2	1
3	7	Drinking	2	1
4	7	Drinking	2	1
5	8	Drinking	2	1

Table 5: Guideline used in this research for identical classification of visual video observations liked to the software classification

Behaviour	Identical classification by evaluation software
Foraging	0 = other activity
Chewing roughage	2 = eating
Chewing concentrates	2 = eating
Drinking	4 = drinking
Licking	0 = other activity
Tongue movements	0 = other activity
Cribbing	0 = other activity
Flehmen response	0 = other activity
Scratching	0 = other activity
Other behaviour	0= other activity

4. Results

4.1 Results trial 1: Comparison of means of visually and automatically detected chewing movements

The numbers of chewing movements measured visually in 10-min periods of time, when horses stabled on straw had no food available, differ from 0 to 425 chewing movements amongst the total of 15 measurement periods. In contrast to the chewing movements registered automatically, by the EquiWatchHalter, in 10-min periods of time, which vary from 0 to 809. An overview with the number of chews of al measurement periods is present in annex 2. In six out of 15 measurement periods there was a deviation of more than 200 chewing movements.

As shown in figure 11 and in table six, the average number of chewing movements counted through visual observation of all three horses was 103, in comparison to the automatic measurement system, the EquiWatchHalter, with 256 chewing movements.

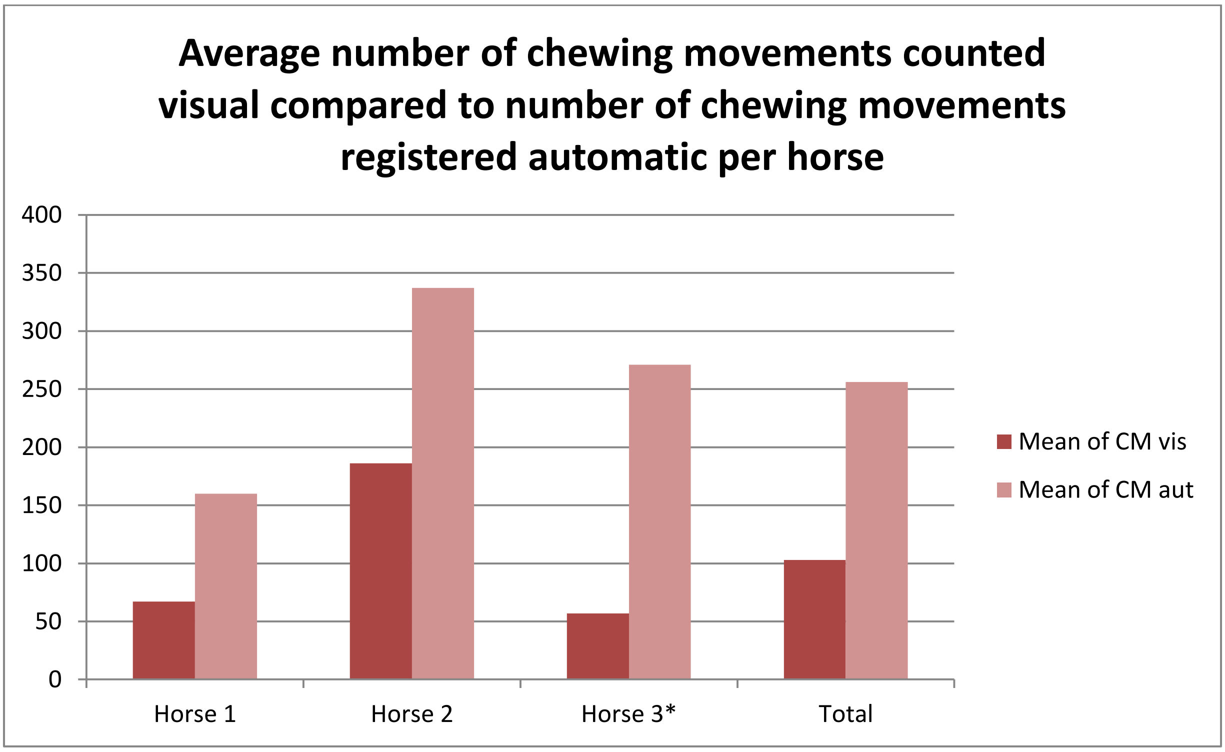


Figure 11: Average number of chewing movements (CM) counted visual (vis) compared to number of chewing movements (CM) registered automatic per horse.

***= horse performing stereotypic behaviour cribbing**

In table 6 the average number of chewing movements counted by visual observation was compared to the number of chewing movements registered by the EquiWatchHalter. This table provides the deviation between these two parameters in number of chewing movements. This results in a total deviation, of the averages of all three horses, of plus 153 chewing movements.

Table 6: Mean of chewing movements counted visual and registered automatic per horse and the average deviation in number of chewing movements.

Horse	N	Mean of CM vis	Mean of CM aut	Average deviation in number of CM
Horse 1	5	67	160	+93
Horse 2	5	186	337	+151
Horse 3*	5	57	271	+214
Total	**15**	**103**	**256**	**+153**

N=number of measurement periods per horse

* = Horse performing stereotypical behaviour cribbing

CM=chewing movements

4.2 Results trial 2: Comparison of visually observed oral behaviour in horses with the classification made by evaluation software RumiWatchConverter

In total a frequency of 349 observations took place divided over 10 oral behaviours in horses. In figure 12 the total division of all observed oral behaviour in horses is provided. This figure shows that in 112 out of 349 observations other behaviour was performed by the horse, which covered 32,1 % of all observations. The secondly most performed oral behaviour was chewing roughage which covered 27 % of all observations. With a difference of six observations 25,5% of the observations was covered by the oral behaviour foraging. This shows that foraging behaviour and chewing roughage were the two oral behaviours that were the most commonly performed by the horses during the periods the horses were filmed and that these two behaviours together cover more than 50% the of the total (n=349) observations. In annex 3 the division of the frequency of the observed oral behaviour in horses is presented in percentage.

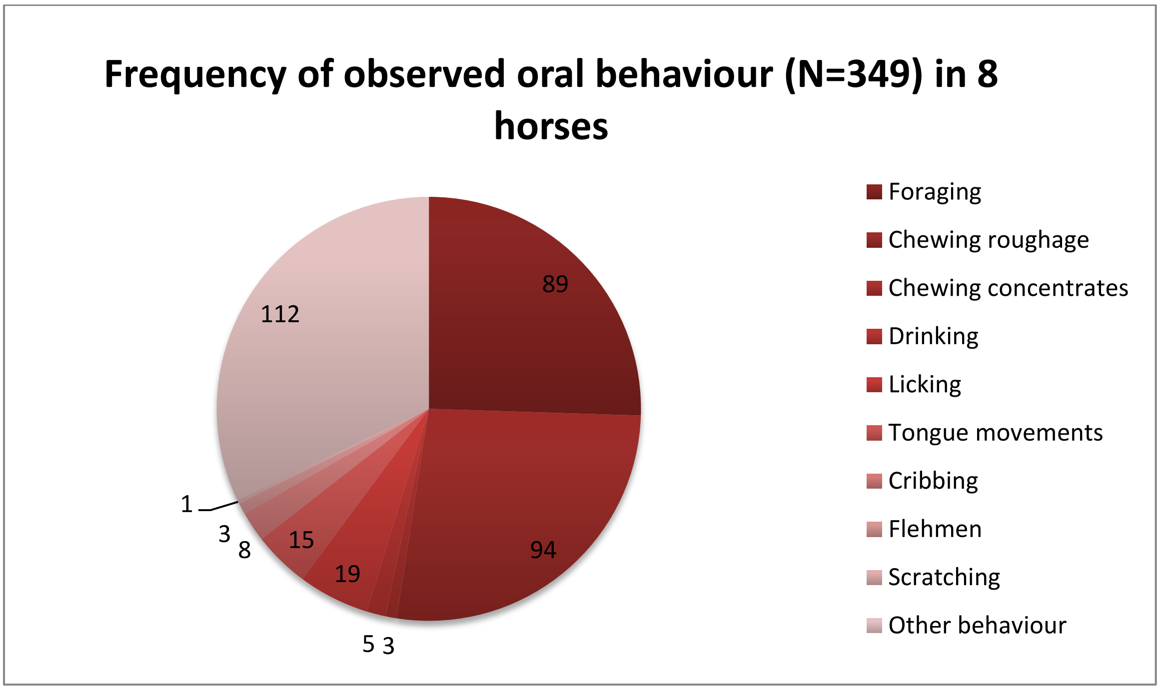


Figure 12: Division of frequency of observations per oral behaviour.

According to the classification per behaviour as given in table 5, 108 out of 349 observations, of oral behaviour in horses, have been classified with the identical classification by the evaluation software RumiWatchConverter. This means that more than 50%, namely 69%, of the observations is classified differently by the RumiWatchConverter compared to the visual classification.

4.2.1 Results trial 2 per oral behaviour

Foraging

The oral behaviour foraging was observed 89 times as shown in figure 12 and is classified, by the RumiWatchManager, as eating 52 times, as ruminating 32 times and only 5 times as other activity.

Chewing roughage

The oral behaviour chewing roughage, which should be classified by the RumiWatchManager as eating according to table 5, was observed with a frequency of 94 and was classified as ruminating 43 times, as eating 46 times and as other activity five times.

Chewing concentrates

Chewing concentrates was only observed 3 times. Two out of these three observations have been classified as eating and one of the three observations was classified as ruminating.

Drinking

Drinking was performed five times in total and all these observations were classified as eating.

Licking

The oral behaviour licking was performed 19 times in this examination. Eight out of 19 observations licking was registered as other activities. Licking was detected five times as eating and five times as ruminating. Additionally one of the observations of licking was classified as drinking.

Tongue movements

Tongue movements were classified as other activity, in 11 out of the 15 observations. Out of the four other classifications tongue movements were classified as eating and drinking once and as twice as ruminating.

Cribbing

Cribbing was classified two times as other activities. Out of the other observations cribbing was classified as drinking once, as eating twice and three times as ruminating.

Flehmen response

The oral behaviour flehmen was observed three times. This behaviour was classified once as ruminating and twice as eating.

Scratching

Scratching was observed once and was classified as ruminating.

Other behaviour

The other behaviour was classified as other activity 34 out of 112 observations. The 78 observations that were classified, where classified as ruminating 43 times, as eating 32 times and three times as drinking.

In table 7 an overview of the classifications per oral behaviour in horses is provided.

Table 7: Division of classification by RumiWatchConverter per observed behaviour

Classification by RumiWatchManager → Observed oral behaviour ↓	**Total N per observed behaviour**	**0= other activity**	**1= ruminating**	**2= eating**	**4= drinking**
0= other behaviour	112	34	43	32	3
1= foraging	89	5	32	52	0
2= chewing roughage	94	5	43	46	0
3= chewing concentrates	3	0	1	2	0
4= Drinking	5	0	0	5	0
5= licking	19	8	5	5	1
6= Tongue movements	15	11	2	1	1
7= Cribbing	8	2	3	2	1
8= flehmen	3	0	1	2	0
9= scratching	1	0	1	0	0
Total N per Classification	**349**	**65**	**131**	**147**	**6**

N = number of observations

4.2.2 Results trial 2 per classification of RumiWatchConverter

Out of the total of 349 observations ruminating, 131 times, and eating, 147 times, were the most common classifications made by the evaluations software RumiWatchConverter. In figure 13 the distribution between the frequencies of the given classifications given by the evaluations software per category of the evaluation software RumiWatchConverter.

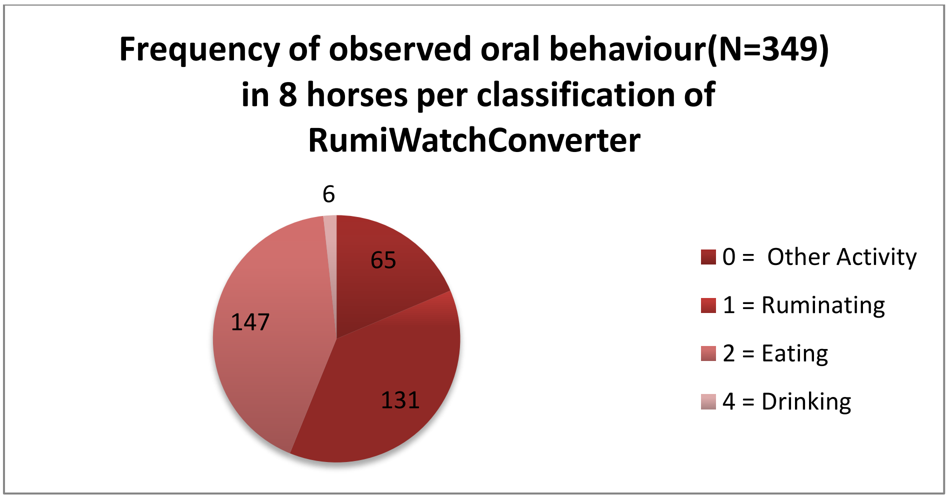


Figure 13: Division of observations per classification of evaluation software RumiWatchConverter.

As shown in table 7 the classification, by the evaluation software, other activity (classification 0 by RumiWatchConverter) was given to the behaviour other behaviour in 34 out of the 65 observations. The other 31 observations that were classified, by the RumiWatchConverter, as other activity, were given to the oral behaviours foraging (5 times), chewing roughage (5 times), licking (8 times), tongue movements (11 times) and cribbing (2 times).

Ruminating

The classification ruminating (classification 1 by RumiWatchConverter) was given to a total number of 131 observations. As shown in table 7 the classification ruminating was given to mostly to the following three oral behaviours: foraging (32 times), chewing roughage (43 times) and other behaviour (43 times).

Eating

The classification eating (classification 2 by RumiWatchConverter) was classified to the oral behaviour chewing concentrates twice and chewing roughage 46 times. Out of the other 99 observations that were classified as eating in 32 observations the horses were performing other behaviour and in 52 of the observations the horses were performing foraging behaviour. The other 15 observations were divided over the other observed oral behaviours as shown in table 7.

Drinking

Only in six observations the behaviour was classified as drinking (classification 4 by RumiWatchConverter). In none of these observations the horse was actually drinking. The classification drinking was given in three of the six cases when a horse was performing other behaviour. The other three classifications where given to the oral behaviours licking, once, tongue movements, once, and cribbing, once, as shown in table 7.

5. Discussion

5.1 Practical points of discussion

Filming of the horses was performed spread over three days at two different barns with the aim to get as much different oral behaviours of horses on video. The quality of the videos was influenced by the light in the barn, the person filming but also the activity and curiosity of the horse. In one of the two barns the light was minimal, which made it difficult to get a good quality film. Therefore, some parts of the video were to dark and could not be analysed. The same happened when horses were very active in the stall. These horses were difficult to follow with the camera as well as the horses that were very curios and came real close to the camera at some points. Two out of the three filming days the observer was by herself and had to film and for instance feed concentrates by herself. This caused a lot of camera movements sometimes during filming. The one time there was one person to assist and this worked better and the quality of the videos was better. Within the 165 minutes of video it happened 15 times that a horse had disappeared from view for a short period or that it was too dark to detect the oral behaviour the horse was performing.

While analysing the videos in some of the observations one behaviour got classified in more than once category by the evaluation software, RumiWatchConverter. This happened when the RumiWatchConverter changed its categories while the observations still took place and same behaviour was still performed. If an observation was classified in two classifications this could be due to a delay, for instance 1 second, between starting the camera to film and the time set on the laptop and so with the RumiWatchConverter because this time was synchronized with the laptop. In periods of foraging and chewing roughage double classifications as ruminating and eating could be caused due to changes in the rhythm of the chewing movements made by the horse. The RumiWatchConverter recognizes a certain rhythm in the pressure peaks and classifies jaw movements based on this rhythm. If a change in rhythm of chewing is caused by a horse the RumiWatchConverter might detect the movements at ruminating instead of eating or as eating instead of ruminating.

As horses do not ruminate in the second trial of this research the classification ruminating by the evaluation software RumiWatchConverter was, in the agreement, classified as incorrect at all times. However, as ruminating in cows is still classified when jaw movements are performed it could be discussed wheatear the classification ruminating should be classified as incorrect at all times or in case the horse is chewing roughage or concentrates as correct.

Another point of discussion is the observation of foraging behaviour in horses. During periods of foraging the observer concluded that while horses perform foraging behaviour it also eats and therefore performs chewing movements. However, while analysing the videos it was hardly possible to distinguish foraging behaviour form eating while performing foraging behaviour. Therefore, in this research no distinction has been made between chewing while foraging and foraging alone. In further research the foraging behaviour of horses should be observed better to see if the EquiWatchHalter in combination with the RumiWatchConverter is able to distinguish these two oral behaviours performed together from each other.

5.2 Discussion results of trial 1

The span of the visual counted chewing movements in trial 1 ranged from 0 to 425, compared to a span range from 0 to 809 in automatically registered chewing movements. This might be due to the fact that the one horse is performing more foraging behaviour in straw as the other and that the one horse might be eating more straw compared to the other. Also the time of the measurement might have an effect on the number of chews counted because a horse might show less foraging behaviour when it has just eaten its food. It might be difficult for the measurement system to make a distinction between foraging behaviour and chewing behaviour of horses which might cause the large differences between the visual counted chews and the automatically registered chews.

The results of the first trial show a difference of plus 154 chewing movements between the average number of chewing movements counted through visual observation and the average number of chewing movements registered by the EquiWatchHalter. The average number of chewing movements registered by the EquiWatch is more than double the average number of the chewing movements counted through visual observation.

Compared to the research of Werner et al. (2014), who found a difference of 52 chewing movements between the average number of chewing movements counted through visual observation and the average number of chewing movements registered by the RumiWatchHalter, this is a large difference. However, the results of the research done by Werner et al. (2014) were calculated over a lot more (n=56) 10-minute observation periods compared to 15 10-minute observation periods in this research and in this research horses were observed while they had no food available while in the study by Werner et al. (2014) the periods of counting chewing movements took place while horses were fed hay.

This might also explain the larger difference between the average number of chewing movements counted through visual observation and the average number of chewing movements registered by the EquiWatchHalter. The horse performs other different behaviour because it is not eating and the chance of registering performed oral behaviour as chewing movements, by the EquiWatchHalter, is present.

The large difference between the numbers of chewing movements counted through visual observation and the numbers of chewing movements registered by the EquiWatch in horse 3 could also indicate this. This is the horse performing the stereotypic behaviour cribbing. These cribbing movements have not been counted while visually counting the chewing movements and might possible have been detected as chewing movements by the EquiWatchHalter what causes the large differences between the two measurement methods in this horse.

5.3 Discussion results of trial 2

The oral behaviour foraging was classified by the evaluation software as other activity, which is in this research interpreted as the identical classification, in only 0,6% of the cases. It is suggested that this might be because of the fact that chewing while foraging difficult to distinct from foraging only by analysing the videos. This might be supported with the fact that 58,4% of the observations of foraging was registered as eating by evaluation software the RumiWatchConverter.

Something that was remarkable while analysing the videos was that short periods of other behaviour, for instance short pauses in performing certain behaviour where most of the time not recognized as another behaviour, than the previous performed behaviour, by the RumiWatchConverter and these periods were classified the same as the behaviour that was performed in the previous observation. This suggests that the evaluation software is not able to differentiate really short periods of other behaviours of pauses in a certain performed behaviour.

The results of all observations that were done showed that 241 out of all observations, which were 349 observations, were classified differently. This result was possible influenced by the negative results of the observations of the foraging behaviour. What also has an influence on this negative overall result is the fact the ruminating was classified as incorrect at all times.

The results of the oral behaviour drinking indicate that the evaluation software might not be able to recognize drinking in horses. The oral behaviour drinking was performed by the horses five times and none of these five observations was classified as drinking. However, the classification drinking was given to an observation six times. As was described in none of these cases the horse was actually drinking but the classification drinking was given to the behaviours licking, tongue movements and cribbing once and to the other behaviour three times. This supports the suggestion that the RumiWatchManager is not able to detect drinking behaviour in horses. Zehner et al. (2012) did research to the validation of the RumiWatch on water intake behaviour in cattle. Zehner et al (2012) found a specific pressure profile of water intake recorded by the noseband sensor of the RumiWatchHalter in cows. The pressure profile that was found was clearly distinguishable from those of rumination and feed intake in cows. This pressure profile is based on the jaw movements made by the cow while drinking. However, horses hardly move their jaws while drinking.

The classification eating, by the RumiWatchConverter, was classified incorrectly in 99 out of 147 cases. The classification eating was given to the oral behaviour foraging in 52 out of the 99 incorrect classifications. This was possible due to the fact that horses are eating and so chewing while they are preforming foraging behaviour which could nog be distinguished while analysing the videos.

6. Conclusion

The results of the research done with the RumiWatchHalter on horses, while eating different types of food, by Werner et al (2014) have shown that it is feasible to use the automatic measurement system RumiWatch for horses. The mean deviation in percentage between visual and automatic observations was approximately 8% in total, which was according to Werner et al (2014) highly encouraging regarding the fact that the system was developed for cows.

However, the results of trial one of this investigation demonstrate that there is a much bigger difference between the measurement of counting chewing movements by visual observation and the chewing movements registered by the EquiWatchHalter when no food is available for the horse. This was calculated over less recorded 10-minute periods and might be influenced by the crib-biting horse but still indicates that a large amount of noise data saved as chewing movements by the EquiWatch.

This concludes that there were movements of the horse its jaw recorded automatically as chewing movements, which were not counted as chewing movements by visual observation. These movements of mandibular motion could be other oral behaviours such as licking, biting or cribbing. This can be substantiated with the results of the second trial of this study. These effects of these other oral behaviours have been examined in the second trial of this research and the results of this trial are presented in the next chapter of this report.

The results of the second trial of this research demonstrate that out of 349 observations of oral behaviours in horses, 241 observations have been classified incorrectly by the evaluation software RumiWatchConverter. This means that more than half of the observations of the oral behaviour of horses are classified incorrectly. The classification eating was given to a number of 147 observations were as only in 48 of the cases the horses were actually showing eating behaviour. This concludes that there are oral behaviours performed by the horses that cause jaw movements, which are registered as chewing movements, which are actually not chewing movements. For instance the oral behaviour licking was classified as eating five out of 19 observations. The oral behaviour foraging was classified as eating in 52 out of 89 observations. This substantiates the fact that there are jaw movements and oral movements performed by the horse that are classified as chewing movements. The results of all oral behaviours performed and the percentage of correct classifications is added in annex 4. The results of all four classifications ant their percentage of correct classifications is added in annex 5.

The results of this research also conclude that the oral behaviour drinking in horses cannot be detected by the RumiWatchConverter in its current state. The oral behaviour drinking was observed five times and was in none of these five cases registered as drinking. However, the classification drinking was given to six observations and in none of these cases the horse was actually drinking.

In conclusion, based on the outcome of this study, the EquiWatch is not a reliable measurement system for the registration of equine chewing activity. To increase the reliability of the EquiWatch, the recording of chewing activity needs to be optimized and the evaluation software needs to be changed to make it more suitable for horses. The analysing algorithm, developed for cattle, needs to be adapted to consider the specific eating and chewing behaviour of horses.

7. Recommendations

The EquiWatchSystem is not, yet, suitable for 24 hour measurements or measurements of longer periods, which is the final goal for Pavo as mentioned earlier. This is because of the fact that within 24 hour measurement periods, there will be periods present when horses are left without food. This will result in a large amount of noise data caused by foraging behaviour in straw and other oral movements that are registered as chewing and so does not provide a reliable measurement.

Therefore, it is recommended to the Dutch equine feed company Pavo to wait with performing 24 hour of longer measurements with the EquiWatchHalter on horses until the system is further developed and the evaluation software is optimized and adapted to horses and only use the EquiWatch for small periods of feeding a certain feed. What is recommend to Pavo is to keep performing test researches for instance on shavings or flax to find out if this causes the same amount of noise data or maybe this causes less noise data and is a more reliable option for measurements of longer periods of time.

Pavo can also use the EquiWatch for the measurement of chewing activity of horses between different feed types. The research by Werner et al. (2014) has shown that the EquiWatch is a reliable to for the measurement of chewing activity while eating so this is an option for Pavo.

To the developers of the EquiWatch it is recommended to do in depth research to the oral and feeding behaviour of horses so that the system and algorithm can be adapted to horses and tested later on. It is also recommended to change the evaluation software to horses and remove the rumination classification so that there is one evaluation software present for horses and a different one for cattle so that there a no numbers given on ruminating chewing movements in horses. Therefore, more research need to be done to find out if the classification ruminating can just be used as chewing in horses or that is need to be removed from the software.

References

Alexander, F. (1966) ''A study of parotid salivation in the horse''*. Journal of Physiology,* 184, 646-656

Alexander, F., Hickson, J. C. D. (1970) The salivary and pancreatic secretions of the horse. In: Phillipson, A. T. (ED.), *Physiology of Digestion and Metabolism in the Ruminant.* Oriel Press, Newcastle upom Tyne, pp.375-389.

Asheley, F. H., Waterman-Pearson, A. E., Whay, H. R. (2005) Behavioural assessments of pain in horses and donkeys: application to clinical practice and future studies. *Equine Veterinary Journal,* 37, 565-75.

Bonin, S. J., Clayton, H. M., Lanovas, J. L. et al. (2007) Comparison of mandibular motion in horses chewing hay and pellets. *Equine Veterinary Journal 39,* 258-262.

Boswinkel, M. A., Ellis, A. D., Sloet van Oldruitenborgh-Oosterbaan, M.M. (2007) The influence of low versus high fibre haylage diets in combination with training or pasture rest on equine gastric ulceration syndrome (EGUS). *Pferdeheilkunde 23,* 123-130, 2007

Brambell, R. (1965) Report of the Technical Committee to Enquire into the Welfare of Animals kept under Intensive Livestock Husbandry Systems. Her Majesty's Stationary Office. London.

Brøkner, C., Nørgaard, P., Hansen, H. H. (2009) Effect of feed type and essential oil product on equine chewing activity*. Journal of Animal Physiology and Animal Nutrition,* 92, 621-30.

Brøkner, C.; Nørgaard, P.; Søland, T. M., 2006: The effect of grain type and processing on equine chewing time. *Pferdeheilkunde* 22, 453–460.

Brüssow, N., Voigt, K., Vervuert, I., Hollands, T., Cuddeford, D., Coenen. M. (2005) The effect of the order of feeding oats and chopped alfalfa to horses on the rate of feed intake and chewing activity. *Equine Nutrition Conference Hannover.*

Carmalt, J. L., Allen, A. (2008) The relationship between cheek tooth occlusal morphology, apparent digestibility and ingesta particle size reduction in horses. *Journal of the American Veterinary Medical Association,* 233, 452-5.

Clayton, H. M., Bonin, S. J., Johnson, T., Lanovaz, J. L., Mullineaux, D. R. (2003) Three- dimensional movements in the temporomandibular joint in horses chewing hay and pellets. *In: Proceedings of the 18th Equine Nutrition an Psycology Society Symposium,* Michigan State University, East Lansing, MI, USA, 4-7 June 2003, p. 282

Cooper, J. J., Albentosa, M. J., (2005) Behavioural adaptation in the domestic horse: potential role of apparently abnormal responses including stereotypic behaviour. *Livestock Production Science* 92, 177–182.

Cooper, J. J., Mason, G. J. (1998) The identification of abnormal behaviour and behavioural problems in stabled horses and their relationship to horse welfare: a comparative review. *Equine Veterinary Journal* 27, 5-9.

Davies, Z. (2005) Introduction to horse biology*.* Oxford: Blackwell publishing.

Davies, Z. (2009) Introduction to horse nutrition. Oxford: Wiley-Blackwell.

Dixon, P/ M., Tremaine, W. H., Pickles, K., et al. (2000) Equine dental disease part4: a long-term study of 400 cases: apical infections of cheek teeth. *Equine Veterinary Journal,* 32, 9-18.

Duphey, J.P., Martin-Rosset, W., Dubroeucq, H., et al (1997) Compared feeding patterns in ad libitum intake of dry forages by horses and sheep*. Livestock Production Science 52,* 49-56.

Du Toit, N., Burden, F. A., Dixon, P. M. (2009) Clinical cental examinations of 357 donkeys in the UK. Part 2: Epidemiological studies on the potential relationships between different dental disorders, and between dental disease and systemic disorders. *Equine Veterinary Journal,* 41,395-400.

Ellis, A. (2004) Paard en Voer. Praktische gids voor gezond voeren en beweiden. Zutphen: Roodbont Uitgeverij.

Ellis, A. D., Thomas, S., Arkell, K., Harris, P. (2005) Adding chopped straw to concentrate feed: the effect of inclusion rate and particle length on intake behaviour of horses*. Pferdheilkunde,* 21, 35-7.

Ellis, A. D., Hill, J. (2005) Digestive physiology of the Horse*. In: Nutritional Physiology of the Horse*. Nottingham University Press, Nottingham UK, pp. 7-41.

Ellis, A. D. (2010) Biological basis of behaviour and Feed Intake, In: A.D. Ellis, A.C. Longland, M. Coenen, N. Miraglia, 2010. *The impact of Nutrition on the Health and Welfare of Horses*, EAAP Publication No. 128, Wageningen Academic Publishers, pp. 53-74

Ellis, A.D., Fell, M., Luck, K., Gill, L., Owen,H., Briars, H., Barfoot, C., Harris, P. (2015) Effect of forage presentation on feed intake behaviour in stabled horses. *Applied Animal Behaviour Science*.

Frape, D. (2010) Equine Nutrition and Feeding. Oxford: Wiley-Blackwell.

Geor, R. J., Harris, P. A., Coenen, M.(2013) Equine Applied and Clinical Nutrition*.* Saunders Elsevier.

Greet, T. R. C., Rossdale, P. D. (1987) The digestive system. *Veterinary notes for Horse Owners,* ed.: P. D. Rossdale, Stanley Paul and Co. Ltd., London. PP 5-24

Hampson, B. A., de Laat, M. A., Mills, P. C., & Pollitt, C. C. (2010). Distances travelled by feral horses in 'outback' Australia. *Equine Veterinary Journal*, *42*(s38), 582-586.

Hansen, R. M. (1976) Foods of free-roaming horses in Southern New Mexico. *J Range Manag. 19,* 437.

Harris, P. A., Silence, M., Inglis, R., et al. (2005) Effect of short (<2 cm) Lucerne chaff addition on the intake rate and glycaemic response of sweet feed*. Pferdheilkunde,21, 87-8.*

Hothersall, B., Casey, R. (2011) Undesired behaviour in horses: A review of their development, prevention, management and association with welfare. *Equine Veterinary Education* 24, 479–485.

Houpt, K. A., Elia, J., Stalker, M, (2004) Roughage craving in horses*. Proceeding of the 38th International Congress, ISAE,* Helsinki, Finland, P.78.

Elia, J. B., Erb, H. N., Houpr, K. A. (2010) Motivation for hay: Effect of a pelleted diet on behaviours and physiology of horses. *Physiology & behaviour 10.*623-627

Lowder, M. Q., Mueller, E. (1998) Dental disease in geriatric horses. *Veterinary clinics of North America Equine 14 (2)*, 365-380.

MacFadden, B. (1994) Population dynamics, behavioural ecology and paleothology. In: *Fossil horses. Systematics, Paleobiology and evolution of the Family Equidea,* Cambridge university press, Cambridge. Pp 263-297

Malamed, R., Berger, J., Bain, M. J., Kass, P., Spier, S. J., (2010) Retrospective evaluation of crib-biting and windsucking behaviours and owner-perceived behavioural traits as risk factors for colic in horses. *Equine Veterinary Journal* 42, 686–692.

McGowan, T. W., (2009) Aged Horse Health, Management and Welfare. PhD thesis University of Queensland, Brisbane, Australia.

McGreevy, P. D., French, N. P., Nicol, C. J. (1995a) The prevalence of abnormal behaviours in dressage, eventing and endurance horses in relationship to stabling. *Veterinary record* 137, 36-7.

McGreevy, P.D., Cripps, P.J., French, N.P., Green, L.E. and Nicol, C.J. (1995b) Management factors associated with stereotypic and redirected behaviour in the Thoroughbred horse. *Equine veterinary Journal* 27, 86-91.

McGreevy, P. D., Nicol, C. (1998) Physiological and behavioural consequences associated with short-term prevention of crib-biting in horses. *Physiology & Behaviour* 65, 15–23.

Meyer, H., Ahlswede, L., Pferdekamp, M. (1975) Untersuchungen über Freßdauer, Kaufrequenz und Futterzerkleinerung beim Pferd. *Deutsche Tierärztliche Wochenschrift,* 87, 49-96.

Meyer, H., Coenen, M., Grurer, C. (1985) Investigation of saliva production and chewing in horses fed various feeds*. Proceedings of the Equine Nutrition and Physiology Society*, East Lansing MI, pp. 38-41.

Meyer, H., Coenen, M., Prost, D. (1986a) Digestive physiology of the horse. 14 Feed insalivation and passage in the equine upper intestinal tract. *Journal of Animal Physiology and Animal Nutrition* 56, 171-183.

Meyer, H., Coenen M. and Probst D. (1986b): Beiträge zur Verdauungsphysiologie des Pferdes. 14. Mitteilung: *Futtereinspeichelung und –passage im Kopfdarm des Pferdes*. J Anim Physiol a Anim Nutr 56, 171-183

Mills, D., Nankervis, K. (1999) Equine Behaviour: Principles & Practice. Oxford: Blackwell Publishing company.

Moeller, B. A., McCall, C. A., Silverman, S. J. (2008) Estimation of saliva production in crib-biting and normal horses. *Journal of Equine vetrenary Science28,* 85-90.

Müller, C. E. (2009) Long-stemmed vs. Cut haylage in bales-Effects on fermentation, aerobic storage stability, equine eating behavior and characteristics of equine faeces. *Animal Feed Science and Technology 152.*307-321

Nydegger, F., Gygax, L., & Egli, W. (2011) Mesure automatique des mouvements de rumination par capteur de pression. *Recherche Agronomique Suisse*, 2, 60-65.

Nickel, R., Schummer, A., Seiferle, E. (1979) The Viscera of Domestic Animals, 2nd rev edn by Schummer A, Nickel R, Sack Wo. Springer-Verlag, New York, pp. 180-198.

Putman, R. J., Pratt, R. M., Ekins, J. R., Edwards, P. J. (1987) Food and feeding behaviour of cattle and ponnies in the New Forest, Hampshire. *J. appl. Ecol.* 24. 369-380

Ralston, S. L., Foster, D. L., Divers, T., Hintz, H. F. (2001) Effect of dental correction on feed digestibility in horses. *Equine Veterinary Journal,* 33, 390-93.

Sisson, S., Grossman, j. D. (1959) *The Anatomy of Domestic Animals, fourth ed*. W. B. Saunders co. Philadelphia, pp. 406-407.

Stick, J. A., Robinson, N. E., Krehbiel, J. D. (1981) Acid-base and electrolyte alterations associated with salivary loss in the pony. *American Journal of Veterinary Research, 42,* 733-737

Vervuert, I., Brüssow, M., Bochnia, M., Cuddeford, D., Coenen, M. (2012) Electromyographic evaluation of masseter muscle activity in horses fed (i) different types of roughage and (ii) maize after different hay allocations. *Journal of Animal Physiology and Animal Nutrition 97,*515-521

Werner, J., Zehner, N., Umstatter, C., Nydegger, F., Schick, M. (2014). Application of a noseband pressure sensor for automatic measurement of horses' chewing activity: a pilot study. *International conference of Agricultural Engineering*, Zurich.

Zehner, N., Niederhauser, J. J., Nydegger, F., Grothmann, A., Keller, M., Hoch, M., Haeussermann, A., Schick, M. (2012) Validation of a new health monitoring system (RumiWatch) for combined automatic measurement of rumination, feed intake, water intake and locomotion in dairy cows. Liestal, Switzerland.

Zehner, N., Werner, J., Nydegger. F., Umsätter, C., Wyss. C., Hock. M., Schick. M. (2014) EquiWatch-Eine neue Methode zur Erfrassung der Kauaktivitët bei Pferden. *Agroscope Science 3.*

Zeitler-Feicht, M. H. (2008). Handbuch Pferdeverhalten: Ursachen, Therapie und Prophylaxe von Problemverhalten. Ulmer.

Annex

Annex 1: Additional information about the horses used for the experiments.

Horse	Name	Gender	Age	Breed
1	Fien	Mare	19	KWPN
2	Ruby	Mare	17	KWPN
3	Joule	Gelding	23	KWPN
4	Simone	Merrie	17	Gelders horse
5	Velvet	Merrie	13	KWPN
6	Wizard	Gelding	12	KWPN
7	Casper	Gelding	8	KWPN
8	Pernille	Mare	20	KWPN

Annex 2: Results of 10 min periods of measuring chewing movements counted visually and automatically including the deviation in number of chewing movements between these two methods.

Horse	Observation	CM vis	CM aut	Deviation of CM
1	1	94	186	+92
1	2	157	201	+44
1	3	0	0	0
1	4	82	415	+333
1	5	0	0	0
2	1	425	809	+384
2	2	387	699	+312
2	3	0	0	0
2	4	0	0	0
2	5	117	175	+58
3*	1	145	432	+287
3*	2	36	282	+246
3*	3	9	300	+291
3*	4	0	79	+79
3*	5	93	260	+167

CM vis = visual counted chewing movements
CM aut = Chewing movements counted by EquiWatch
Deviation= deviation between the CM measured visually and the CM measured automatically
*= horse performing the stereotypic behaviour cribbing.

Annex 3: Division of frequency of all observations per oral behaviour in percentage

Behaviour	N	percentage of number of observations
1. Foraging	89	25,5%
2. Chewing roughage	94	27,0%
3. Chewing concentrates	3	0,9%
4. Drinking	5	1,4%
5. Licking	19	5,4%
6. Tongue movements	15	4,3%
7. Cribbing	8	2,3%
8. Flehmen response	3	0,9%
9. Scratching	1	0,3%
10. Other behaviour	112	32,1%
Total	**349**	**100%**

N = number of observations

Annex 4: Percentage of correct classification per oral behaviour.

Oral behaviour	Total N	N classified correctly	percentage of observations correctly classified
1. Foraging	89	5	5,6%
2. Chewing roughage	94	46	48,9%
3. Chewing concentrates	3	2	66,7%
4. Drinking	5	0	0%
5. Licking	19	8	42,1%
6. Tongue movements	15	11	73,3%
7. Cribbing	8	2	25%
8. Flehmen response	3	0	0%
9. Scratching	1	0	0%
10. Other behaviour	112	34	30,4%
Total	**349**	**108**	**31%**

N = number of observations

Annex 5: Division of observations per classification of RumiWatchConverter.

Classification of RumiWatchManager	N	percentage of number of observations
0 = Other activity	65	18,6%
1 = Ruminating	131	37,5%
2 = Eating	147	42,1
4 = Drinking	6	1,7%
Total	**349**	**100%**

N= number of observations

Annex 6: Percentage of correct classification of RumiWatchConverter classifications.

Classification	Total N	N classified correctly	Percentage of observations correctly classified
0= Other activity	65	34	52,3%
1= Ruminating	131	0	0%
2= Eating	147	48	32,7%
4= Drinking	6	0	0%
Total	**349**	**82**	**23,5%**