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Straight from the horse's mouth

What we can learn about rein tension by observing horse behaviour

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Cover: Horse at the walk with light tension on the reins
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Abstract

Horse-rider-interaction is largely dependent on rein tension signals which, through pressure and release, communicate with the horse about pace, direction of travel and appropriate head posture. However, the pressures applied on the horse's mouth and/or head via the reins can cause pain and discomfort, leading to evasive behaviour and oral injuries. This thesis investigated rein tension signals from the perspective of equine behaviour and learning. Rein tension data were collected while backing up the horse from stand-still, with the handler standing next to the horse, comparing a bitted bridle with a soft halter, and in the ridden horse, making transitions from trot to walk using a bitted bridle. The results showed that rein tension signal magnitude could be reduced in a single training session through applying classical and operant learning principles. The rein tension signal was characterised by an increase in rein tension of less than 10 N (less than ~1kg) in each rein, regardless of baseline rein tension. Bit pressure elicited more evasive head/neck/mouth behaviour, with the main function to reduce oral pressure, compared with pressure on the nose from a soft halter. In terms of learning, the horses performed equally well with the halter and the bitted bridle. Thus studying horse behaviour can reveal the rein tension magnitude at which a horse feels comfortable and rein tension can be effectively reduced using the principles of classical and operant learning.

Keywords: rein tension, equine behaviour, equine welfare, equine learning, dressage, horse-back riding, horse-rider-interaction

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Tygelspänning från hästens perspektiv. Vad vi kan lära oss om tygelspänning genom att observera hästens beteende

Sammanfattning

Häst-ryttare-interaktion är till stor del beroende av tygelspänningssignaler som, genom tryck och eftergift, kommunicerar tempo, riktning och huvudposition till hästen. Dessvärre kan tryck från bettet i hästens mun, eller från ett bett-löst huvudlag, orsaka både smärta och obehag och därmed leda till undvikande beteende och munskador. Denna avhandlings syfte var att undersöka tygelspänningssignaler ur ett beteende- och inlärningsperspektiv. Tygelspänningssignaler undersöktes genom att samla in tygelspänningsdata både då hästen ryggades från stillastående, med tränaren ståendes bredvid hästen, jämförandes tränsbett med en mjuk grimma, såväl som hos den ridna hästen, genom övergångar från trav till skritt med tränsbett som utrustning. Resultatet visade att genom tillämpning av inlärningsprinciperna kunde tygelspänningssignalens kraft minskas till hälften under ett enda träningspass. Tygelsignalen karaktäriserades av en ökning av tygelspänning på mindre än 10 N (mindre än ca 1kg) i varje tygel, oavsett grundtygelspänning. Tryck från bettet framkallade mer undvikande huvud/hals/munbeteende hos hästarna jämfört med trycket på nosen från den mjuka grimman. Dessa beteendens huvudfunktion var att minska trycket i munnen från bettet. Inlärningsmässigt presterade hästarna lika bra med grimman som med tränsbettet. Slutsatsen från denna avhandling är att hästens beteende kan studeras för att avgöra om tygelspänningen som används ligger på en nivå som hästen känner sig bekväm med. Mängden tygelspänning kan effektivt minskas med hjälp av inlärningsprinciperna för klassisk och operant inlärning.

Nyckelord: tygelspänning, hästbeteende, hästvälfärd, hästinlärning, dressyr, ridning, interaktion mellan häst och ryttare

Dedication

To Sigge and Ralf, you are the light of my life.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Eisersiö, M., Byström, A., Yngvesson, J., Baragli, P., Lanata, A. & Egenvall, A. (2021). Rein tension signals elicit different behavioral responses when comparing bitted bridle and halter. *Frontiers in Veterinary Science* 8 (652015), 1-13.

II. Eisersiö, M., Yngvesson, J., Byström, A., Baragli, P. & Egenvall, A. (2021). A rein tension signal can be reduced by half in a single training session. *Applied Animal Behaviour Science* 243 (105452), 1-9.

III. Eisersiö, M., Yngvesson, J., Hartmann, E. & Egenvall, A. (2023). Gaping for relief? Rein tension at onset and end of oral behaviors and head movements in unridden horses. *Journal of Veterinary Behavior* 59, 8-14.

IV. Eisersiö, M., Egenvall, A., Yngvesson, J., Hernlund, E. & Byström, A. What is reinforced? The timing of the release of rein tension and the horse's response latency for trot to walk transitions (manuscript).

Papers I-III are reproduced with the permission of the publishers.

The contribution of Marie Eisersiö to the papers included in this thesis was as follows:

I. Outlined the research objectives, designed the experiment, carried out data collection, video analysis, data analysis, statistical analysis and writing (original draft, reviewing and editing).

II. Outlined the research objectives, designed the experiment, carried out data collection, video analysis, data analysis, statistical analysis and writing (original draft, reviewing and editing).

III. Outlined the research objectives, designed the experiment, carried out data collection, video analysis, data analysis, statistical analysis and writing (original draft, reviewing and editing).

IV. Outlined the research objectives, designed the experiment, carried out data collection, video analysis, data analysis, statistical analysis and writing (original draft).

1. Introduction

This thesis explores communication between horse and rider via the reins and the relationship between rein tension and horse behaviour. The reins act as a connecting link between the rider's hands and the horse's head, and thus have a major influence on the horse both physically and mentally (McLean & McGreevy, 2010). Horses generally wear a bridle with a bit in their mouth when trained and ridden, but various bitless alternatives are becoming increasingly popular among riders (Robinson & Bye, 2021). The bit is attached to the reins and, by applying tension on either a single rein or both reins, the rider can communicate desired changes of speed, direction and head posture to the horse (Steinbrecht, 1995). While this may sound easy and straightforward, communicating with the horse via the reins involves several challenges and may affect the horse's physical and mental welfare.

First, the horse is a prey animal and has to be calm and feel safe during all training. If the horse's flight response is activated during training, it will focus on survival and escape rather than communication and understanding of the rider's signals (Starling *et al*., 2016). The horse has to be given the opportunity to feel safe in the training environment and the rider has to communicate with the horse without causing flight responses or painful sensations from the signals. The horse's mouth and head have very sensitive tissues and excessive pressure from the bit or a noseband can cause both pain and fear (Mellor, 2020).

Second, for clear communication between horse and rider, the rider has to be aware of the principles of operant learning and what their signals actually communicate to the horse in terms of reinforcing the animal's responses (McLean, 2005). Unintentional reinforcement of incorrect responses will lead to confusion and frustration for both horse and rider (McGreevy & McLean, 2007).

Third, it takes a lot of riding skill to handle the reins properly, as the rider needs to have a supple, balanced seat in the saddle (Engell *et al*., 2016), softness in the arms to keep the hands still relative to the horse's mouth (Terada *et al*., 2006) and a feel for the timing, magnitude and duration of rein tension signals relative to the horse's responses and behaviours (Miesner *et al*., 2016).

In the past, the horse was mainly a working animal, used for transport, warfare and agricultural purposes (Kyselý & Peške, 2022). Nowadays, riding a horse is mainly a leisure activity, at least in the Western world. People ride and train horses because it is fun and increases their own sense of wellbeing (Schwarzmüller-Erber *et al*., 2021). The welfare of the ridden horse has therefore been scrutinised more thoroughly in recent years (Lesimple, 2020). Discussions about whether equestrianism has a social licence to operate have emerged lately (Douglas *et al*., 2022; Heleski, 2023) and stewards and judges at rider competitions are becoming more observant of rider misbehaviour towards their horses (FEI Code of Conduct, 2023). At international equestrian competitions, stewards check noseband tightness and oral health of the horse immediately after it leaves the competition arena (FEI Manual for Dressage Stewards, 2021). Blood, scars and lesions are reported and can lead to a warning and/or exclusion from competing for some time (FEI Warning Cards, 2023).

Swedish animal welfare legislation states that equipment should not cause the animal harm (SJVFS, 2019:26). Using rein tension to communicate with the horse involves a risk of causing pain and injuries, as applying excessive pressure to the horse's mouth and/or head can lead to pain and even injuries in many horses (Johnson & Porter, 2006; Tuomola *et al*., 2021a). Thus rein tension and rein tension signals should be given more attention in terms of the ridden horse's welfare.

The above-mentioned issues, along with other implications of rein tension are addressed in this thesis.

2. Background

Ever since horses were first domesticated around 6000 years ago, it is believed that some type of bit or headstall has been used to control and direct the horse (Anthony & Brown, 1991). Early bits were made of leather, antlers or other organic materials (Anthony & Brown, 1989), and bit wear on the second premolar in the upper jaw has been found in horses as early as 4000 BC (Anthony & Brown, 1991). Metal bits were developed during the 14th Century BC and various forms of bit have emerged since then, but the basic principles and appearance of the bit are still the same (Waran *et al.*, 2007). In modern times, a bridle with a bit is the most common headstall used in the Western world, but numerous bitless bridles and headstalls that press on various structures of the horse's head instead of the mouth are also available (Vogt *et al.*, 2019; Robinson & Bye, 2021).

2.1 The bit in the horse's mouth

2.1.1 Anatomy of the equine mouth

The horse is an herbivore and, over millions of years, its oral cavity has been adapted for eating grass, leaves and herbs. The front teeth, the incisors, bite off the grass, while the cheek teeth grind the food (Bonin *et al.*, 2007). The anterior cheek teeth are called premolars, while the rear cheek teeth are called molars. The first premolar is either absent, or rudimentary (a so-called wolf tooth), which can be present in the upper or lower jaw on one or both sides. Horses also have maxillary and mandibular canine teeth, although these are commonly rudimentary in mares.

The horse's teeth, consisting of enamel, cementum and dentin, are subjected to constant morphological changes throughout the horse's life due to substantial occlusal wear from foraging along with compensatory tooth eruption (Staszyk *et al*., 2015). If the teeth are not worn down evenly, *e.g.* due to insufficient amounts of forage or malocclusion, hooks and sharp enamel ridges can develop, leading to sores in the horse's oral cavity (Dixon & Dacre, 2005).

The horse's tongue is large and fills up most of the oral cavity. Depending on the size of the bit, the tongue may have to adapt in shape and position when a bit is placed in the horse's mouth (Engelke & Gasse, 2003; Anttila *et al*., 2022). Even before any pressure has been applied to the bit, it creates an indentation in the tongue and this indentation deepens as rein tension is applied (Clayton & Lee, 1984). When rein tension is applied, the tongue is pinched between the bit and the lower jaw (Clayton & Lee, 1984; Engelke & Gasse, 2003; McGreevy & McLean, 2010). This can cause the horse to retract the tongue and place it above the bit, likely to avoid or lessen the pressure on the tongue (Manfredi *et al*., 2010).

2.1.2 Bit-related oral injuries

When excessive pressure is applied repeatedly to tissues in the horse's mouth in the same locations over a long period of time, it may lead to micro traumas to the oral tissue and result in chronic ulcers (Uldahl *et al*., 2022). Other injuries to the soft tissues that may occur in the horse's mouth in connection with bridle use are wounds in the corners of the mouth from the bit (Uldahl & Clayton, 2019), damage to the buccal mucosa due to the noseband pressing the mucosa against the cheek teeth (Johnson & Porter, 2006) and damage to the palate from too long a snaffle bit that folds and presses against the palate (Manfredi *et al*., 2005). Even the mandible can be damaged during riding with a bit, in the toothless area between the incisors and cheek teeth (Jansson *et al*., 1998; Van Lancker *et al*., 2007).

Bit wear is another common bit-related injury where the bit rests against the premolars and damages those (Johnson & Porter, 2006). This is due to the bit being too long or tightened too high in the horse's mouth, or to the horse lifting the bit with the tongue and biting on it (Clayton & Lee, 1984), likely due to nervousness (Johnson & Porter, 2006) or in an attempt to relieve pressure on other sensitive areas (Manfredi *et al*., 2010).

Investigations on the oral health of competition horses post-competing have found that bit-related lesions are common in several different riding disciplines, including eventing horses (Tuomola *et al.*, 2021a), Icelandic horses (Björnsdóttir *et al.*, 2014) and dressage horses and ponies (Uldahl & Clayton, 2019).

As a rider and horse owner, it is important to be aware of the injuries that may occur in the horse's oral cavity from bit and bridle use. Wounds, pressure injuries and bit wear are rarely spotted unless an oral inspection is performed. According to recent recommendations, the anterior part of the horse's mouth should be examined daily by the rider (Tuomola *et al.*, 2021a), while a full mouth exam, including the rear part of the horse's mouth, is advised once a year using sedation and a mouth gag (Johnson & Porter, 2006).

2.1.3 Pressure

Whereas researchers have investigated the pressure created by nosebands (Casey *et al.*, 2013; Doherty *et al.*, 2017), there is not yet any research about factors that influence bit pressure distribution within the horse's mouth. Pressure is the amount of force that is applied on an area and can be calculated using the formula: Pressure = Force/Area. To estimate the risk of injury from a bit or a bitless bridle, the time during which the pressure is applied and the contact tissue's resistance to pressure must also be considered (Gefen *et al.*, 2022).

The size and fit of the bit and the smoothness of the bit surface determine the size of area subjected to pressure. For example, a thin bit will press on a smaller area in the horse's mouth and generate higher pressure than a thicker bit, even if the force is the same. However, a bit that is too thick for the horse will indent the tongue more and may lead to excessive pressure on the tongue (Anttila *et al.*, 2022). Likewise, if the bit has sharp edges, spikes or a pointed middle joint, the load will be distributed to even smaller areas and hence the pressure will be higher (McGreevy & McLean, 2010).

A smooth single- or double-jointed snaffle bit of a thickness that fits the horse's mouth is usually described as a "kind" bit (Tuomola *et al.*, 2021b). Likewise, a bitless headstall, *e.g.* a halter, with a wide, smooth, soft noseband is likely to be more comfortable for the horse and could be termed a "gentle" training tool (McGreevy & McLean, 2010). However, the most important component in rein tension magnitude and the pressures exerted on the horse's mouth/nose/head is the rein tension created by the rider/handler. The pressures applied will depend on rider signal behaviour (Egenvall *et al*., 2012), the magnitude of pressures the rider creates via the reins (Hawson *et al*., 2014; Eisersiö *et al*., 2015) and, most importantly, the rider's ability to make themselves understood (McGreevy & McLean, 2007).

Bit-related oral injuries are a highly relevant animal welfare problem, especially since horse owners can be completely unaware of these injuries and of how they occur (Johnson & Porter, 2006; Tell *et al*., 2008). Dental pain has been found to affect horse behaviour during handling and riding (Pehkonen *et al*., 2019) and it is therefore likely that painful sensations from the bit or bridle will affect the horse's overall behaviour (Cook & Kibler, 2019) or mouth behaviour (Manfredi *et al*., 2010) to a greater or lesser extent. Studying the horse's behaviour and facial expressions (Gleerup *et al*., 2015) in relation to rein tension and rein tension signals is thus of great importance for understanding how the horse perceives the pressure applied in terms of physical sensations and comprehension of rider communication.

2.2 Equine behaviour and learning

Understanding equine behaviour and how horses learn is the foundation for successful interactions between horse and rider (McGreevy & McLean, 2007). Domesticated riding horses still have the same behavioural needs and largely the same behavioural reactions and repertoire as wild horses (Feist & McCullough, 1976). The horse is still a grass-eating, social prey animal that prefers to live in herds on large, open areas (McGreevy, 2004). While modern horses have been bred to be cooperative and non-aggressive, it should be remembered that even after centuries of domestication, the horse is still not a riding animal by nature. With a rider on its back, the horse has to develop the strength needed to carry the rider in balance through various riding exercises, jumping obstacles and climbing hills (Miesner *et al*., 2016). The riding horse also has to learn the signals used for communication (McCall, 1990). The signals that riders use are generally tension or directing actions with the reins, weight shifts in the saddle via the rider's seat and pressure changes with the rider's legs on the horse's belly (McGreevy & McLean, 2010).

As a prey animal, the horse has to learn quickly how to act in different situations, *e.g.* when it is time to flee and when it is safe to continue grazing or resting. As a species, the horse is thus both very observant of changes and a quick learner. By interacting with herd mates, the horse also becomes skilled in understanding subtle signs of communication (Christensen *et al.*, 2002). Horses communicate with one another using body language and body positions, facial expressions involving the nose, mouth, eyes and ears, vocal sounds, smelling body odours and touches (Feist & McCullough, 1976). Touches can be friendly nuzzles and scratches, staying close with a herd mate, or play-biting and tumbling around (McDonnell & Poulin, 2002). Aggression in horses is (always) shown with the intent to create distance (McGreevy, 2004). Threats with aggressive body language, intended to intimidate the target, can escalate to physical interactions involving bites and kicks (McDonnell & Haviland, 1995). Horses that grow up in a herd with other horses, as most horses do, thus become skilled at reading body language and interacting with other individuals.

The combination of being a prey animal and a herd animal makes the horse an exemplary student in learning human body language, pressure signals and rider intentions. In other words, horses are very good learners and can learn new signals, or an exercise, in just a few repetitions, provided that the rider clearly explains what they want using the principles of learning.

Horse training mainly relies on the learning principles of associative learning, *i.e.* classical and operant conditioning, and non-associative learning, *i.e.* habituation and sensitisation (McLean & Christensen, 2017). These are universal principles of learning that apply to all species, including humans (Skinner, 1938), and are at play whether we are aware of them or not.

2.2.1 Associative learning

Classical conditioning

Classical conditioning is an important learning principle for riders to be aware of. The definition of learning through classical conditioning is that two previously unrelated stimuli become associated through the order of events (Cooper, 1998). In other words, chains of events become associated.

The fact that events close in time become associated was first discovered by Ivan Pavlov (1849-1936) during his physiology experiments (Pavlov, 1927). He began by measuring saliva excretion in dogs, but soon realised that his dogs started to salivate not only at the sight and smell of food, but as soon as the caretaker entered the room to serve the food. The sound of the caretaker coming through the entry door had become associated with eating food, since this sound and the food appeared close in time. More specifically, the sound of the caretaker always preceded the food. Pavlov then experimented to see if other sounds could be associated with food. He started ringing a bell before serving the dogs food and found that the dogs soon started to salivate at the sound of the bell. The sound of the bell thus predicted the arrival of food and had thereby become associated with eating.

In horse training, the principles of classical conditioning are invaluable for reducing the magnitude of pressure signals and for associating a new (lighter) signal to a previously learnt signal (McGreevy & McLean, 2007). By always starting out with a very light pressure signal in any request, before escalating the pressure, the horse will soon associate the light pressure signal with escalating pressure and respond already at the lighter signal (McLean & Christensen, 2017). Likewise, when training a horse *e.g.* to halt from a seat signal, *i.e.* a shift in weight in the saddle, instead of a rein signal, one should always start with the seat signal and then add the rein signal immediately afterwards (McGreevy & McLean, 2010). The seat signal will then predict the rein signal and thus become associated with the rein signal. Using classical conditioning, it is thus possible to train the horse to respond to lighter signals and thereby reduce the magnitude of rein tension needed for communicating with the horse (Baragli *et al*., 2015).

Operant conditioning

Operant conditioning involves the most crucial learning principles for riders to understand theoretically and apply in practice. The principles of operant conditioning were discovered during the 1900s and it is sometimes referred to as trial-and-error learning, as it involves the animal learning from the consequences of its own behaviour (Cooper, 1998).

One of the first researchers to document this was Edward Thorndike (1874-1949). He is most famous for his cat experiments, where he put a cat in a puzzle box containing a pedal. If the cat pressed on the pedal, the box opened and the cat could leave the box and was given food. In the first trials, it took a long time for the cat to (accidentally) press on the pedal, as the cat had not yet learned to associate pressing on the pedal with the box opening. However, through repetition, the cat formed an association between its own behaviour of pressing on the pedal and the box door opening, and then performed this behaviour faster and faster. The food given to the cat after getting out of the box increased the cat's motivation for escaping the box. Through trying different behaviours, the cat learned which behaviour that led to this favourable consequence (Thorndike, 1911).

In the 1950s, B.F. Skinner (1904-1990) further developed this framework to assess how animals and humans learn from the consequences of their behaviour, through investigating learning in pigeons (Skinner, 1938). Skinner discovered that the principles of operant conditioning can be divided into four different quadrants depending on whether a stimuli is added (positive) or withdrawn (negative) and whether this action leads to an increase (reinforcement) or decrease (punishment) in the same behaviour over time. Table 1 and the sections below provide further explanations.

Table 1. *Schematic description of operant conditioning with examples of practical use during training*

	Something is withdrawn (-)	Something is added (+)
Increasing behaviour (reinforcement)	*Negative reinforcement* (a pressure signal is withdrawn at the correct response)	*Positive reinforcement* (a food reward is added at the correct response)
Decreasing behaviour (punishment)	*Negative punishment* (scratches are withdrawn when horse is nuzzling back with too much force)	*Positive punishment* (a harsh voice is added as the horse does something dangerous)

Negative reinforcement

In horse training, the most common training method used is negative reinforcement, often referred to as 'pressure and release' in common language (Ahrendt *et al*., 2015). When sitting astride a horse, using a variety of pressures and touches is a convenient and suitable means of communication. The rider can shift their weight in the saddle in various ways, apply pressure or touches with one or both legs on the horse's belly and apply various pressures on the reins attached to a bit or a bitless bridle

(McGreevy & McLean, 2010). A common misconception is that these pressure signals are the most crucial component in the communication between rider and horse and the determining factor for successfully training the horse. In fact, it is the timing of the withdrawal of these pressure signals, or touches, which trains the horse to perform a particular response (McLean & Christensen, 2017). Horses are motivated to escape pressure, and the pressure signal thus motivates the horse into action. Initially, the horse may attempt a number of different behaviours. However, the horse will soon learn and remember the behaviour that led to release of pressure/touch and will perform that behaviour again in response to the same stimuli/pressure signal. In other words, the rider explains and confirms the correct response to the horse by releasing pressure/touch as soon as the horse performs that correct response (Ahrendt *et al*., 2015).

From the horse's perspective, quick, distinct and frequent releases of pressure provide information about the behavioural response that leads to release of pressure, and is thus necessary for effective learning (Baragli *et al*., 2015). Understanding how to relieve pressure is calming to the horse, as predictable and controllable situations lead to lower stress levels (McLean, 2005). On the other hand, relentless and/or harsh pressure from the rider's signals will infallibly lead to resistance and stress. If no behaviour leads to release of pressure, the horse will either become more and more stressed or habituate to the pressure and respond less to the pressure signals applied (McLean & McGreevy, 2010).

Since horses learn from the release of the pressure signals, the timing of the release is vital for reinforcing the correct response. If the release is given before or after the correct response, the rider is in essence reinforcing something else. Inconsistent release will confuse the horse and make responses less distinct (McGreevy & McLean, 2007).

Positive reinforcement

Primary reinforcers, something that is added that increase behaviour, are for horses, most often food and/or scratches (McCall, 1990). Praising the horse with the voice or patting the horse on the neck are generally secondary reinforcers, which means that they have to be learnt to be reinforcing (McGreevy, 2004). Praising the horse with the voice can thus become reinforcing to the horse if coupled (through classical conditioning) with the feeling of a content rider, rest, release of pressure signals and/or scratches or treats (McGreevy & McLean, 2010).

2.2.2 Non-associative learning

The learning principle habituation plays a large role in accustoming the horse to stimuli associated with being a riding horse (Christensen *et al*., 2006). Habituation means that the horse becomes desensitised and stops responding to a stimulus that is repeated, *i.e*. no flight reaction is shown at the sight, feel, smell or sound of that stimulus (Cooper, 1998). It is important that the horse habituates to the saddle, the rider and other stimuli from objects touching the horse or that is present in the surroundings. However, if the learning principles are not applied properly, the horse may also habituate to rider signals, as described above.

If a horse has become desensitised to a certain rider signal, the horse must be trained to be sensitised to this signal instead (McGreevy & McLean, 2010). This is effectively done through associative learning, using classical and operant conditioning, by always beginning with a light signal, followed by a timely release, as explained above. Sensitisation means that the horse responds more, *i.e*. exhibits a larger reaction, to a stimuli (McLean & Christensen, 2017). Unfortunately, horses may become sensitised to stimuli to which they should be habituated. If the horse is repeatedly frightened in a certain situation (*e.g*. loading on a horse trailer) or by a certain stimulus (*e.g*. electrical clippers), instead of being desensitised through low and gradual exposure, the flight response may escalate over time and with exposure (McGreevy, 2004). Thus habituation and sensitisation both play a major role when training the horse to be a calm and attentive partner, and whether this is successfully done largely depends on the skills of the horse trainer.

2.3 Horse-rider-interaction via the reins

As outlined in section 2.2, horses are keen learners. They can quickly learn a new exercise or signal, provided that the learning principles described above are used to explain the behavioural response that the rider wants to achieve. However, for the rider, learning how to ride and train a horse is much more complicated. Learning to ride a horse, and making progress as a rider, is a task that requires the rider to understand and recognise the horse's natural behaviour and how horses learn and communicate (McLean & Christensen, 2017). The rider also needs to develop balance, suppleness, stability and general body awareness (Wilkins *et al*., 2022), as well as an ability to control their emotions and destructive thoughts (Wolframm & Micklewright, 2011). Most importantly, the rider has to develop an "equestrian feel", which is perhaps the most difficult part of horseback riding. Equestrian feel is defined by Lundesjö Kvart and Melander Bowden (2022) as:

> "embodied knowledge encompassing riders' ability to feel the horse's actions and to act appropriately".

Becoming a skilful rider is thus a process that takes multiple years and most riders feel that there is always room for improvement in their skills as a rider and as a horse trainer.

Rein tension signals are an important part of the communication between horse and rider, and developing 'good hands' is a prerequisite for reaching higher levels in the art of riding and/or equestrian competitions. The equitation literature, both past and present, recommends that the contact between the rider's hand and the horse's mouth, *i.e*. the baseline rein tension, should be light (Ödberg & Bouissou, 1999; Miesner *et al*., 2016) and that the rider's hand should fluently follow the horse's movement and head movement (Steinbrecht, 1995; Terada *et al*., 2006).

The sensitivity of the horse's mouth, along with the ability for rein tension signals to affect the vertebral column (Rhodin *et al*., 2005) and balance of the horse (Harris, 2017), make rein tension signals a very delicate means of communication and it is recommended that all riders should be thoroughly educated in how to use their hands on the reins (Miesner *et al*., 2016).

2.3.1 Measuring rein tension

Measuring the tension created on the reins, which correlates to the magnitude of pressure the horse's mouth (or nose/head) is subjected to, is a technical challenge (Clayton *et al*., 2021). A rein tension meter has to be light-weight and small enough to not interfere with the normal handling of the reins. It also has to be durable and sturdy enough to withstand dirt, dust and moisture, temperature changes and being handled among horses (Clayton *et al*., 2003). In addition, the measurement range, sampling rate and resolution have to be adequate to cover the full spectrum of rein tension. A measuring range of 0-500 N will likely cover most ridden situations (Eisersiö *et al*., 2015; Egenvall *et al*., 2016) and will also be adequate for trotters (Hartmann *et al*., 2022), including a safety range without breaking (Eisersiö, 2013). The sampling rate should be at least 50 Hz, but preferably 100 Hz, to avoid missing peak values that could otherwise occur between the samples (Clayton *et al*., 2021). If the resolution, *i.e*. detectable changes in output, is too low, the pressure changes in rein tension, specifically at lower magnitudes, will be undetected (Clayton *et al*., 2021).

One of the first studies to use rein tension meters and measure rein tension in a scientific experiment was that by Clayton *et al*. (2003). Since then, a few different rein tension meters have been used in scientific studies, but they all rely on a similar measuring technique for collecting rein tension data. A rein tension meter generally consists of load cells attached to the reins, a battery and an A/D converter and logger that can store the data or transmit it wirelessly to a computer or smartphone. The battery provides the load cells with an electrical current. The load cells for rein tension meters commonly contain strain gauges which measure changes in electrical resistance. When tension is applied on the reins, the electrical resistance in the strain gauges changes, as does the electrical output (Eisersiö, 2013).

A rein tension meter should always be calibrated prior to experiments to determine the corresponding electrical output for a certain magnitude of rein tension (Clayton *et al*., 2003). In physics, tension is defined as pulling force. Rein tension is the force applied to the reins by the rider and/or the horse and is thus measured in Newtons (N).

2.3.2 Factors affecting rein tension

The rein tension studies conducted to date have shown that rein tension magnitude can differ substantially between riders (Hawson *et al*., 2014; Eisersiö *et al*., 2015; Christensen *et al*., 2021) and between horses (Piccolo & Kienapfel, 2019), and also with the context of the study (Warren-Smith *et al*., 2007; König von Borstel & Glißman, 2014). However, some common characteristics have been found. Rein tension is generally lowest at the walk, slightly higher at the trot and highest at the canter. Previous studies have reported measured mean rein tension at the walk of 5-15 N in each rein, at the trot of 6-22 N in each rein (Warren-Smith *et al*., 2007; Kuhnke *et al*., 2010; Eisersiö *et al*., 2015) and at the canter of 16-27 N in each rein (Kuhnke *et al*., 2010; Eisersiö *et al*., 2015). It also appears that riders have different levels of baseline tension on the reins (also referred to as support or contact on the reins) (Hawson *et al*., 2014; Eisersiö *et al*., 2015), which is likely one of the explanations for the vastly different magnitudes of rein tension among riders. The magnitude of rein tension on the left versus right rein has been shown to be affected by handedness of the rider and laterality of the horse (Kuhnke *et al*., 2010).

Another rein tension trait that is consistent between studies is that rein tension varies with the stride cycle, describing a cyclic pattern with characteristic peaks of rein tension corresponding to different events within the horse's gait. Interestingly, the point in time at which these peaks occur relative to the horse's stride cycle differs between riders and horse-rider combinations (Egenvall *et al*., 2015). For example, Egenvall *et al*. (2015) found that the rein tension pattern at the trot generally features peaks of rein tension corresponding to the suspension phase of the trot, in particular when the rider is sitting at the trot. This pattern is likely related to the propulsive forces from the horse pushing off from the ground (Byström *et al*., 2009) while the rider is either unable to stabilise the wrist relative to the horse's mouth (Terada *et al*., 2006) or may have used the reins to stabilise their position in the saddle to some extent. In contrast, Clayton *et al*. (2003) found peaks of rein tension during the support phase of the trot when studying a single rider, and attributed these peaks to the nodding action of the horse's head and neck during the support phase of the trot. When rein tension was measured in unridden horses wearing side reins of different length and elasticity (attached to a surcingle around the horse's belly), the peaks of rein tension strictly occurred when the horse was nodding the head downward during the support phase (Clayton *et al*., 2011).

In conclusion, when there is tension on the reins, this tension always varies in magnitude and peaks in rein tension generally occur along with the horse's stride cycle. These rein tension peaks are related to the horse's head movement and the rider's hand movement, as well as the rider's position in the saddle. From the horse's perspective, the bit pressure thus varies constantly and one may wonder how the horse can tell the difference between bit pressures from the rider's rein tension signals and bit pressure variations connected to the stride cycle. This constant variation in rein tension magnitude also makes it difficult to identify communicative rein tension signals in rein tension data.

2.3.3 Horse behaviour related to pressure from the bit

Performing behaviour is the horse's language. By studying the horse's behaviour, one can tell how the pressure variations applied on the horse's mouth/nose/head affect the horse both physically and mentally. Oral behaviours are commonly shown by horses in relation to pressure from the bit (Quick & Warren-Smith, 2009; Piccolo & Kienapfel, 2019), indicating that horses have a need to interfere with the bit pressure. A study by Manfredi *et al*. (2010) confirmed that horses showed significantly more oral behaviours when rein tension was applied compared with when no tension was applied. These oral behaviours displayed in response to rein tension were likely performed to manipulate the bit and thus influence the oral structures on which the bit was pressing.

If oral behaviour is not enough to alleviate bit pressure, the horse may try other behaviours, *e.g*. pulling on the reins. Horses pulling on the reins in response to rein tension was observed by Williams and Warren-Smith (2010) and Górecka-Bruzda *et al*. (2015) when studying competition horses and this behaviour seems to be performed in an attempt to break free or, trying to get a longer/looser rein. In contrast, bit-naïve horses in a study by Christensen *et al*. (2011) instead gaped and raised their head in an attempt to break free from rein tension when fitted with side reins.

As a flight animal, being held or restrained is potentially stressful. Rein tension signals can be perceived as restraining, since the pressure applied affects the head and neck of the horse. The feeling of being restricted may lead to the horse trying different evasive behaviours to either get longer/looser reins, by pulling on the reins, or avoiding the pressure altogether, by moving the nose towards the chest. If the horse does not know the behavioural response that will lead to release of the pressure, it may trial several different behaviours (Thorndike, 1911), including pulling on the reins, in the search for the release. Through the rider consistently releasing pressure at the correct behaviour, the horse will instead learn how to respond to the rein tension signal applied (see section 2.2.1 *Associative learning*).

Humans interacting with horses have to learn about equine ethology and how to interpret the horse's body language and facial expressions using ethological frameworks (McDonnell, 2003). Poor knowledge of equine ethology can lead to misinterpretation of the horse's behaviour. For example, it is common for riders to label a horse as naughty or stubborn when in fact the horse is frightened, in pain, or highly motivated to perform activities other than that sought by the rider (Bell *et al*., 2019). With sound knowledge of equine ethology, the rider can study the horse's behaviour and understand how the horse feels and perceives a situation, and what the horse is most motivated to do in that situation. By applying the learning principles, the horse can be trained to handle a fearful situation and respond appropriately to rider signals.

2.3.4 Voluntary rein tension

In ridden studies, measured rein tension largely reflects the rider's preferred level of contact on the reins and the magnitude of rein tension during rein tension signals used by the rider for communication. To learn more about the horse's preferred magnitude of rein tension, it is important to study the magnitude of rein tension that the horse will voluntarily apply to the reins.

In competitive dressage, it is often said that the rider wants the horse to seek contact with the bit. It is unlikely that the horse has a desire to have tension on the reins (McGreevy, 2011), other than the fact that consistent contact between the horse's mouth and the rider's hands might make rein tension variations more predictable and make it easier for the horse to manipulate bit pressure with different behavioural responses (Manfredi *et al*., 2010).

Accompanied by knowledge of equine ethology and learning, one can assess the magnitude of rein tension that the horse prefers. Piccolo and Kienapfel (2019) did this by studying rein tension in horses with a rider compared with when unridden with side reins. Rein tension was significantly lower without a rider, *i.e*. the horses did not seek equivalent contact with the bit when wearing side reins. Similarly, the horses in the study by Christensen *et al*. (2011) neither sought contact with the bit nor habituated to bit pressure as hypothesised. Kau *et al*. (2020) also studied horses' voluntary rein tension, using side reins, comparing two different kinds of bits. The magnitude of rein tension applied by the horses in Kau *et al*. (2020), and in Piccolo and

Kienapfel (2019), was strikingly different from that in ridden studies, with a maximum rein tension of 7.5 N in each rein in the voluntary studies compared with 50-100 N in the ridden studies (Kuhnke *et al*., 2010; Eisersiö *et al*., 2015). This indicates that riders in general are likely to apply much more pressure on the horse's sensitive oral tissues than is comfortable for the horse.

2.4 Horse training – from theory to practice

Training a horse to become a willing, content and well-functioning riding horse requires systematic training. The horse must be trained both physically and mentally for it to manage the tasks required and to perform well as a riding horse. A common goal in all horse training is to develop each horse's individual qualities to their full potential and for the horse to become an all-around schooled riding horse that is a pleasure to ride (Miesner *et al*., 2016). The rider's task is to teach the horse the communicative signals and then guide and assist the horse in finding its balance under the rider.

The dressage training scale was developed by experienced horse trainers and provides an overview of the basic characteristics of a riding horse (Miesner *et al*., 2016). It provides an example of how to structure the training to develop rideability and achieve a durable and balanced riding horse (Figure 1).

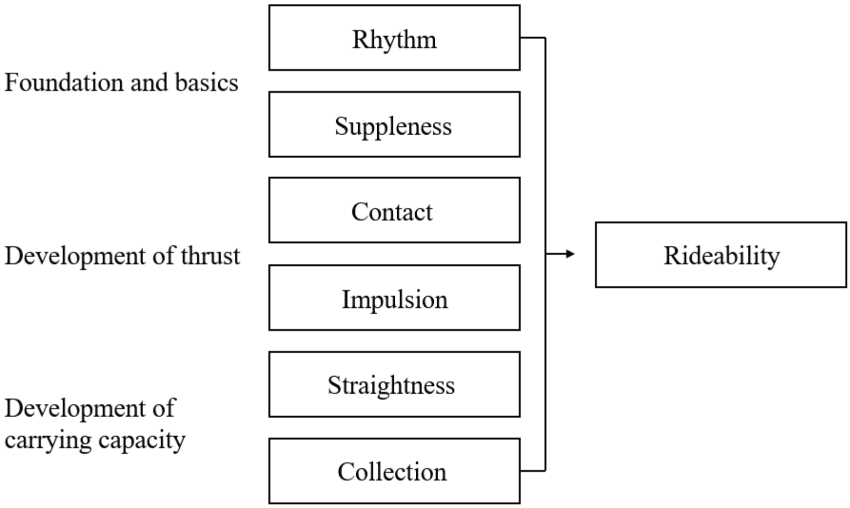

Figure 1. The dressage training scale, an example of how to structure the training of the horse.

The basic phase of training, according to the dressage training scale, involves finding and keeping a steady rhythm in all gaits, transitions and changes of direction, *i.e.* a rhythm that is not rushed and that is free from excessive tension in the horse. In parallel, it is important to develop suppleness and relaxation in the horse while carrying a rider, *i.e.* reducing excessive muscle tension, and for the horse to move with flexibility, elasticity and relaxed, rhythmical strides (Miesner *et al.*, 2016). The rider should ride with light contact on the reins and encourage the horse to carry the head and neck downwards/forwards (McGreevy & McLean, 2010). This basic training phase also helps the horse to find its own balance under a rider (Miesner *et al.*, 2016).

From the horse's learning perspective, the basic phase in the dressage training scale involves going forwards from a light (leg) signal and then maintaining the same speed and rhythm, while staying calm, until the rider gives a signal for another response (McGreevy & McLean, 2007). This stage of training has to be built up progressively by (i) reinforcing the horse's basic attempt in going forwards, (ii) using classical conditioning to train the horse to respond to light pressure signals and (iii) training the horse to persist in the same speed and rhythm without additional signalling (McGreevy & McLean, 2010).

The next phase of the dressage training scale involves teaching the horse to accept contact with the bit and thus habituate to a certain (preferably low) level of pressure in the mouth (Baragli *et al*., 2015). The rider should offer contact to the horse, by keeping the arms and hands soft and steady, but should never take contact with the bit by pulling back on the reins (Miesner *et al*., 2016). According to the dressage training scale described in Miesner *et al*. (2016), contact between the rider's hands and the horse's mouth should instead be achieved through the thrust from the hindlegs reaching forward towards the horse's centre of gravity. If the rider tries to take contact by pulling back or uses the reins with force, the horse will inevitably try to escape the contact either by pushing against the bit (Egenvall *et al*., 2012) or by moving the nose closer to the chest (going behind the bit/hand) (Miesner *et al*., 2016).

Unfortunately, there is a strong focus on the horse's head posture in contemporary riding (McLean & McGreevy, 2010). Riders tend to want their horse to arch the neck and look round to mimic more advanced training (Bornmann *et al*., 2020) and may therefore use the reins excessively (McGreevy *et al*., 2010). The reason for the focus on head posture among riders may be poor knowledge of equine biomechanics or may be related to riders trying to mimic role models found in competitive elite dressage (Lashley *et al*., 2014; McGreevy *et al*., 2010). Asking the horse to submit to pressure from the bit for the sake of head posture will lead to a great risk of increasing stress levels and conflict behaviour (Kienapfel *et al*., 2014), while obscuring the deceleration signals and thereby making the horse's decelerating response worse (Starling *et al*., 2016).

Likewise, trying to train the horse to do all stages in the dressage training scale at once will make it challenging for the horse to understand the rider's requests. Trying to perform riding exercises with the focus on straightness and collection, in terms of elevating the withers and increasing flexion of the hindlegs, while the foundational phase of rhythm and suppleness is not confirmed, sets the horse up for failure (Heuschmann, 2007). For instance, performing downward transitions can be done at any level of training, but the focus is different depending on the training stage of the horse. According to the dressage training scale, the goals for basic downward transitions are that the horse keeps the same rhythm and stays supple and relaxed while having light contact with the reins. The next stage of a downward transition is for the horse to maintain impulsion and contact with the bit through the transition. When these basics are in place, the rider can ask the horse to also stay perfectly straight and maintain collection by stepping under with the hindlegs through the entire transition (Miesner *et al*., 2016).

It should always be remembered that horses do not know about dressage or training scales. In fact, the horse has no idea what the rider wants unless this is explained clearly using the learning principles. The importance of using clear communication through the use of *e.g*. negative reinforcement when training horses has been thoroughly described in the scientific literature (*e.g*. Baragli *et al*., 2015; McLean & Christensen, 2017). In particular, studies emphasise the importance of releasing pressure signals at the correct time and in relation to the correct response (McGreevy, 2011).

However, knowledge has to be implemented by riders to be meaningful. At present, the extent to which riders actually use the learning principles in their everyday riding and training of their horse is not known. Previous research has found that riders and horse trainers have limited knowledge of learning theory terminology, in particular negative reinforcement (Brown & Connor, 2017; Luke *et al*., 2023). The importance of rewarding basic attempts before asking for refined responses (Warren-Smith *et al*., 2005) and the enormous power of the release in explaining the rider's intentions to the horse are likely not well understood (McLean, 2005). Increasing theoretical and practical knowledge among riders of equine behaviour and learning is important for overall improvement of the welfare of the ridden horse.

3. Aims of the thesis

The overall aim in this thesis was to investigate rein tension from the perspective of equine behaviour and learning, by investigating how rein tension affects the horse's behaviour and learning, and how the horse's behaviour and learning affect rein tension.

Specific objectives were to:

- Investigate the characteristics of a rein tension signal and the release for (i) backing up the horse (Paper I) and (ii) decelerating from trot to walk (Paper IV).
- Quantify the timing of the release of rein tension for communicating an exercise to the horse (Papers I and IV).
- Examine whether the magnitude of a rein tension signal can be reduced over repeated trials when training the horse to back up (Paper II) and when performing repeated downward transitions from trot to walk (Paper IV).
- Determine whether the horse's behavioural response differs between pressures from the bit in the horse's mouth compared with pressure on the nose from a halter (Paper I).
- Scrutinise how oral behaviours and head/neck movements affect rein tension and investigate whether the horse's behaviour increases or decreases rein tension (Papers III and IV).
- Investigate whether features of riders' rein tension signals are associated with rein tension magnitude, horse response latency, behaviour and/or head posture in conjunction with downward transitions (Paper IV).

4. Material and methods

The work reported in Papers I-IV in this thesis was carried out at the Swedish National Equestrian Centre, Strömsholm, during spring and autumn 2019 and was approved by the Animal Ethics Board in Uppsala (Dnr. 5.8.18-02567/2019) and the Swedish Ethical Review Authority (Dnr. 2019-01211). Since the horse's behavioural responses to rein tension were studied, it was decided that all horses must pass a mouth exam, by a veterinarian with expertise in equine dentistry, prior to data collection. A more detailed description of the material and methods used in each study can be found in Papers I-IV.

4.1 Horses and facilities

Data collection for Papers I-III was performed using 20 Warmblood horses, of which 10 were categorised as young horses (five mares, five geldings) and 10 as adult horses (four mares, six geldings). The young horses were 4-5 years old (mean 4.7 years ± 0.46 years) and had been ridden for a year or two. The adult horses were 7-15 years old (10.3 ± 2.65 years) and had been ridden for four years or more. All were school horses at the Equestrian Centre and were mainly trained in dressage and jumping. Eight of the horses used in Papers I-III were also used in Paper IV (7-15 years old, 10.3 ± 2.86 years).

The experiments in Papers I-III (referred to as the 'stable study') were conducted in an aisle (7 m x 2 m) in a grooming area at the Equestrian Centre and involved studying the rein tension signal for backing up the horse, with the trainer standing next to the horse. In Paper IV, the experiment (referred to as the 'ridden study') was conducted in an indoor riding arena (69 m x 25 m) at the Equestrian Centre and involved studying rider rein tension signals for transitions from trot to walk.

4.2 Rein tension meter

Custom-made rein tension meters were used for collecting rein tension data in Papers I-IV (Figure 2). These rein tension meters consisted of load cells (Futek, CA, USA (Papers I-IV); Forsentek, China (Paper IV)) wired to an amplifier and an inertial measurement unit (IMU) (x-io technologies, Bristol, UK), recording rein tension data at 100 Hz. The measurement range was 0-500 N and the resolution was 10 bit. The load cells were attached to intact leather reins close to the bit. The amplifier and IMU were taped onto the crown piece of the bridle and halter for Paper I-III. For Paper IV the amplifier and IMU were taped onto a crown piece with side pieces that was placed over the horse's regular bridle. Each rein tension meter was calibrated before and after the experiments by hanging 10 different known weights ranging between 0.2 and 10 kg from one rein at a time.

Figure 2. Rein tension meter in position. The load cells are attached to the reins and wired to the IMU/amplifier package, which is taped on a crown piece, with side pieces attached to the bit using fast clips.

4.3 Study design

4.3.1 Papers I-III

In Papers I-III, the horses were trained to step back in response to escalating rein pressure, *i.e.* a rein tension signal, with the handler standing next to the horse's withers (Figure 3). The horses were tested once with the reins connected to their own bitted bridle (noseband removed) and once with the reins attached to the nosepiece of a halter, in random order. The horses all had correctly fitting snaffle bits. Eleven horses had double-jointed snaffles, five horses had single-jointed snaffles and four horses had straight bits. In Paper III, only data from the bridle treatment were used.

The rein tension signal was applied by the handler holding the hands on the reins above the horse's withers and then gradually increasing tension on both reins until the horse took a step back. The handler stepped back along with the horse, staying next to the horse's withers. As the horse lifted the first front hoof to step back, rein tension was completely released by the handler opening and lowering the hands. Backing up was repeated eight times, with one minute in between each trial. If the horse stepped back immediately from a light rein tension signal, in the next trial the handler asked for another step back before completely releasing the rein tension. The horses were asked for a maximum of three steps back, with a small release of rein tension for each step. The left side of the horse was video-recorded during the trials (Canon Legria HF R806, Canon Inc, Tokyo, Japan, 25 Hz). The rein tension meter was synchronised with the video camera at the beginning and end of each treatment (bridle/halter) by pulling on the left rein five times (not affecting the horse's mouth) in front of the camera.

Figure 3. Position of the handler in Papers I-III (the stable study) when training horses to back up in the aisle, with (top image) the reins with rein tension meter connected to a nylon halter and a nylon halter underneath or (bottom image) the reins connected to a bit and a nylon halter underneath. The belly girdle is for heart rate measurements (data not included in this thesis). Source: published in part in Paper III.

4.3.2 Paper IV

In Paper IV, nine riders performed eight transitions from sitting trot to walk, in straight lines and in both directions, on each of the eight school horses. The riders were all female and all were students from the Equine Studies program at the Equestrian Centre (21-32 years old, 23.3 ± 3.63 years). The riders participated on two days each and rode four horses per day, while the horses participated on all three days and were ridden by three of the riders each day. The horses were unfamiliar to the riders, who had not ridden them before or had only ridden them once or twice before data collection.

The horses wore their usual saddle and bridle. An ISES taper gauge (www.equitationscience.com/store) was used to fit the nosebands correctly. Five horses wore double-jointed snaffles and three horses wore single-jointed snaffle bits. The horses were equipped with the rein tension meter by placing the crown piece with the amplifier/IMU package on top of the horse's bridle and attaching the side pieces and the reins with the loads cells to the bit using fast clips.

Half of the riding arena was used for warm-up and half for the trials (34.5 m x 20 m each) (Figure 4). The warm-up and trials were video-recorded and the rein tension meter was synchronised with the video cameras before and after both. All horses were hand-walked for 10 minutes before entering the riding arena. Each rider was given 10 minutes to warm up the horse at the walk and trot and was asked to focus on developing a good feel and communication with the horse. After the warm-up, the trials began. The riders were asked to prepare the horse appropriately for each of the eight transitions from trot to walk and to make the transition at a different location in the riding arena each time. Immediately after each transition and before they commenced trotting again, the riders were also instructed to grade each transition on a scale of 1 to 5 (1=poor, 5=good), and to comment on how the transition felt. After each ride, the rider was asked a few open questions about their experience of making the transitions with the particular horse. They were asked how they want a good transition to feel, how the transitions felt over time and what they would have liked to improve in their own riding and/or in the horse. Rider grades and comments and their replies to the questions are not reported in this thesis.

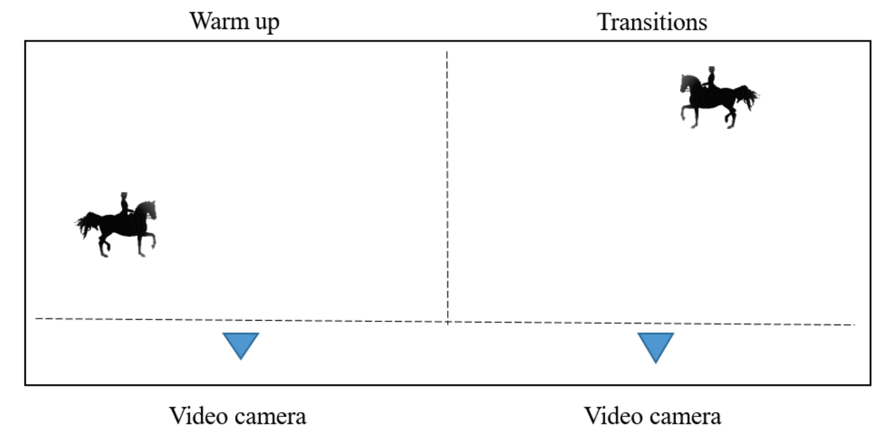

Figure 4. Experimental set-up in the riding arena.

4.4 Data processing

Processing of data was organised as follows. First, video recordings were scrutinised at normal speed and at frame level in the video editing program Adobe Premiere Elements (Adobe, CA, USA). Using the protocols from the video recordings, the rein tension data corresponding to recorded events were identified and quantified in Matlab (MathWorks Inc., MA, USA) using custom written code. Data sets of descriptive rein tension data along with the video-recorded events were created in Matlab and then further managed and analysed statistically in RStudio (Rversion 1.2.5019, RStudio, MA, USA).

4.4.1 Papers I and II

In the video recordings in Papers I and II, the onset and end of the rein tension signal were annotated in a protocol. Likewise, the onset of backing was defined as when the horse lifted the first front hoof to step back. Horse behaviour was recorded as present/absent during the rein tension signal. The behaviours observed were divided into two categories: head/neck/mouth behaviour (head/neck movement and mouth behaviour) and inattentive behaviour (attention and turning head/neck) (Table 2).

Response latency in the horse to the rein tension signal was calculated as the time from onset of the rein tension signal to the onset of backing. The timing of the release was defined as the time from onset of backing to release of the rein tension signal.

Table 2. *Ethogram used for the horses trained to back up in the stable aisle with the handler standing next to the horse's withers (Papers I-II)*

Behavioural category		*Behaviour*	*Description*
Inattentive behaviour	Attention	Looking at something	Directed gaze, pointed ears and immobile posture
		Investigating	Investigating the environment with nose and/or mouth
	Turning head/neck	Away	Turning the head and neck away from handler
		Towards	Turning the head and neck towards the handler for contact
Head, neck, mouth behaviour	Head, neck movement	Upward	Head/neck raised upwards
		Downward	Head/neck lowered downwards
		Forward	Nose pushed forwards
		Backward	Nose drawn in toward the chest
		Toss	Quick upward vertical movement of the head
	Mouth behaviour	Biting on bit	The bit is pulled up inside the mouth and horse is biting on it
		Open mouth (Gaping)	Visible gap between upper and lower jaw

4.4.2 Paper III

The video recordings in Paper III were analysed on frame level, to record the onset and end of the rein tension signal and of the horse's behaviour. As in Papers I and II, the onset of the rein tension signal was calculated as the time when the handler shortened the reins and placed the hands above the horse's withers. The end of the rein tension signal, the release, was defined as the moment when the handler started to lower the hands.

In Paper III, which only involved the bridle treatment, the behaviours included were the head/neck/mouth behaviours from Paper I-II (Table 2), *i.e.* open mouth, biting on the bit, head toss, and moving the head upward, downward, forward and backward. The onset and end of each of these behaviours were recorded at frame level during the rein tension signal. The onset of each behaviour was calculated as the time when the horse initiated the movement that would lead to the subsequent behaviour, while the end was when the horse stopped doing the behaviour.

The magnitude of rein tension at the onset and end for each rein tension signal and during each behaviour was determined. The duration of each behaviour was calculated.

4.4.3 Paper IV

Using the video recordings, five different phases of the downward transitions were identified and recorded in a protocol on frame level in Paper IV, and the magnitude of rein tension during each of these was determined. These five phases were:

- Preparation – trot in a straight line before commencing the rein tension signal and the downward transition.
- Rein tension signal – from onset of the rein tension signal to two frames before the release began. The rider became more rigid, leaning back slightly, not following the horse's movement as fluently, and the reins became tauter (no slack, commissures of the horse's lips sometimes pulled backward from the bit pressure).
- Downward transition – from last trot diagonal to when the first hind limb of the walk touched the ground.
- Release – from releasing rein tension until rein contact was picked up again. The rider lowered and/or moved the hand forward so that the reins became a little slack, or at least less taut.
- Walk – from the end of the downward transition phase to as many strides as the horse walked in a straight line without preparing for trot.

Horse behaviour and head posture were also recorded using the video material. The same head/neck/mouth behaviours as in Papers I-III were used (Table 2), except that biting on the bit and head toss were excluded. Behaviour was first recorded as present/absent during each of the phases and then the onset and end of each behaviour were recorded at frame level (regardless of phase) using the same approach as in Paper III. The magnitude of rein tension at the onset and end of each behaviour was also recorded.

'Head posture' was recorded as the predominant head posture during preparation, downward transition and walk, and the predominant head posture in close proximity before (rein tension signal) and after the onset of the release (release). If the bridge of the horse's nose was at the vertical, or up to 10 degrees in front of the vertical or five degrees behind the vertical, the head posture was classified as 'at the vertical'. If the bridge of the nose was more than 10 degrees in front of the vertical, it was termed 'in front of the vertical', while if it was more than five degrees behind the vertical it was termed 'behind the vertical'. In addition, the onset and end of the head postures 'in front of the vertical' and 'behind the vertical' were recorded at frame level, but not used in Paper IV.

The horse's response latency was calculated as the time from the onset of the rein tension signal to the onset of the downward transition. The rider's timing of the release was calculated in two ways: as the time between the onset of the downward transition and the onset of the release, and as the time between the onset of walk and the onset of the release. The timing of the release was then divided into three categories: release 'before' the transition, 'during' the transition and 'after' the transition.

4.5 Statistical methods

Descriptive statistics were calculated for rein tension variables and timing variables (median, mean, standard deviation (sd), minimum, maximum, quartiles and range). Rein tension data were first calculated and analysed for the left and right rein separately and then added together. The sum of the left and right rein tension was used in all statistical models that included rein tension. All statistical analyses were performed in RStudio and the R packages used were: tidyverse, gapminder, dplyr, lme4, lmerTest, emmeans and ggplot2.

Rein tension data and response latency were not normally distributed and were therefore transformed along the ladder of powers to find the most suitable transformation for the outcome for each model. Each model was reduced manually and Akaike's information criterion (AIC) was evaluated during modelling to find the best model fit. Pearson's residuals were plotted and QQ-plots were used to check the normality of residuals.

Estimated marginal means and contrast *p*-values were computed to compare category levels in the models. Contrast *p*-values were Tukey-adjusted for multiple comparisons and the limit for significance was set to $p<0.05$.

4.5.1 Paper I

Linear mixed and logistic mixed regression models were used in Paper I. The outcome variables in the linear mixed models were maximum rein tension during the rein tension signal and response latency. The explanatory variables were: headstall (bridle/halter), age group (young/adult), number of steps (1-3) and the 11 behaviour variables (looking at something, investigating, turning away, turning towards handler, head upward, head downward, head forward, head backward, head toss, biting on the bit, and open mouth). Horse and the interaction between horse and order of treatment were modelled as random variables.

In the logistic regression models, presence/absence of head/neck/mouth behaviour and of inattentive behaviour were modelled as outcomes in two different models. Headstall and age group were the explanatory variables in the inattentive behaviour model, while headstall, maximum rein tension and response latency were explanatory variables in the head/neck/mouth behaviour model. Horse was included as a random variable in both models.

4.5.2 Paper II

Linear mixed models were created in Paper II, with response latency and maximum rein tension during the rein tension signal as the outcome variables. The explanatory variables were headstall (bridle/halter), age group (young/mature), order of treatment (first treatment/second treatment) and trial (1-8), all analysed as categorical variables. Horse was included as a random variable. All two-way interactions between the four explanatory variables (headstall, age group, order of treatment, trial number) were tested. Non-significant interactions were removed based on type III p-value <0.05. Non-significant main effect explanatory variables were forced into the models.

Two logistic regression models were used for analysis of behaviours. Head/neck/mouth behaviour was outcome in one model and inattentive behaviour was outcome in the other model. Headstall, order of treatment and trial number were the explanatory variables and horse was included as a random variable.

4.5.3 Paper III

Significant differences between onset and end rein tension for each of the head/neck/mouth behaviours in Paper III were evaluated using linear mixed models (onset to end models). Rein tension was the outcome variable and time point (onset/end) was the explanatory variable, modelled as a categorical fixed effect. Horse and the interaction between horse and trial were included as random variables.

The magnitude of rein tension at the onset of the rein tension signal was compared with the magnitude at the onset of the observed behaviours, as well as between the behaviours, using linear mixed models (onset model). Rein tension was the outcome and behaviour and the rein tension signal was the explanatory variable, modelled as fixed effect with behaviour and the rein tension signal on different levels within the same variable.

Likewise, linear mixed models were used to determine whether there was a significant difference in end rein tension among behaviours (end model), using rein tension as the outcome and behaviour on different levels within the same variable as the explanatory variable. Horse and the interaction between horse and trial were modelled as random variables in both the onset and the end model.

4.5.4 Paper IV

Five different linear mixed models were created in Paper IV. The outcome variable for model 1 was median rein tension, for model 2 minimum rein tension, for model 3 maximum rein tension, and for models 4 and 5 response latency. The explanatory variables were head posture (at/in front of/behind the vertical), timing of the release (before/during/after), trial number (1-8) and behaviour (open mouth, head upward, head backward; present/absent) in all models. Models 1-3 also included phase, and the interactions between phase and the other explanatory variables were tested *a priori*. Models 4 and 5 differed by including either minimum or maximum rein tension as an explanatory variable. In models 1-3, horse, rider and the interaction between horse, rider and trial number were modelled as random variables, while in models 4 and 5, horse, rider and the interaction between horse and rider were random variables.

5. Main results

In Papers I and II, eight rein tension signals were applied with the bridle and eight with the halter for each of the 20 horses, resulting in 320 rein tension signals studied in total in each paper. Paper III only included the rein tension signals applied with the bridle, which resulted in a total of 160 rein tension signals being included in that study. In Paper IV, nine riders making eight transitions from trot to walk with each of the eight participating horses resulted in 576 transitions. However, due to rein tension meter failure, rein tension data from one horse-rider combination were missing, resulting in a total of 568 transitions being included in the study in Paper IV.

5.1 Paper I

Since the study design in Paper I involved applying a gradually increasing rein tension signal, there was a positive correlation between the maximum magnitude of rein tension during the rein tension signal and the horse's response latency (Pearson's product-moment correlation coefficient (rho) 0.69, confidence interval (CI) 0.63 0.74, $p<0.001$).

In 18% of the trials, the horses began backing before the rein tension signal was applied, *i.e.* while the handler was picking up the reins. For more than 90% of the rein tension signals, the release of rein tension was given within one second from the onset of the horse backing up.

Overall, the horse's behaviour had a significant effect on both the magnitude of rein tension during the rein tension signal and the horse's latency to respond to the rein tension signal by backing up. If the horse performed other behaviours than backing up when the rein tension signal was applied, this was associated with a significant increase in both response latency and rein tension.

Inattentive behaviours, such as the horse looking at something, investigating the environment or turning the head towards or away from the handler, were significantly more common when the rein tension signal was applied on the halter compared with the bridle (odds ratio (OR) 1.76, 95% CI 1.03 3.05), and in young horses compared with adult horses (OR 4.42, 95% CI 1.73 13.41) (Figure 5).

Mouth behaviour and head/neck movements were significantly less common with the halter compared with the bridle (OR 0.22, 95% CI 0.12 0.42). The odds of the horse displaying mouth behaviour or head/neck movements also increased significantly with increasing rein tension (OR 1.048 per 1 N, 95% CI 1.02 1.08) and response latency (OR 1.34 per 1 s, 95% CI 1.13 1.62).

If the horse displayed no other behaviour than backing up when the rein tension signal was applied, response latency and rein tension were significantly lower when the horse wore a bridle (~0.5 s and ~5 N lower) compared with a halter.

Figure 5. (Left) Horse in the halter treatment during application of the rein tension signal, showing the behaviour ‘looking at something’. The reins are taut and attached to the rings of the halter. (Right) Horse in the bridle treatment during application of the rein tension signal. The reins are taut and attached to the bit and the horse is opening the mouth and moving the head/neck forward.

5.2 Paper II

Studying the rein tension signal for backing up the horse, over eight trials, revealed that the horses quickly learned the procedure (Paper II). Rein tension was significantly lower in the seventh and eighth trial compared with the first (p<0.02), and this applied to both bridle and halter. Likewise, in the second treatment, rein tension was significantly lower (p<0.01) and the horses responded significantly faster (p<0.001) compared with the first treatment, regardless of whether bridle or halter was the first treatment for the horse. Descriptive statistics showed that group median maximum rein tension (sum of left and right rein) decreased from 35 N to 17 N in the first eight trials of the bridle treatment and from 25 N to 15 N during the first eight trials of the halter treatment. Rein tension continued to decrease and at the eighth trial in the second treatment, the rein tension signal was 10 N (5 N in each rein) for both bridle and halter.

Descriptively, median response latency was reduced from 6 s for bridle and 5 s for halter in the first trial of the first treatment to 2.6 s for bridle and 2.3 s for halter in the eighth trial of the first treatment. Response latency was then further reduced to 1.6 s for both bridle and halter in the eighth trial of the second treatment.

Head/neck/mouth behaviour was significantly less common in the seventh and eighth trial compared with the first trial in the first treatment and also less common in the second treatment compared with the first treatment. Inattentive behaviour was significantly less common in the second treatment.

5.3 Paper III

Horse behaviours had a significant effect on rein tension magnitude in Paper III and were associated with either an increase or decrease in rein tension. Rein tension decreased significantly from onset to end for the behaviours open mouth (19 to 11 N), biting on the bit (11 to 5 N) and head upward (16 to 12 N) in the onset to end models. Conversely, rein tension increased significantly from onset to end for the behaviours head forward and head downward.

There was a significant increase in rein tension between the onset of rein tension signal and the onset of each head/neck/mouth behaviour, *i.e.* no head/neck/mouth behaviours were shown until the rein tension had increased significantly from the handler applying the rein tension signal (Figure 6). Head forward and head downward resulted in significantly higher end rein tension than all other behaviours.

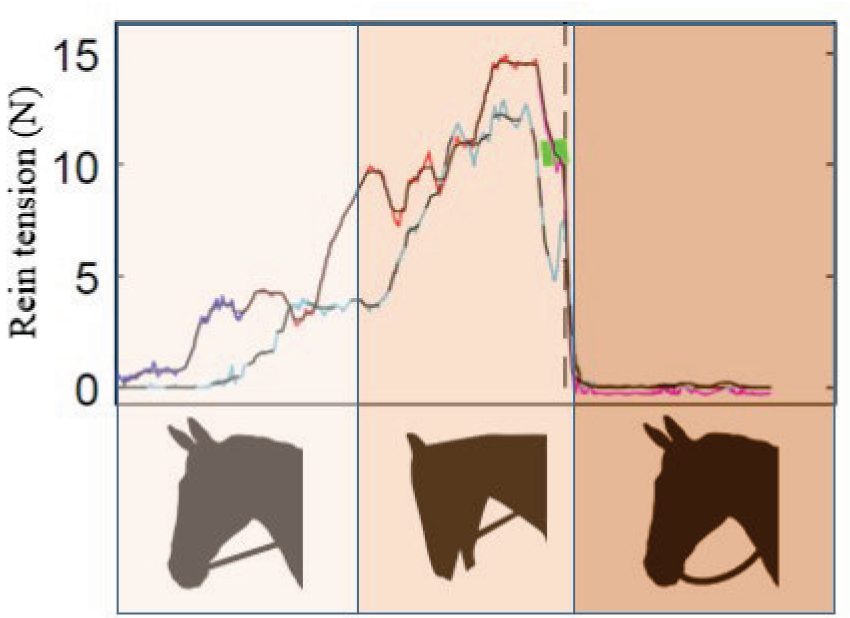

Figure 6. Graphical example of the association between rein tension and horse behaviour. As rein tension increases (left), the horse opens the mouth and rein tension decreases (centre), upon which the horse closes the mouth (right). Source: graphical abstract from Paper III.

5.4 Paper IV

Descriptively, horses in Paper IV showed less oral behaviour and head/neck movements during the release than during the rein tension signal, but there was no reduction in these behaviours across the trials (Table 3).

Table 3. *Occurrence of different behaviours/head postures during the rein tension signal and the release. There were 71 possible events for each transition number. Behaviour is counted as present/absent. Head posture refers to head posture in close proximity to the release (0.5 s before the onset of release for rein tension signal, 0.5 s after for release)*

		Transition number							
Behaviour/ Head posture	Event	1	2	3	4	5	6	7	8
Open mouth	Signal	13	10	12	14	9	8	12	10
	Release	2	5	1	3	2	4	2	6
Head upward	Signal	19	16	22	22	23	21	21	18
	Release	2	0	3	3	2	3	4	3
Head forward	Signal	2	5	1	1	2	2	3	0
	Release	0	2	0	0	0	0	0	0
Head backward	Signal	5	6	4	4	4	5	6	5
	Release	3	1	0	3	2	3	1	1
Front of vertical	Signal	19	13	15	15	18	16	9	9
	Release	17	11	10	12	16	14	8	7
At vertical	Signal	31	43	35	37	36	35	39	45
	Release	35	44	41	38	37	36	41	41
Behind vertical	Signal	21	15	21	20	17	20	23	17
	Release	19	16	20	21	18	20	22	23

Median rein tension was reduced descriptively from onset to end for the behaviours open mouth, head upward and head backward, but increased from onset to end for head forward (Table 4).

Table 4. *Descriptive statistics on rein tension (N) at the onset and end of recorded behaviours in all phases*

Behaviour/ Head posture	Min.		1st Qu.		Median		3rd Qu.		Max.	
	Onset	End	Onset	End	Onset	End	Onset	End	Onset	End
Open mouth	9	2	30	23	43	37	62	55	162	135
Head upward	10	5	42	39	65	56	92	80	154	178
Head backward	3	3	26	20	41	34	54	74	139	145
Head forward	7	26	26	57	73	78	117	97	197	165

The timing of the release mainly affected median rein tension during the release and the downward transition, and this effect was connected to the horse's gait (model 1). When the release was given before the downward transition, *i.e.* at the trot, median rein tension was significantly higher during the release phase (35 N) than when the release was given during or after the transition (29-30 N). Similarly, when the rider had released rein tension before the downward transition, median rein tension was significantly lower during the transition phase (37 N) than when the release was given during or after the downward transition (43/54 N).

For all release categories, median rein tension was significantly higher during the rein tension signal phase than during all other phases. The only exception was the downward transition phase if the rein tension signal was still ongoing, *i.e.* the release was given after the downward transition, which means that the same data were included in the rein tension signal phase and the downward transition phase. Median rein tension increased by approximately 15 N (7.5 N in each rein) from the preparation phase to the rein tension signal when the horse had head posture at the vertical and displayed no other behaviours than decelerating from trot to walk (Table 5). Median rein tension was significantly higher (~10 N) during the rein tension signal and the downward transition phase if the horse had the bridge of the nose in front of the vertical, compared with at the vertical or behind the vertical. Minimum rein tension increased significantly from the preparation phase to the rein tension signal, and decreased significantly from the rein tension signal to the walk, regardless of head posture and timing of the release (Table 5).

Table 5. Back-transformed least square means, standard error (SE) and confidence intervals (CI) of the sum of the left + right rein median, minimum and maximum rein tension (N) divided by the phase of the transitions. Values shown represent when the horse had head posture 'at the vertical' and displayed no other behaviours than transitioning from trot to walk

	Phase	Estimate	SE	Lower CI	Upper CI
Median	Preparation	46	3	40	54
	Rein signal	61	4	52	71
	Transition	44	3	38	51
	Release	37	3	32	43
	Walk	26	2	22	30
Minimum	Preparation	15	2	12	20
	Rein signal	21	2	16	27
	Transition	19	2	15	24
	Release	17	2	13	22
	Walk	3	0	3	5
Maximum	Preparation	102	6	89	117
	Rein signal	115	7	100	132
	Transition	80	5	70	92
	Release	69	4	60	79
	Walk	78	5	68	89

Maximum rein tension decreased over successive trials and was significantly lower at the fifth and eighth trial (88 N) compared with the first (98 N). Maximum rein tension was significantly lower during the release when the horse moved the head upward. Head backward during the release phase was associated with significantly lower median, minimum and maximum rein tension during the release. In all phases, open mouth was associated with significantly lower minimum rein tension, and significantly higher maximum rein tension.

Release before the transition was associated with longer response latency than release during or after the transition. When minimum rein tension was lower (model 2) or maximum rein tension was higher (model 3), response latency was also longer. Likewise, response latency was longer if the horse opened the mouth or moved the head upward during the rein tension signal, compared with when not showing these behaviours.

6. General discussion

Throughout the work in this thesis, horses' behavioural responses to rein tension were explored from both a behavioural-learning perspective and a functional perspective. The results obtained demonstrate that applying rein tension will motivate horses to alter their behaviour. This is to be expected, since the pressure signals used in horse training are intended to motivate the horse into some form of action (McGreevy & McLean, 2010), which is then reinforced through the withdrawal of pressure, following the principles of negative reinforcement learning (Ahrendt *et al*., 2015).

Previous findings of conflict behaviour in association with rein tension (Christensen *et al*., 2011; Piccolo & Kienapfel, 2019) were confirmed in this thesis, as numerous evasive behaviours were exhibited before the horses learned the correct response. Prior to learning, horses do not know the behaviour that will lead to the withdrawal of pressure and may try behaviours other than the correct (desired) response to gain relief from pressure (McGreevy & McLean, 2010). Novel findings were made in this thesis regarding the function of different head/neck/mouth behaviours related to rein tension. Behaviours such as gaping and different head/neck movements, which are often described as conflict behaviours (Christensen *et al*., 2011; Kienapfel *et al*., 2014; Górecka-Bruzda *et al*., 2015), were found to also have the function to alter the magnitude of rein tension. Thus, some conflict behaviours can both express frustration and be a means of managing a situation.

In the remainder of this chapter, the rein tension signals and the behavioural responses displayed by the horses in Papers I-IV in this thesis are compared and discussed relative to previous findings. Key findings are discussed in a wider context, while more detailed discussions on specific results can be found in Papers I-IV.

6.1 Rein tension signals

The overall aim in this thesis was to investigate rein tension signals and the horse's behavioural response to rein tension. The different studies described in Papers I-IV were designed to isolate the signalling process between rider and horse via the reins and facilitate identification of rein tension signals in the rein tension data. As described in Chapter 2, rein tension will vary with the horse's gait and stride cycle (Egenvall *et al.*, 2015; Egenvall *et al.*, 2016) and this variation is connected to the horse's head movement, rider position in the saddle (Eisersiö *et al.*, 2015) and rider hand movements and rein tension signals (Egenvall *et al.*, 2012). Thus, the data collection in the stable study (Papers I-III) was designed to reduce the variation in rein tension magnitude contributed by the horse's gait and rider movements. This study thus represent a simplified situation, with auxiliary factors affecting rein tension magnitude eliminated (Figure 7).

The ridden study (Paper IV), on the other hand, added a range of variation to rein tension data by including the horse's gait and stride cycle and also rider position and hand movements, as well as the study design of asking the riders to perform downward transitions that felt good and correct to them (Figure 7). The intention was to resemble "normal dressage training" and the riders in Paper IV likely focused on several different aspects of the downward transition (Argue & Clayton, 1993), not merely the rein tension and the rein tension signals they applied. However, in order to facilitate identification of the rider's rein tension signals from the video recordings, the riders were asked to make the transitions in straight lines with the side of the horse facing the video camera.

Figure 7. Example of the variation in rein tension during (upper image) the ridden study (Paper IV) and (lower image) the stable study (Papers I-III). The y-axis in the graph beneath the images runs from 0-80 N for the ridden study and from 0-50 N for the stable study. Note the variation in rein tension with the horse's stride cycle in the ridden horse compared with the horse in stand-still.

In the ridden study, if the horse had the head posture ‘at the vertical’ and displayed no other behaviour than decelerating from trot to walk, median rein tension for the sum of the left and right rein increased from 46 N to 61 N when comparing the preparation phase with the rein tension signal (Paper IV). The maximum rein tension increased from 102 N to 115 N for the same phases. Thus, the rein tension signal in the ridden study involved an increase in rein tension of about 15 N (*i.e.* about 7.5 N in each rein). In the stable study, baseline rein tension was close to zero before the signal began, as the reins were resting on the horses’ neck between trials. Controlling for behaviour, the maximum rein tension then increased to about 10 N during the rein tension signal for the bridle treatment (*i.e.* about 5 N in each rein).

Comparing data from the ridden study and stable study revealed that the magnitude of the rein tension signal differed to a large extent, yet the increase from baseline rein tension to the rein tension signal showed similar values (5 N in each rein compared with 7.5 N in each rein). Similarly, the ridden horses in a study by Warren-Smith *et al*. (2007) had about 5/3.5 N rein tension in the left/right rein when going straight, increasing to 15/12.5 N in the left/right rein for halting from trot or walk, which is around a 10 N increase in rein tension in each rein. The ridden horses studied in Paper IV were thus ridden with a substantially higher baseline rein tension than in Warren-Smith *et al*. (2007), yet the signal to the horse showed similar values (7.5 N and 10 N increase in each rein, respectively).

It could thus be suggested that the baseline rein tension is the primary reason why rein tension magnitude reached higher values during the ridden study compared with the stable study. In other words, baseline rein tension, *i.e*. the rider’s contact/support on the reins (Eisersiö *et al*., 2015; Clayton *et al*., 2021) may be the decisive factor in the magnitude of rein tension in rein tension signalling. This relationship requires further investigations, especially since horses seem reluctant to habituate to stimuli that cause discomfort (Christensen *et al*., 2011; Baragli *et al*., 2015), but can also be described as “hard-mouthed” (Bohara *et al*., 2023).

The head posture ‘in front of the vertical’ was associated with higher magnitude of rein tension during the rein tension signal, the downward transition and the release phase in the ridden study (Paper IV). Head posture in itself is unlikely to cause increased rein tension, so the greater magnitude of rein tension is likely due to either the horse or the rider resisting on the reins more during this head posture (Miesner *et al*., 2016). The head posture ‘at the vertical’, or more specifically “on the bit”, is generally sought after by riders (McGreevy *et al*., 2010), and the horse being “above the bit” is generally regarded as a manifestation of a poor decelerating response (McGreevy & McLean, 2010) or excessive tension in, primarily, the poll and the back muscles (Miesner *et al*., 2016). According to Miesner *et al*. (2016) a horse ‘on the bit’ is a horse moving with rhythm and suppleness, seeking contact with the bit and flexing at the poll. Miesner *et al*. (2016) suggest that training the horse to be ‘on the bit’ can be achieved when rhythm and suppleness are established and the thrust from the hindlegs step in toward the horse’s centre of gravity. McGreevy and McLean (2010), on the other hand, claim that having the horse ‘on the bit’ is achieved through progressive training that first involves having longitudinal flexion (lengthening of the neck), followed by lateral flexion of the horse’s body and neck, and finally vertical flexion (flexing at the poll). Flexing at the poll implies that the bridge of the horse’s nose is at or close to the vertical. Neither of these authors considered increased rein tension as a means of improving equine biomechanics, achieving correct head posture or improving the contact with the bit. Thus, the higher rein tension during the head posture ‘above the bit’ is unjustified.

Although the rein tension in the ridden study was considerably higher than that in the stable study, rein tension was also rather high in the first trials in the stable study compared with in previous studies (Warren-Smith *et al*., 2007; Piccolo & Kienapfel, 2019). The reasons for the relatively high magnitude of rein tension when backing up the horses were due to both the study design where the handler gradually increased the rein tension magnitude, and the auxiliary behaviour that the horses displayed as they tested different behaviours in response to the rein tension signal. However, since only the behaviour backing up led to prompt withdrawal of bit pressure, the horses began responding faster and displayed fewer other behaviours over the course of trials, which led to a reduction in the magnitude of rein tension. In particular, head/neck/mouth behaviour was reduced over successive trials in the stable study, but not in the ridden study.

6.2 Timing of the release

Use of learning principles in the context of horseback riding provides a way to communicate with the horse. By always beginning with light pressure when using escalating pressure signals, horses learn, through classical conditioning, to respond to the light pressure signals (Baragli *et al*., 2015). A clear sign that the horse understands the trainer's signals is a prompt response to light signals (Warren-Smith *et al*., 2005). In other words, when the horse understands the rider's rein tension signals, rein tension should become lighter, response latency should decrease and, most importantly, the horse should show fewer other behaviours than the correct response (McGreevy & McLean, 2007).

The timing of the release is crucial for clearly communicating the correct response to the horse (McLean, 2005). Comparing the timing of the release between the stable study and the ridden study, the release of rein tension was given within one second from the onset of backing up for 91% of the rein tension signals in the stable study, while in the ridden study the release was given during the downward transition in 70% of the transitions.

No firm conclusions could be drawn from the data on the factors that contributed to the early release in 19% of the downward transitions and late release in 11% of the downward transitions. One could speculate that the rider may have felt that the horse was going to decelerate and therefore gave the reins early to reinforce the horse's attempt, as previously reported by Egenvall *et al*. (2012). The late release may have been related to the horse's horizontal balance during the downward transition (Tans *et al*., 2009). If the rider felt that the horse was "leaning on the bit" (Górecka-Bruzda *et al*., 2015), *i.e*. bearing down on the bit, during the downward transition, the rider may have delayed the release of rein tension in order not to reinforce that behaviour. However, since knowledge of learning theory seems to be low among riders in general (Luke *et al*., 2023), it is also possible that the riders in the ridden study paid more attention to their signals than to their timing of the release relative to the transition.

The release also differed in magnitude comparing the stable study and the ridden study. Rein tension was released completely in the stable study, i.e. the reins were resting on the horse's neck between trials. While in the ridden study, rein tension was approximately 37 N at the release and 26 N at the walk (sum of left + right rein). In addition, it should be borne in mind that in the stable study there was one single handler applying the rein tension signals and the release, while the ridden study involved nine different riders. The timing of the release was therefore also more diverse in the ridden study. These discrepancies in features of the release between the stable study and the ridden study may be one of the reasons why maximum rein tension during the rein tension signal was reduced by half for backing up the horses, while it was only reduced by 10% for the downward transitions from trot to walk.

Delayed reinforcement can be stressful and can lead to deterioration of previously learned responses, as found by Yakamoto *et al*. (2009) on studying delayed reinforcement in dogs. However, a study by Warren-Smith *et al*. (2005) on lead training in foals, found that reinforcing the correct response by releasing the lead rope after one step forwards led to quick learning of the applied pressure signal, although releasing the lead rope after four steps led to more correct responses in the long term. Elaborating on this, Egenvall *et al*. (2012) suggest that a quick release of pressure will reinforce the horse's attempt and provide the horse with information on the correct response. However, if the release is too quick it may not reinforce the behaviour sought by the trainer. In the study by Warren-Smith *et al*. (2005), releasing the lead rope after the foal had taken four steps may have helped the foal understand that walking was the correct behaviour, not just taking single steps or other behaviours.

Through signals, trainers and riders can shape the horse's behaviour, but for the horse to understand the correct behaviour it must be trained progressively by reinforcing one criterion at a time. The timing of the release is the main means of shaping behaviour using negative reinforcement and the rider or trainer must be very aware of their timing of the release and of the behaviour that they want to reinforce. The discrepancy in timing of the release observed in the ridden study in Paper IV indicates a need for more research on riders' general timing of the release in different situations and different riding exercises.

6.3 Response latency

Releasing rein tension before the downward transition (early release) was associated with longer response latency in the ridden study. This is not surprising, since an early release in fact reinforces the horse in slowing down or preparing for the transition, but probably does not reinforce the actual transition. This is in line with previous findings by Egenvall *et al*. (2012), who investigated young horses making downward transitions from trot to walk, using two different methods in a cross-over design. In one method, the riders were asked to give a decelerating rein tension signal during the trot and not release the rein tension until the horse walked. In the other method, the riders were instructed to release rein tension as soon as the horse decelerated and then repeat the rein tension signal several times until the horse walked. Using repeated releases to reinforce the deceleration response was associated with longer response latency in that study, but was also associated with lower rein tension, and less conflict behaviour like gaping, tilting the head and pushing against the bit, compared with not releasing until the horse walked (Egenvall *et al*., 2012).

Interestingly, in the ridden study in Paper IV, both lower minimum rein tension and higher maximum rein tension were associated with longer response latency. The lower minimum rein tension may be related to the early release, while the higher maximum rein tension may indicate miscommunication between horse and rider.

Response latency did not decrease over the trials in the ridden study, while in the stable study response latency decreased by more than half in the first eight trials (from 6 s to 2.6 s for the bridle treatment). In fact, in 18% of all trials in the stable study, the horse started backing up while the handler was picking up the reins, *i.e*. before the rein tension signal was even applied. Through classical conditioning, those horses had learned the procedure for the exercise and the handler picking up the reins had become a predictor of the rein tension signal. The lack of decrease in response latency in the ridden study may be explained by the riders' primary focus during the trials. As the riders were instructed to perform downward transitions that felt good and correct to them, features of proper biomechanics with impulsion, straightness and collection, before, during and after the transition (Tans *et al*., 2009) may have been a higher priority for them than quick response latency and low rein tension. Likewise, it should be noted that the stable study involved the horses learning a semi-new rein tension signal, while the signalling for the downward transitions in the ridden study was already familiar to the horses. Thus, improvements in performance were perhaps easier to detect in the simplified situation in the stable than in the more complex ridden situation.

In reality, however, the ridden and stable study should not have differed to a large extent in terms of communication between horse and rider. The rider should always start simple and with light pressure, ask for one criterion at a time and make sure that the horse understands each signal applied (McGreevy & McLean, 2007). If the horse responded immediately to a light rein tension signal, the criterion for a correct response in the stable study was altered by adding an additional step back in the next trial. Likewise, one could assume that the riders in the ridden study focused on rhythm and suppleness at first in their downward transitions during warm-up, then added more focus on contact and impulsion, and finally also concentrated on straightness and collection through the entire transition, without losing the previous features (Miesner *et al*., 2016). The training approach and structure of riders when trying to improve a ridden exercise merits further investigation.

6.4 Gaping for relief

By being observant of the horse's behavioural responses during training and riding, much can be learned about the horse's perspective and understanding of the signals and riding exercises humans are trying to convey, both when conducting research (Hall & Heleski, 2017) and during regular training of the horse (McGreevy & McLean, 2007). The behavioural response of horses to rein tension was of particular interest in this thesis.

Behaviour is moulded by its consequences, as the animal learns that a certain behaviour leads to a reduction in an aversive event and/or an increase in a desirable outcome (Baragli *et al*., 2015). The horse's behaviour in response to rein tension can therefore be interpreted as the horse either wanting to avoid or escape the bit pressure applied (Manfredi *et al*., 2010), or wanting a desirable outcome, such as longer, looser reins (Górecka-Bruzda *et al*., 2015).

Gaping and pulling on the reins are generally regarded as conflict behaviours (Christensen *et al*., 2011; Górecka-Bruzda *et al*., 2015). However, whereas there likely is a conflict between the rider's signals and the horse's interest when these behaviours are shown (König von Borstel *et al*., 2017), comparing the magnitude of rein tension at the onset and end of these and the other head/neck/mouth behaviours observed in this thesis suggests that these behaviours also have the function of reducing or escaping rein tension. Gaping (open mouth), biting on the bit and moving the head upward all led to a reduction in rein tension, from onset to end, indicating that these behaviours were performed to reduce the pressure from the bit on the oral structures. Head downward and head forward, on the other hand, led to an increase in rein tension from onset to end, but as these behaviours were short they were likely performed with the intent of achieving a longer, looser rein (Górecka-Bruzda *et al*., 2015). Previous success in pulling the reins out of the rider's hands by moving the head quickly forward or downward will have reinforced those head movements, as the consequence was reduced bit pressure and freer head carriage (McGreevy & McLean, 2010). However, in both the stable study and the ridden study, the behaviours that directly led to a reduction in rein tension, specifically open mouth and head upward, were more common than the behaviours that increased rein tension, *i.e*. head downward and head forward.

In the ridden study, open mouth was associated with higher maximum rein tension and lower minimum rein tension. Open mouth during high rein tension is not surprising, as it probably reflects the horse's attempt to diminish oral pressure. Similarly, Ludewig *et al*. (2013) found that gaping was more common with short reins, and thus higher rein tension, compared to normal length reins. It is more surprising that open mouth was also shown when minimum rein tension was lower. This may be related to the fact that open mouth led to a reduction in rein tension from onset to end also in the ridden study.

Based on observed behaviour of horses in response to rein tension, the results in this thesis indicate that the pressures applied by the bit on the horse's mouth were uncomfortable, and perhaps even painful, as they led to more evasive head/neck/mouth behaviour with the function of reducing or escaping rein tension compared with pressure on the nose from the soft textile halter. In fact, the horses showed very few head/neck/mouth behaviours when pressure was applied to the halter. Thus the pressure from the halter was apparently not uncomfortable to the same extent as bit pressure, and the higher proportion of inattentive behaviours, in particular investigative behaviour, may indicate that the horses were more relaxed when wearing the halter.

It is interesting that backing up the horse with a halter generated similar learning results as the bitted bridle in terms of rein tension and response latency. Rein tension magnitude and response latency were reduced to a similar degree with the bridle and halter. The main difference between these two headstalls was thus the type of behaviours displayed by the horses. These results are in line with findings by Quick and Warren-Smith (2009) who found that horses performed equally well with a bitted as with a bitless bridle but that behaviour differed, with more mouth opening with a bit and more head lowering with a bitless bridle.

From the horse's perspective, it should be noted that using the same amount of rein tension on a bit as on *e.g.* a soft textile halter involves a completely different feeling for the horse. The physical structures and body tissues (Staszyk *et al*., 2015), the area of application (McGreevy & McLean, 2010) and the tissue's resistance to pressure (Gefen *et al*., 2022) all differ immensely when pressure is applied through a metal piece in the mouth compared with a textile band on the bridge of the nose. However, it should also be noted that bitless alternatives are sometimes very sharp, for example a metal or rope noseband pressing on the bridge of the horse's nose.

The difference in behavioural response to pressure observed in this thesis for the bit compared with the halter indicates that riders and horse trainers should be made clearly aware that the bit is a powerful training tool. The horses in this thesis wore a simple snaffle bit and yet numerous evasive behaviours were displayed. One can assume that the behavioural responses of the horses would be even more intense if the horses had worn bits with sharp edges, leverage or high ports, which concentrate pressure on a smaller surface, compress the lower jaw and the tongue, or press on the palate or bars when rein tension is applied (Johnson & Porter, 2006; Manfredi *et al*., 2010).

6.5 What if we just tighten the noseband?

The results in this thesis indicated that the horses in the stable study showed gaping because they felt discomfort in the mouth from the bit. If the horse is gaping due to discomfort from pressure on the oral structures and gaping is elicited already at a median rein tension of 18 N (9 N in each rein), what if we tighten the noseband of the bridle, preventing the horse from gaping?

Previous research has found that a tight noseband sensitises the horse's mouth, making the horse more sensitive to rein tension signals (Randle & McGreevy, 2013; Pospisil *et al*., 2014). Thus, the horse's motivation threshold for gaping is probably even lower than 18 N if the noseband is tightened. The increased oral sensitivity with a tight noseband is likely due to the reduced possibility to move the jaw and to manipulate the bit with the tongue (Clayton & MacKechnie-Guire, 2022), which horses are otherwise able to do in response to bit pressure to alleviate certain oral structures from the pressure applied (Manfredi *et al*., 2010). A tight noseband has also been found to generate stress responses in the horse (Fenner *et al*., 2016).

The noseband on bridles is intended to prevent the horse from opening the mouth excessively (Clayton & MacKechnie-Guire, 2022), but it is also there to stabilise the bridle on the horse's head and prevent it from moving sideways (Weller *et al*., 2020). The noseband should be loose enough so that at least two adult fingers can be fitted between it and the bridge of the nose (McGreevy, 2015). However, an even looser noseband is often a good choice, as oral injuries are prevalent due to nosebands pressing the buccal mucosa against the cheek teeth, causing ulcers and lesions (Johnson & Porter, 2006; McGreevy, 2015).

The advantages of a loose noseband are many. As stated above, there will be less risk of oral injuries, less stress for the horse, the horse can more easily manipulate the bit to avoid pain and discomfort, and most importantly, riding becomes more transparent as horse evasive behaviour is not hidden from the rider or spectator (Fenner *et al*., 2016). The evasive behaviour then has to be dealt with through improved training and handling of the reins in both horse and rider, regular mouth inspections (Johnson & Porter, 2006; Uldahl *et al*., 2022), and rider training in how to use the hand (Miesner *et al*., 2016). To sum up, when evasive behaviour is allowed to be visible, the rider is obliged to understand how rein tension signals can affect the horse both physically and emotionally (McGreevy & McLean, 2007).

Unfortunately, gaping in response to bit pressure is commonly referred to as a form of resistance in the horse that can be solved through a tightened noseband (McGreevy, 2015), even though science has proven otherwise. The International Society for Equitation Science (ISES) position statement on restrictive nosebands (2019) therefore recommends that governing bodies:

> "recognise mouth-opening as the result of undesirable rider- or tack-induced factors including pain, discomfort and errors in training, rather than a sign of resistance, and accept that any physical restriction of jaw movement may have the potential to compromise horse welfare."

6.6 The bit is not the problem…

…it is the rider's hand. As described throughout this thesis, pressure in the horse's mouth from the bit involves several potential welfare issues for the horse including pain, mouth injuries, discomfort and misunderstandings. Due to these problems, one might suggest removing the bit and instead training the horse with a bitless bridle as a simple and easy solution to the problem (Cook & Kibler, 2019). However, while the horses in the stable study (Papers I-III) showed fewer evasive behaviours when wearing a halter, merely removing the bit and proceeding as usual would not solve the problems of bridle-induced oral injuries and evasive behaviour due to excessive rein tension. For example, Uldahl and Clayton (2019) found bridle-induced oral injuries in horses ridden without a bit, and Robinson and Bye (2021) recorded high pressure underneath the noseband of a side-pull bridle (with reins attached to rings on a noseband). Similarly, tests by Vogt *et al*. (2019) on horses' voluntary magnitude of rein tension showed that the horses applied similar magnitude of rein tension on a snaffle bit as on various forms of bitless bridles, but less rein tension on a side-pull. Likewise, Schofield (2018) found that horses raised their head more with a bitless bridle, compared with a bitted bridle, likely in an attempt to avoid rein tension. Thus, it should be remembered that rein tension will not be diminished by removing the bit from the mouth and applying pressure on other sensitive areas of the horse's body (Schofield, 2018), since the same amount of pressure is instead distributed on the other tissues (Robinson & Bye, 2021). Interestingly, the riders in Randle and Wright (2013) had the perception that a cross under bitless bridle is more severe than a snaffle bit.

Moreover, no head/neck/mouth behaviours were displayed in the stable study until rein tension had increased to approximately 5 N in each rein, by the handler applying the rein tension signal. Likewise, the horses stopped gaping and/or raising the head when rein tension had dropped back below 5-6 N in each rein (the end rein tension). This further indicates that the problem is not the bit in itself, but the magnitude of pressure that is applied on the reins. Likewise, studies of horses' voluntary rein tension indicate that 5 N tension in each rein likely does not cause discomfort to the horse (Piccolo & Kienapfel, 2019). Hence, the problem is rather the rider's hand and skills in communicating with the horse, and thus the solution is to teach riders how to ride and train horses with more feel for the pressures applied on the horse's mouth and a better understanding of how rein tension signals affect the horse physically and mentally. In particular, it is likely that diminishing baseline rein tension, *i.e.* the contact on the reins, would benefit the communication between rider and horse, since if the reins are already tight, even more rein tension needs to be applied for signalling.

6.7 Personal reflections on the way forward

To address the issue of excessive rein tension affecting the ridden horse's welfare, more emphasis should be placed on educating riders in equine behaviour and learning theory. In particular, riding teachers must be well versed in equine behaviour and learning theory and methodically and clearly teach their students about equine body language, instincts, how horses learn and, in particular, how to make themselves understood to the horse.

More emphasis needs to be placed on proper use of negative reinforcement. Negative reinforcement is about the *release of pressure* and the release should be emphasised much more in riding instructions and riding handbooks. Most riders are likely aware that releasing pressure is important, but it is unlikely that they realise the importance of the release for communication at stride level, for shaping the horse's behaviour or for re-training an unwanted behaviour. There should also be more emphasis on the basic training of the horse, *i.e.* training the basic responses of stop, go and turn (McGreevy & McLean, 2010), before moving on to more complex exercises.

Further, it should be recognised and highlighted by authorities, riding teachers and trainers that the bit is a powerful tool and that rein tension, even on a bitless bridle, involves placing pressure on sensitive tissues. At a certain magnitude of rein tension, the pressure applied becomes painful and thus the rider is in essence controlling the horse through pain. There needs to be greater transparency about this fact, since it is likely that riders in general are ignorant of the painful sensations which bit pressure can create.

I would suggest that the way forward is to place more emphasis on (i) educating riders, riding instructors and horse trainers in equine behaviour and learning theory, (ii) highlight that the bit and bridle are powerful tools for controlling the horse and (iii) underline the importance of the basic training of both horse and rider, building a solid foundation of a balanced rider with clear and consistent signals and a horse confirmed in the basic responses, stop, go and turn, in all gaits. This also implies always restoring the basic responses when problems, which can be traced to miscommunication between horse and rider, arise in training.

6.8 Future studies and methodical considerations

This thesis examined two different situations when studying rein tension signals for communicating an exercise to the horse. The studies were designed to demonstrate learning of a (semi-)new rein tension signal (stable study) and the procedure for communicating an established rein tension signal (ridden study). Learning new signals and being trained using established signals are situations that horses and riders encounter regularly during horse-rider interaction. Future studies should focus on rider education in equine behaviour and learning theory, and in equine biomechanics.

A question that arose during data analysis was whether the riders in the ridden study were aware of the importance of the timing of the release in reinforcing the correct response, or whether they focused more on the timing of their signals and on the horse's biomechanics. It might have helped in interpretation of the results if the riders had been interviewed about their knowledge of learning theory and about the training strategy they used to communicate how they wanted the horse to respond.

In future research, a similar experiment could be conducted focusing on reducing rein tension and/or structuring the learning process more clearly, by asking the riders to improve one specific trait of the downward transition at a time. It would also be interesting to ask riders to explain a training process and how they would go about teaching the horse a new signal or new exercise, and then have them demonstrate it with a horse.

More research is also needed on bit-related oral injuries. Research has shown that pre-competition (Uldahl *et al.*, 2022) and post-competition bit- and bridle-related oral injuries are common in horses (Björnsdóttir *et al.*, 2014; Uldahl & Clayton, 2019; Tuomola *et al.*, 2021a). The question is whether there were any signs of poor riding technique in the riders of affected horses or whether bit-related oral injuries occur from rein tension practices which appear normal in an equitation context. More research is certainly needed and future studies should investigate how both baseline rein tension and signalling rein tension magnitude can be reduced through the use of learning theory and knowledge of equine behaviour, so as to avoid riders using rein tension in a way that habituates the horse to bit pressure.

7. Main conclusions

The overall conclusion from the work in this thesis was that equine behaviour and magnitude of rein tension are associated to a large extent. Rein tension affects the horse's behaviour, *i.e.* by altering their behaviour horses can influence the magnitude of rein tension to which they are subjected.

Specific conclusions were that:

- The rein tension signal was characterised by an increase in rein tension of 5 N (stable study) and 7.5 N (ridden study) in each rein compared with baseline rein tension.
- In the stable study, the release was given within one second from the horse lifting its first front hoof to step back in more than 90% of the trials. In the ridden study, the riders primarily released the rein tension signal before (19%) or during (70%) the downward transition. However, in 11% of the trials the release was given after the transition, *i.e.* at the walk.
- The horses had a longer response latency from the onset of the rein tension signal to transition if rein tension was released before the downward transition.
- Maximum rein tension was reduced over subsequent trials in both the stable study and the ridden study. The rein tension signal magnitude was reduced by half in eight trials in the stable study, and further reduced in the following eight trials. In the ridden study, rein tension signal magnitude was reduced by 10%. This discrepancy in the magnitude of the reduction can likely be attributed to the difference in timing of the release or in training objectives between the stable study and the ridden study.

- Horses learned a semi-new rein tension signal equally well with a halter as with a bitted bridle, except that the bitted bridle invoked more evasive behaviour with the head/neck/mouth. The incidence of head/neck/mouth behaviour declined over successive trials in the stable study, but not in the ridden study.
- The halter was associated with more investigative behaviour than the bit, which may indicate that the horses were more relaxed while wearing the halter.
- Open mouth, head upward and biting on the bit were the most common head/neck/mouth behaviours and, when performed, they all led to a reduction in rein tension magnitude from onset to end.

General conclusions were that:

- Applying rein tension signals, with a timely release, trains the horse to perform the correct response and, depending on the magnitude of the rein tension, likely also triggers the horse to manipulate the bit pressure through various head/neck/mouth behaviours.
- Oral injuries, stress and conflict behaviour are common in riding horses subjected to pressure from the reins. Therefore rein tension and rein tension signals should be reduced to the level of pressure that the individual horse is comfortable with, judging from the horse's behavioural response to the pressure.
- Riders and horse trainers can quickly reduce the magnitude of rein tension signals for communication by using the principles of learning and being quick and consistent in releasing rein tension at the correct response.
- Reducing baseline rein tension (the contact between the rider's hand and the horse's mouth) is important in reducing the magnitude of rein tension signals.

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Popular science summary

Horse riding is based on communication between horse and rider. The rider senses the horse's movements and mood and gives signals to the horse regarding the desired pace, direction and posture. Signalling in equestrian sports is usually based on varying pressures from the rider's legs, seat and reins, and the horse learns the meaning of these pressure signals mainly through release of the pressure. Rein signals can be given either via a bit, which creates pressure inside the horse's mouth, or via some form of bitless bridle, which creates pressure on different parts of the horse's head. The problem with rein tension signals is that when the pressure from the bit or the bitless bridle is too strong, it can lead to injuries in the horse's mouth and/or on the horse's head. In addition to creating pain, pressure signals can also be experienced as stressful and frustrating if the horse does not understand how to get rid of the pressure, or at least reduce it. Horses are motivated to get rid of pressure, so through the principle of negative reinforcement the horse learns which behaviour leads to the removal of pressure. Thus it is the release, *i.e.* the rider reducing the pressure signal or removing the pressure completely, that is the most important element in signalling with pressure signals.

The large risk of pain, mouth injury, stress, and conflict behaviours as a consequence of rein tension signals is the problem area behind this thesis. The purpose of the studies that were carried out was to investigate rein tension signals from a behavioural and learning perspective. It is known that the tension in the reins always varies in time with the horse's gait and stride cycle, and is also affected by the rider's seat and rein signals and the horse's behaviour. In order to study rein signals in isolation, three different studies were carried out in a stable aisle with the trainer standing next to the horse's withers (stable study). The horses were trained to back up by the trainer gradually increasing rein tension until the horse lifted its first front hoof to step backwards. At that behaviour, rein tension was completely released to confirm to the horse that it had performed the correct behaviour. This procedure was repeated eight times with a bitted bridle (without a noseband) and eight times with the reins attached to a soft, textile halter. Half of the horses were trained with the halter first and then the bitted bridle and the other half were trained with the bitted bridle first and then the halter. Rein tension was measured by a rein tension meter attached to the reins, while horse behaviour and the trainer's actions were assessed based on video recordings.

Signalling via rein tension during riding was examined in a ridden study, the aim of which was to identify the characteristics of rein tension signals used to communicate deceleration from trot to walk and the rider's timing of the release in relation to the deceleration response. Data were collected for nine riders riding the same eight horses, resulting in 72 different horse-rider combinations. The riders were asked to execute eight decelerations from trot to walk with each horse. The horses were ridden with a bitted bridle and the noseband was tightened to the degree permitted by an ISES taper gauge (~1.5 cm space at the nasal bone). A rein tension meter was used to collect rein tension data. Horse behaviour and riders actions were evaluated from video recordings.

The results showed that pressure from the bit in the horse's mouth led to avoidance or conflict behaviours, mainly mouth behaviours and various head movements. This was particularly evident in the stable study, where the horses when trained with a halter displayed very few evasive behaviours. With a halter, the horses were less attentive and were instead interested in investigating their environment. The fact that these horses showed exploratory behaviour can be interpreted as them being more relaxed when wearing a halter instead of a bitted bridle. Head movements, such as raising the head, and mouth behaviours, such as gaping, were displayed by the horses during both the stable study and the ridden study, and these behaviours led to a reduction in rein tension. In particular, the horses gaped when the pressure from the bit became too strong and stopped gaping when the pressure decreased. Thus, the opportunity to open the mouth to reduce pain and discomfort from the bit is paramount for the welfare of the riding horse. The horses were sensitive to bit pressure to different degrees, but on average they tolerated about 10 N (~1 kg) of rein tension in each rein during the stable study before they felt a need to open their mouth to reduce the pressure load from the bit. In the ridden study, the horses began gaping when the rein tension reached approximately 20 N in each rein. However, not all horses showed gaping behaviour and it is likely that the noseband prevented gaping to some extent.

On average, less than 10 N was required in each rein to signal to the horse to back up or to slow down from trot to walk. The difference in rein tension between the stable study and the ridden study can be traced to the fact that the riders in the ridden study rode with a baseline tension in the reins of on average 22 N (~2.2 kg) in each rein, while in the stable study the rein tension was zero before the rein signal was given. The baseline tension on the reins is usually referred to as the support, or the contact, between the rider's hand and the horse's mouth. The tension on the reins to signal a deceleration response from trot to walk was thus increased by 10 N in each rein, in addition to the baseline tension. It is therefore likely that reducing the rein force to which the horse is exposed is largely dependent on the rider reducing the baseline rein tension, *i.e.* the contact on the reins, while riding.

As mentioned above, the timing of the release is the most important element of the signalling process when pressure signals are used. In the stable study, the release was given immediately when the horse started the correct behaviour, which was backing up. Since only the behaviour backing up led to a reduction in pressure from the bit, or the halter, over successive trials the horses showed fewer other behaviours in response to the pressure and instead learned to back up from light rein pressure. In the riding study, however, the timing of the release differed. The release was usually given during the actual deceleration from trot to walk, which confirmed to the horse that slowing down was the correct behaviour. In 19% of the decelerations, however, the release was given before the deceleration, during the trot, and in 11% the release was given after the deceleration, when the horse had already started to walk. The rein tension required to make the decelerations also did not decrease to any great extent despite eight repetitions.

This thesis showed that studying horse behaviour can reveal whether rein tension magnitude is at a level where the horse feels comfortable. Greater focus should be placed on the important role of the release of pressure for communication and for learning to take place, as well as on the function that different horse behaviours have for the riding horse. Governing organisations within the equine industry should more strongly emphasise that bits and some forms of bitless headgear are powerful tools and must be handled accordingly.

Populärvetenskaplig sammanfattning

Ridning bygger på kommunikation mellan häst och ryttare. Ryttaren känner av hästens rörelser och sinnesstämning och ger signaler till hästen angående önskat tempo, riktning och kroppshållning. Signalgivning inom ridsport bygger oftast på tryck från ryttarens skänklar, sits och tyglar och hästen lär sig innebörden av dessa trycksignaler främst genom att ryttaren lättar på trycket vid rätt beteende. Tygelsignaler kan ges via bett, som skapar tryck i hästens mun, alternativt via någon form av bettlöst huvudlag, som skapar tryck på olika delar av hästens huvud. Det problematiska med tygelsignaler är att då trycket från bettet, alternativt trycket på hästens huvud, är för kraftigt kan det leda till skador och trycksår av olika slag på strukturerna i hästens mun och/eller på hästens huvud. Utöver att skapa smärta kan trycksignaler även upplevas stressande och frustrerande om hästen inte förstår hur den ska bli av med, eller minska, trycket. Hästar är motiverade att bli av med tryck och inlärning av trycksignalerna sker genom principerna för negativ förstärkning. Negativ förstärkning innebär att hästen lär sig vilket beteende som leder till att trycket minskar eller försvinner. Alltså är eftergiften, att ryttaren lättar på trycksignalen, eller tar bort trycket helt, det viktigast elementet inom signalgivning med trycksignaler.

Den stora risken för munskador, stress och konfliktbeteenden som konsekvens av signalgivning via tyglarna är problemområdet som ligger till grund för denna avhandling. Syftet med studierna som genomfördes var att undersöka tygelsignaler utifrån ett beteende- och inlärningsperspektiv. Då spänningen i tyglarna alltid varierar i takt med hästens gångarter och stegcykel, och därtill även påverkas av ryttarens sits och tygelsignaler, samt hästens beteende, syftade den första studien som genomfördes till att studera tygelsignaler i en avskalad situation. Denna första studie genomfördes därför på en stallgång (stallet-studien) med tränaren ståendes bredvid hästens manke. Hästarna tränades till att rygga genom att tygelspänningen gradvis ökade tills hästen lyfte sin första framhov för att kliva bakåt. Vid det beteendet släpptes tygelspänningen helt för att bekräfta för hästen att den gjort rätt beteende. Detta förfarande repeterades åtta gånger med träns och tränsbett (utan nosgrimma) respektive med tyglarna fästa till en tyggrimma. Hälften av hästarnas tränades med grimma först och sedan tränsbett och andra hälften tränades med tränsbett först och sedan grimma. Tygelspänningen mättes och registrering av hästarnas beteende, samt tränarens agerande, gjordes utifrån videofilm.

Syftet med den andra studien i denna avhandling var att studera signalgivning via tygelsignaler under ridning (ridna studien). Framförallt var syftet att ta reda tygelspänningssignalers egenskaper för att kommunicera en avsaktning från trav till skritt samt ryttares timing med eftergiften. Data samlades in genom att nio ryttare red samma åtta hästar, vilket gav 72 olika häst-ryttarkombinationer. Ryttarna fick göra åtta avsaktningar från nedsutten trav till skritt på rakt spår. Hästarna reds på tränsbett och nosgrimman var spänd utifrån det mellanrum som en ISES taper gauge tillåter (~1.5 cm mellanrum på nosryggen). Även i detta försök användes en tygelspänningsmätare för att samla in tygeldata. Hästarnas beteende, samt ryttarnas agerande, registrerades utifrån videofilm.

Resultatet var tydligt angående hästarnas beteende, tryck från bettet i hästens mun var förknippat med undvikande- eller konfliktbeteenden framförallt genom munbeteenden och olika huvudrörelser. Resultatet var tydligast för stallet-studien då hästarna under träning med grimma enbart visade ett fåtal beteenden som tydde på obehag. Med grimma var hästarna mindre uppmärksamma och var istället intresserade av att undersöka miljön de befann sig i. Att de visade undersökande beteenden kan tolkas som att de var mer avspända då de bar en grimma istället för tränsbett. Huvudrörelser, som att höja huvudet, och munbeteenden, som att gapa, visade hästarna både under stallet-studien och under den ridna studien och dessa beteenden ledde till att trycket från bettet minskade. Framförallt gapade hästarna när trycket från bettet blev för kraftigt och slutade gapa när trycket minskade igen. Att hästen har möjlighet att gapa för att minska smärta och obehag från bettet är, med andra ord, grundläggande för ridhästens välfärd. Hästar är olika känsliga för bettets inverkan, men i medeltal tolererade hästarna ca 10 N (ca 1 kg) tygelspänning i respektive tygel under stallet-studien innan de hade ett behov av att gapa för att förändra tryckbelastningen från bettet. I den ridna studien gapade hästarna då tygelspänningen i medeltal nådde ca 20 N i respektive tygel. Alla hästar gapade dock inte, men det är troligt att nosgrimman till viss del hindrade hästarna från att gapa i denna studie.

I medeltal krävdes mindre än 10 N i respektive tygel för att signalera till hästen att rygga samt att sakta ner från trav till skritt. Skillnaden vad gäller tygelsignalerna emellan stallet-studien och den ridna studien var att i den ridna studien red ryttarna med en grundspänning i tyglarna på i medeltal 22 N (ca 2,2 kg) i varje tygel, emedan i stallet var tygelspänningen noll innan tygelsignalen gavs. Grundspänningen i tyglarna brukar kallas för kontakten mellan ryttarens hand och hästens mun. Kraften i tyglarna för att signalera en avsaktning från trav till skritt ökade alltså ytterligare 10 N i varje tygel utöver grundspänningen. Det är därför troligt att minskning av de tygelkrafter hästen utsätts för till stor del är beroende av att ryttare minskar grundtygelspänningen d.v.s. kontakten, under ridning.

Som nämnt ovan är timingen för eftergiften (att man lättar på trycket) det viktigaste elementet i signalgivningen då trycksignaler används. I stallet-studien gavs eftergiften omedelbart då hästen påbörjade korrekt beteende, vilket var att rygga. Då enbart beteendet rygga ledde till att trycket från bettet, respektive grimman, försvann visade hästarna färre och färre andra beteenden som respons på trycket och lärde sig istället att rygga för ett lätt tygeltryck. I den ridna studien skiljde sig dock timingen för eftergiften i större omfattning. Eftergiften gavs oftast under själva avsaktningen från trav till skritt, vilket därmed bekräftar för hästen att sakta av är korrekt beteende. Under 19 % av avsaktningarna från trav till skritt gavs dock eftergiften före avsaktningen, under trav, och under 11 % gavs eftergiften efter avsaktningen, när hästen redan börjat skritta. Tygelspänningen som krävdes för att göra avsaktningarna minskade heller inte i någon större omfattning trots åtta repetitioner.

Slutsatsen från denna avhandling är att hästens beteende bör studeras för att avgöra om tygelspänningen ligger på en nivå som hästen är bekväm med. Ett större fokus bör ligga på eftergiftens betydande roll för kommunikation och inlärning samt på vilken funktion olika beteenden har för hästen under ridning. Styrande organisationer inom hästnäringen bör tydligare understryka att bett, samt vissa former av bettlösa huvudlag, är kraftfull utrustning och ska hanteras därefter.

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Rein Tension Signals Elicit Different Behavioral Responses When Comparing Bitted Bridle and Halter

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When a rider maintains contact on the reins, rein tension will vary continuously in synchronicity with the horse's gait and stride. This continuous variation makes it difficult to isolate the rein tension variations that represent a rein tension signal, complicating interpretation of rein tension data from the perspective of horse-rider interaction. This study investigated (1) the characteristics of a rein tension signal and (2) horse response to a rein tension signal for backing, comparing pressure applied by a bit (bridle), or by a noseband (halter). Twenty Warmblood horses (10 young, 10 adult) wearing a rein tension meter were trained to step back in the aisle of a stable. The handler stood next to the horse's withers, applying tension on the reins until the horse stepped back. This was repeated eight times with the bridle and eight times with the halter. Data analysis was performed using mixed linear and logistic regression models. Horses displaying behaviors other than backing showed significantly increased response latency and rein tension. Inattentive behavior was significantly more common in the halter treatment and in young horses, compared with the bridle treatment and adult horses. Evasive behaviors with the head, neck, and mouth were significantly more common in the bridle treatment than in the halter treatment and the occurrence of head/neck/mouth behaviors increased with increasing rein tension and duration of the rein tension signal. When controlling for behavior, the horses responded significantly faster and to a lighter rein tension signal in the bridle treatment than in the halter treatment. By scrutinizing data on rein tension signals in relation to horse behavior and training exercise, more can be learnt about the horse's experience of the pressures applied and the timing of the release. This can assist in developing ways to evaluate rein tension in relation to correct use of negative reinforcement.

Keywords: negative reinforcement, horse-rider interaction, equine behavior, headstall, horse training

INTRODUCTION

Horse training commonly relies on negative reinforcement to train the horse to perform different behaviors (1). Negative reinforcement is a form of operant conditioning where the animal forms an association between its behavior and the subsequent consequences (2). The definition of negative reinforcement is that an aversive stimulus is removed upon performing the correct behavior, which increases the likelihood that the same behavior will appear again in response to the same stimulus (3). In horse training, the aversive stimulus is usually some form of pressure on the horse's body (4), which when applied acts as a signal. Pressure signals in horse training are ideally applied using light pressure first, then gradually increasing the force and/or frequency/intensity until the horse performs the correct response (5–7). However, knowledge and application of these learning principles is lacking among both professional and amateur riders (8). There is thus a need for improvements in application of negative reinforcement in horse training (9). Pressure applied via the reins, either connected to the bit in the horse's mouth or to a noseband, is commonly used for signaling to the horse to decelerate, turn, or modify its head carriage (10). The variables that comprise a rein tension signal are the magnitude and duration of rein tension and the spatial direction in which the rider applies the rein tension signal, while the release of rein tension acts as the reinforcer.

Previous rein tension studies have quantified the magnitude of rein tension in various situations, compared left and right reins, and analyzed rein tension data in relation to other variables, e.g., type of headstall, gait, and riding exercise (11), in relation to a rideability score (12), and with regard to the voluntary rein tension accepted by horses (13, 14). Several studies on rein tension have found that if the rider rides with contact on the reins, the magnitude of rein tension will largely depend on the horse's gait of travel in the order: walk < trot < canter (15–17). In an observational study of rein tension during ridden transitions, Egenvall et al. (18) documented the magnitude of rein tension one second before, during, and one second after transitions between different gaits. They found that the amount of rein tension was highly associated with the gait of travel before and after the transition, with rein tension increasing when the horse was transitioning from a slower gait to a faster gait and decreasing when the horse was transitioning from a faster gait to a slower gait (18).

Apart from any rein tension signals, tension on the reins will also vary with the movements created by the horse's gait pattern, to a large degree in trot and canter and to a lesser degree in walk (19, 20). During riding at sitting trot, rein tension has been found to fluctuate by 15–20 N on average during each stride (19). Stride-split rein tension data in the trotting unridden horse, equipped with side reins, demonstrate similar values, of ∼10 N variation at a neutral rein length and 15 N variation with short reins (21). To complicate matters, the moment in the stride cycle when the rein tension peaks differs between ridden horses (during suspension phase of trot) (19) and unridden horses (during stance phase of trot) (21). The variation in rein tension magnitude is also strongly affected by the rider's handling of the reins when applying rein tension signals (22).

Due to the continuous variation in rein tension that arises when the horse is in motion, rein tension data can appear unpredictable when studying a graph of raw rein tension. It is difficult to intuitively interpret the tension variations constantly occurring throughout a riding session or assess how the horse can feel the difference between a rein tension signal and variations in tension related to the gait. Understanding the communication between horse and rider that is conveyed via the reins, while rein tension is varying continuously due to the gait and stride cycle, is a complex task. The present study was conducted in an attempt to elucidate some aspects of rein tension signals that are otherwise hidden in what appears to be a random rein tension data sequence.

Specific aims of the study were to investigate (1) the characteristics of a rein tension signal and (2) the horse's response to a rein tension signal for backing from pressure applied by a bit (bridle) or by a noseband (halter). Since the bit had a smaller contact area (∼15 mm) than the halter (35 mm) and since the horse's oral structures are more sensitive than the bridge of the nose (1), the hypothesis was that backing the horse with the bridle would require lower amounts of rein tension and lead to a quicker response compared with the halter. To our knowledge, this study is the first to isolate the rein tension signal from a rein tension dataset in order to investigate the characteristics of the horse's response and the variables affecting the rein tension signal.

MATERIALS AND METHODS

The study was conducted at an equestrian center in Sweden on three consecutive days in May 2019.

Horses

Twenty Warmblood horses were recruited for the study: 10 young (five mares, five geldings) and 10 adult horses (four mares, six geldings). The young horses were 4–5 years old (4.7 years ± 0.46) and in training under saddle for about 1 or 2 years. The adult horses were 7–15 years old (10.3 years ± 2.65) and trained in dressage and jumping for more than 4 years. All the horses were used as school horses for students studying to become riding instructors or horse trainers. The horses were either housed in single box stalls ($n = 17$) with daily turn-out into paddocks and fed forage four times per day, or were kept in a loose housing system ($n = 3$) with automatic feeding stations that provide forage about 20 times per day. The horses were healthy and met the expectations of the students' supervisors in terms of performance. Two weeks prior to data collection, all horses underwent an oral examination performed by a veterinarian specialized in equine oral health. All horses were judged fit to participate in the study. Eight of the horses participated in the study on the first day, eight on the second day, and four on the last day. Each horse was only tested on 1 day, once with the bridle and once with the halter, as detailed below.

Rein Tension Meter

A custom-made rein tension meter was used to collect rein tension data. It consisted of a load cell (Futek, USA, weight 20 g) for each rein, wired to an amplifier and an inertial measurement unit (IMU) (NGIMU, x-io technologies, UK). The IMU had 10 bit resolution and a 3.1 V battery, and weighed 46 g. The load cells were attached by a screw to metal plates pinching the rein with screws and bolts. The amplifier-box (weight 52 g) and IMU were taped together and this package was attached to the crown piece of the bridle or halter using tape so that it was placed on the poll of the horse. The wires were attached to the sidepieces of the headstall using tape. The rein tension meter was fastened on the headstall before tacking up the horse. Rein tension data were sampled at 100 Hz and stored on a micro SD card in the IMU. The rein tension meter was calibrated on the first day of the experiment. Calibration was done by suspending 10 known weights ranging between 0 and 10 kg from each meter. This was done several times before the experiment, to confirm stability of data output.

Experimental Set-Up

The location for the treatments was an aisle (7 m long, 2 m wide) in a building used as a grooming area at the equestrian center. On one side of the aisle there were wash racks and on the other side large metal pipes used as dividers between grooming stalls. Behind the grooming stalls, there were windows facing the stable yard. The horses could see and/or hear other horses during the entire experiment.

The order in which the horses were tested was decided by the stable manager. Alternate horses were then assigned to one of two groups. Group 1 (four young, six adult horses) began with the bridle and Group 2 (six young, four adult horses) began with the halter. The same halter was used for all horses, but the horses wore their own bridle and bit. The noseband of the bridles was removed completely. The same reins, with the rein tension meter attached, were used for all horses throughout the experiment. All horses wore snaffle bits. There were 11 horses with three-piece snaffles, five horses with two-piece snaffles, and four horses with straight bits. The bits were between 13 and 20 mm thick closest to the rings and fitted the horses appropriately. The reins were flat leather reins (15 mm wide) with leather stoppers. The halter was full size, made of fabric, and the noseband was 35 mm wide. For the halter treatment, the reins with the rein tension meter were attached to the side rings of the halter's nose piece. For safe and easy handling during changes of headstall, all horses wore their own halter underneath the treatment headstall (**Figure 1**).

The handler in the experiment was author ME, who is right-handed. One horse at a time was led to one of the grooming stalls next to the aisle, where it was equipped with the headstall for the first treatment by the handler and then led to the aisle. During the entire experiment, the horses also wore an ECG monitoring system that consisted of a wide elastic girth fastened with Velcro around their belly, immediately behind the withers. The ECG data were not used in the present study.

The whole experiment was video-recorded using two video cameras. One video camera (Sony HandyCam FDR-AX53, 25 Hz) was stationary and recorded the entire trial for each horse from the frontal view, including change of tack and leading the horse between the aisle and the grooming stall. Another video camera (Canon Legria, 25 Hz) recorded the aisle, capturing a left-side view of the horse during treatment. This camera was operated by a technician following the horse's movement forwards and backwards on the aisle. The handler stood on the horse's left side during the entire experiment (**Figure 1**).

Experimental Design

Each trial began by synchronizing the rein tension meter with the video recordings. For synchronization, the handler placed one hand on either side of the left rein tension meter and pulled it apart five times repeated twice, counting aloud to five. This was to produce repeated tension peaks for visual detection in each dataset. This synchronization was repeated at the end of the first treatment, and at the beginning and end of the second treatment.

The protocol for each treatment comprised the following phases:

1. Baseline—the handler stood next to the horse's withers for 2 min. The reins were resting on the horse's neck and held at the buckle by the handler, who only intervened if the horse moved or attempted something that might damage the rein tension meter.
2. Picking up the reins—the handler lifted the arms, picked up the reins, and placed the hands above the horse's withers, taking the slack out of the reins (**Figure 1**). In some cases, the horse's head and neck were straightened by applying tension on the right rein.
3. Rein tension signal—the handler applied tension on the reins until the horse stepped back. The handler began with light rein tension, gradually increasing the tension until the horse responded by taking a step back. If the horse stepped back immediately on a light rein tension signal in two consecutive repetitions, the criterion was raised for the next repetition, with rein tension applied until the horse stepped back an additional step. The criterion was lowered again (to fewer steps) if the horse resisted, hesitated, or seemed to have difficulty stepping back in the previous repetition. When the horse had stepped back the requested number of steps, rein tension was immediately released. If the horse took more steps than requested, this was simply ignored.
4. Rest—the horse and handler stood still on the aisle, reins held at the buckle, until 1 min had passed from the onset of the previous rein tension signal. The handler only intervened if the horse moved or attempted something that might damage the rein tension meter.
5. Repeat—points 2, 3, and 4, were repeated eight times.
6. Recovery—the horse and handler stood still on the aisle, reins held at the buckle, for a 2-min recovery period.
7. Change tack—the horse was led back to the grooming stall and tacked up with the headstall of the second treatment. Then steps 1–6 were repeated.

Data Extraction

Using the video recordings, the video frames corresponding to the start and stop times for the different phases of the treatments were identified. During the rein tension signal, the moment when the horse lifted the first front hoof to step back was noted in the protocol as the onset of backing. The moment when the handler started lowering the hands, i.e., releasing the reins, was identified as the timing of the release. Each horse's behavior was recorded during the rein tension signal phase. Behaviors were recorded as present/absent, using the ethogram shown in **Table 1**.

Data Analysis

Rein tension data and video recording protocols for each trial, including start and stop times for the different phases and the behavioral recordings, were imported into Matlab (MathWorks Inc., MA, USA) and analyzed using custom-made code. Since the peak rein tension acted as the aversive stimulus, maximum rein tension was used in data analysis. Maximum rein tension was determined for the left and right reins during the phases picking up the reins and rein tension signal for descriptive statistics. The sum of the left and right maximum rein tension was computed for the rein tension signal. Response latency (time to response) was defined as the time between onset of the rein tension signal until the onset of backing as defined above. The time from onset of backing until timing of the release was calculated for repetitions of one step back. Behaviors were partitioned into two categories: Head/neck/mouth behavior (containing all head/neck movement and mouth behavior) and inattentive behavior (including attention and turning head/neck behavior) (see ethogram in **Table 1**).

Statistical Analysis

A dataset with discrete rein tension values calculated per rein and phase, duration of the different phases, and behavioral records was imported into R (version 1.2.5019, RStudio, MA, USA). Descriptive statistics (R packages: tidyverse, ggplot2, dplyr, gapminder) were calculated for the phases picking up the reins and rein tension signal. The main statistical analysis was done using linear mixed and logistic mixed regression models (R packages: lmerTest, lme4, emmeans). The outcome variables maximum rein tension during the rein tension

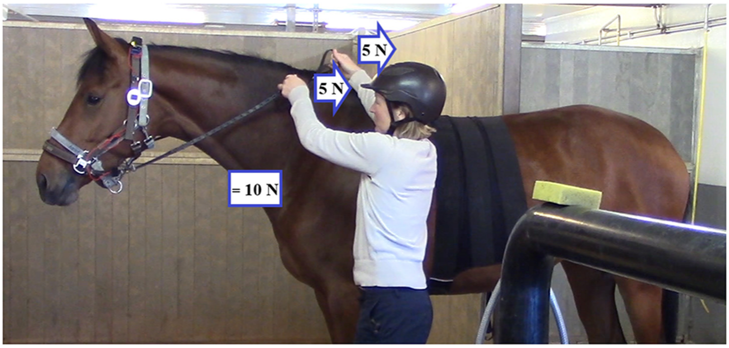

FIGURE 1 | Position of the handler during the treatments. To determine the resultant force to which the horse's nose or mouth was subjected, left and right rein tension values were added. Rein tension values indicated in the figure are only examples.

TABLE 1 | Ethogram used for behavior recording [modified after Egenvall et al. (22) and Fenner et al. (7)].

Behavioral category		Behavior	Description	Horses	*n*
Inattentive behavior	Attention	Looking at something	Directed gaze, pointed ears and immobile posture	14	35
		Investigating	Investigating the environment with nose and/or mouth	9	15
	Turning head/neck	Away	Turning the head and neck away from handler	12	33
		Toward	Turning the head and neck toward the handler for contact	9	24
Head/neck/mouth behavior	Head/neck movement	Upward	Head/neck is raised upward	17	79
		Downward	Head/neck is lowered downward	9	28
		Forward	Nose is pushed forwards	11	22
		Backward	Nose is drawn in toward the chest	6	11
		Toss	Quick upward vertical movement of the head	8	14
	Mouth behavior	Biting on bit	The bit is pulled up inside the mouth and horse is biting on it	12	28
		Open mouth	Visible gap between upper and lower jaw	17	58

For head/neck movements, behaviors were recorded when the horse moved their head and neck in any of the directions described. Horses is the number of horses showing each behavior and n is the number of rein tension signals when each behavior was present.

signal and response latency were modeled using linear mixed model. These variables were not normally distributed and were transformed along the ladder of powers to find the most suitable transformation, which was deemed to be square root transformation. Normality after transformation was checked by plotting Pearson's residuals. The explanatory variables were: Headstall (bridle/halter), age group (young/adult), number of steps (1–3), and 11 dichotomous behavior variables (looking at something, investigating, turning away, turning toward handler, head upward, head downward, head forward, head backward, head toss, biting on the bit, and open mouth), all entered as class variables. Horse and the interaction between horse and treatment group (order of treatment) were modeled as random variables. The full model was first tested including three-way-interactions between the three design variables (headstall, age group, and number of steps). Backwards reduction was done manually, while the three design variables were forced into the final models (without interactions). Akaike's information criterion (AIC) was evaluated during modeling. Bonferroni correction was used while reducing the model. Estimated marginal means were calculated for all variables and contrast *p*-values were used to determine significant differences between level combinations. Contrasts of more than two levels were Tukey-adjusted for multiple comparisons. $P < 0.05$ were considered significant. The covariance structure was set to unstructured.

In addition, logistic regression models were made with the behavioral category variables head/neck/mouth behavior and inattentive behavior as outcome. Headstall and age group were explanatory variables in the inattentive behavior model, while headstall, maximum rein tension, and response latency were explanatory variables in the head/neck/mouth behavior model. Maximum rein tension and response latency were tested for linearity by modeling these variables as categorical variables in the form of equidistant categories and confirming consistent increments between each pair of categories. Horse was included as a random variable.

RESULTS

For each of the 20 horses, eight rein tension signals were applied with the bridle and eight rein tension signals with the halter, resulting in 320 rein tension signals in total, i.e., 160 rein tension signals with the bridle and 160 rein tension signals with the halter. All horses completed the experiment and all data were retrieved for analysis.

Rein Tension Signal and Horse Response

The response latency (time to response) and the magnitude of rein tension (sum of left and right rein) increased simultaneously, with the relationship estimated to rho 0.69

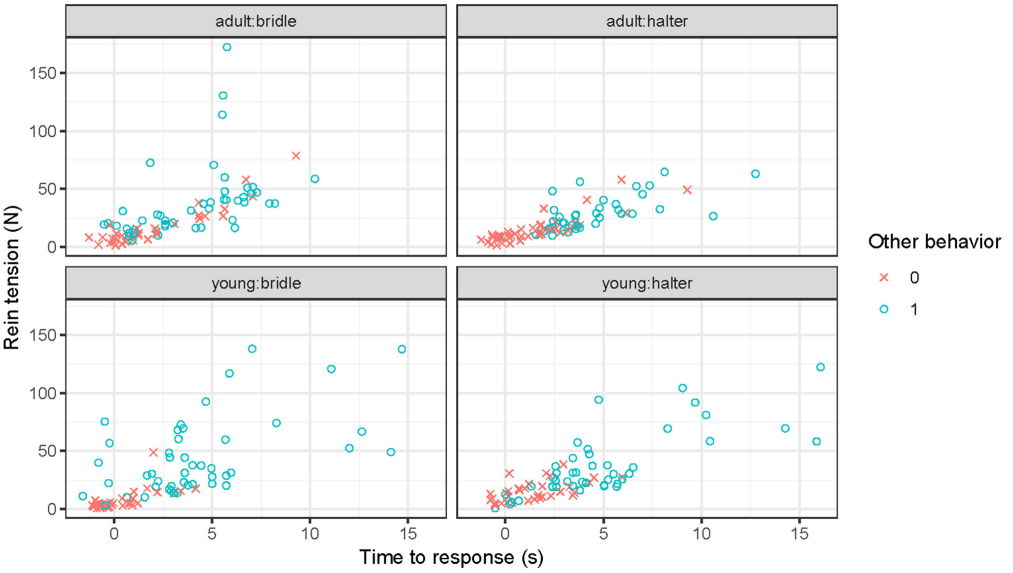

FIGURE 2 | Response latency plotted against maximum rein tension (sum of left and right rein) for bridle and halter for young and adult horses. Color and shape by presence/absence of behaviors other than backing. Data include 20 horses, backing in response to a rein tension signal, each performing eight repetitions with a bridle and eight repetitions with a halter, yielding 320 rein tension signals in total. Each dot represents one of the rein tension signals for one horse. Note that the x-axis starts before zero, as some horses responded already while the handler was picking up the reins. Behaviors included are: Looking at something, investigating, turning away, turning toward the handler, head upward, head downward, head forward, head backward, head toss, biting on the bit, and open mouth.

[Pearson's product-moment correlation, CI [0.63, 0.74], $p < 0.001$]. This relationship, divided by age group and headstall, is illustrated in **Figure 2**. **Figures 3–5** show examples of raw rein tension signals and the diversity in appearance of these rein tension signals, comparing number of steps and different horses.

In 18% of the rein tension signals, the horse responded before the rein tension signal was applied, i.e., started to step back during the phase picking up the reins (22% for bridle, spread over 15 horses; 14% for halter, 10 horses). When the horse started backing before the rein tension signal was applied the response latency variable became negative, as can be seen in **Figure 2**. The release of rein tension was given within one second from onset of backing in 91% of the rein tension signals for bridle and 92% for halter (median 0.5 s bridle/halter).

The correlation between maximum rein tension for left and right rein was estimated to rho 0.86 [Pearson's product-moment correlation, CI [0.83, 0.89], $p < 0.001$]. Descriptive statistics for picking up the reins and the rein tension signal phases can be found in **Table 2**.

Variables Affecting Rein Tension Signal and Horse Response

The results from the final, reduced model of response latency (**Tables 3**, **4**), revealed that, when controlling for behavior, the horses responded significantly faster in the bridle treatment

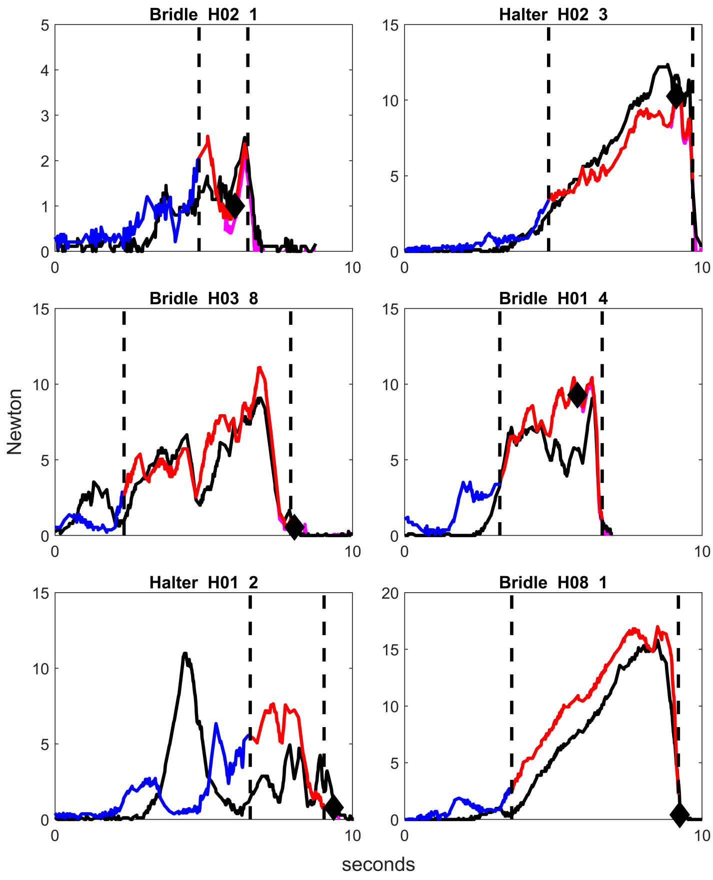

FIGURE 3 | Examples of graphs of rein tension signals using bridle or halter in different horses, from repetitions where the handler applied rein tension for one step back and with no other behavioral response than backing. Blue color on the rein tension curve illustrates the phase picking up the reins, red color illustrates the rein tension signal, and purple illustrates the horse stepping back. Only the right rein is colored. The first vertical dotted line demonstrates the onset of the rein tension signal and the second vertical dotted line displays the lowering of the handler's hands, i.e., release of the rein tension signal. The black diamond signifies the onset of backing. H = Horse, first number is horse number, second number is repetition number. Note that the scale on the y-axis differs slightly between graphs.

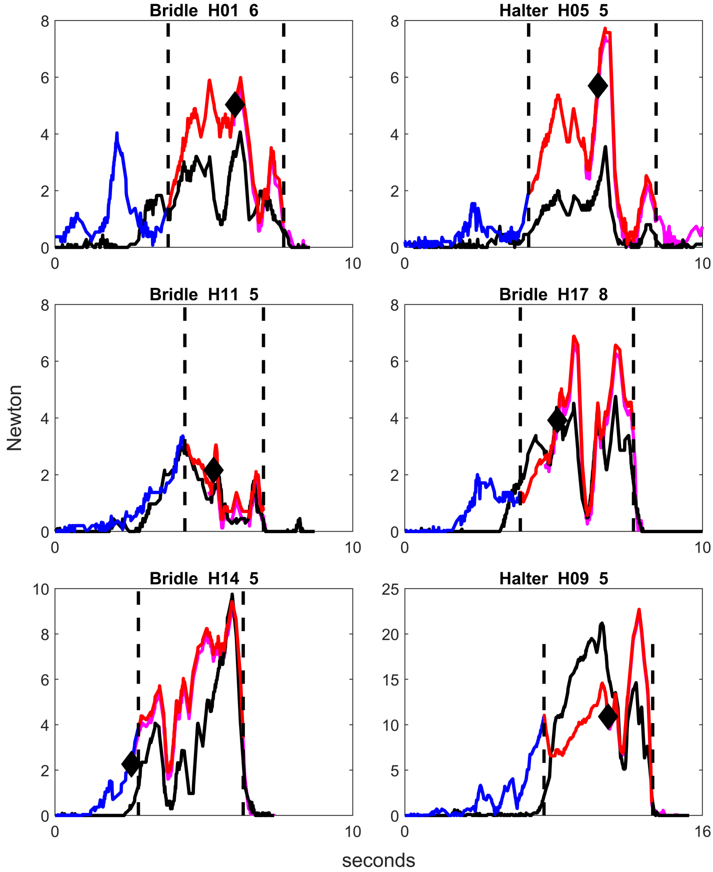

FIGURE 4 | Examples of graphs of rein tension signals using bridle or halter in different horses, from repetitions where the handler applied rein tension for two steps and with no other behavioral response than backing. Blue color on the rein tension curve illustrates the phase picking up the reins, red color illustrates the rein tension signal, and purple illustrates the horse stepping back. Only the right rein is colored. The first vertical dotted line demonstrates the onset of the rein tension signal and the second vertical dotted line displays the lowering of the handler's hands, i.e., release of the rein tension signal. The black diamond signifies the onset of backing. The decrease in magnitude of rein tension shown after the onset of backing demonstrates the release of rein tension for the first step back. H = Horse, first number is horse number, second number is repetition number. Note that the scale on both the x-axis and the y-axis differs slightly between graphs.

(∼0.5 s, **Table 3**) than in the halter treatment. Presence of the behaviors looking at something, investigating, turning toward handler, head upward, head forward, and open mouth was always associated with a significantly longer response latency than when absent ($p < 0.01$). The behavior investigating increased time the most, followed by looking at something, turning toward handler, and head forward (∼2 s; **Table 3**). Two and three steps back were associated with significantly shorter response latency compared with one step back. The same model with behavior excluded resulted in no significant differences between the bridle and halter treatments, while the difference for two and three steps back remained significant (see **Supplementary Material**).

In the model with maximum rein tension as the outcome, rein tension was significantly lower in the bridle treatment compared with the halter treatment (∼5 N; **Table 3**), when controlling for behavior, i.e., if no other behavior was present. All behaviors except biting on the bit, turning toward the handler, head toss, and head backward were associated with significantly more rein tension when present compared with when absent ($p < 0.01$). In particular, investigating, head forward, and head downward increased rein tension most when present compared with when absent (∼20 N; **Table 3**). Two steps back was associated with significantly lower rein tension than one step back. The same model with behavior excluded revealed no significant differences

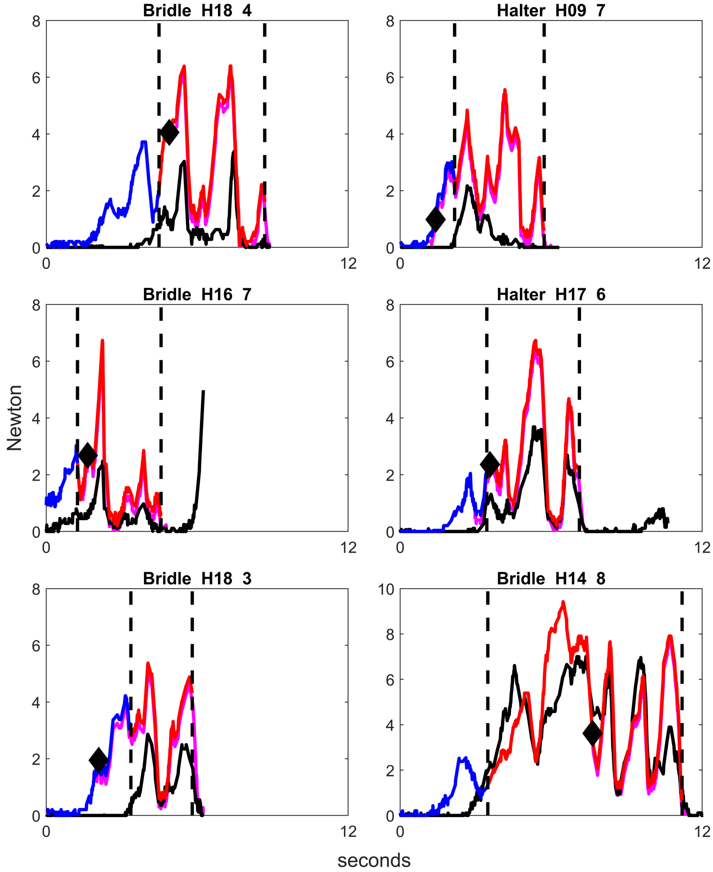

FIGURE 5 | Examples of graphs of rein tension signals using bridle or halter in different horses, from repetitions where the handler applied rein tension for three steps back and with no other behavioral response than backing. Blue color on the rein tension curve illustrates the phase picking up the reins, red color illustrates the rein tension signal, and purple illustrates the horse stepping back. Only the right rein is colored. The first vertical dotted line demonstrates the onset of the rein tension signal and the second vertical dotted line displays the lowering of the handler's hands, i.e., release of the rein tension signal. The black diamond signifies the onset of backing. The repeated decreases in magnitude of rein tension after the onset of backing demonstrate the release of rein tension accompanying each step back. H = Horse, first number is horse number, second number is repetition number. Note that the y-axis differs slightly between graphs.

between the bridle and the halter treatment, but two steps back remained significant (see **Supplementary Material**).

The odds of head/neck/mouth behavior being displayed increased significantly with increasing rein tension, OR 1.048 (95% CI 1.02, 1.08), and response latency, OR 1.34 (95% CI 1.13, 1.62). The odds of the horse showing head/neck/mouth behavior thus increased with 5% for every added newton rein tension and with 34% for every added second the rein tension signal was applied (see **Supplementary Materials** for calculations). There was significantly less head/neck/mouth behavior during the halter treatment, OR 0.22 (95% CI 0.12, 0.42), compared with the bridle treatment. In the halter treatment, there was significantly more inattentive behavior compared with in the bridle treatment, OR 1.76 (95% CI 1.03, 3.05), and the young horses performed these behaviors significantly more often than the adult horses, OR 4.42 (95% CI 1.73, 13.41).

DISCUSSION

Overall, the results showed that the horses responded significantly faster and to a lighter rein tension signal in

TABLE 2 | Descriptive statistics on time variables and maximum rein tension of the phases picking up the reins and rein tension signal.

			Time (s)			Maximum rein tension (N)				
	Headstall	**Number of steps**	**Time to response**	**Duration**	**Rein (left/right)**	**Mean**	**SD**	**Median**	**Range**	**IQR**
Picking up the reins	Bridle (160)	n/a	n/a	3.8	L	4	7	2	0–54	1–4
		n/a	n/a		R	6	10	4	0.9–112	2–5
	Halter (160)	n/a	n/a	4.1	L	4	6	2	0–49	1–3
		n/a	n/a		R	5	5	3	0.7–31	2–5
Rein tension signal	Bridle	1 (105)	3.9	4.5	L	16	16	11	0–75	5–21
					R	19	18	15	0.9–97	7–24
		2 (37)	1	3.8	L	8	10	6	0–38	3–9
					R	9	9	7	0.5–40	4–10
		3 (18)	0.6	4.3	L	8	9	3	1.5–29	2–10
					R	10	11	6	2–41	5–9
	Halter	1 (89)	4.3	4.8	L	15	13	12	0–60	6–17
					R	16	13	13	0.8–70	8–21
		2 (53)	1.9	4.4	L	8	5	7	0.2–21	4–9
					R	9	6	8	2–39	6–10
		3 (18)	0.8	4.7	L	6	5	5	0–17	3–9
					R	9	4	7	2–18	6–13

Numbers in brackets are number of rein tension signals. Data include 20 horses each performing eight repetitions with the bridle and eight repetitions with the halter, resulting in 320 rein tension signals. Rein tension was applied with light tension first and then increased until the horse responded by stepping back.

TABLE 3 | Contrasts between variables within each category for the response latency model and the rein tension model.

Model	**Category**	**Variable**	**Estimate**	**SE**	**Lower CI**	**Upper CI**	***p*-value**
Response latency	Headstall	Bridle-halter	−0.62	0.24	−1.11	−0.14	0.013
	Age group	Adult–young	0.48	0.38	−0.31	1.26	0.220
	Number of steps	1–2	1.27	0.24	0.68	1.86	<0.001
		1–3	1.73	0.31	0.97	2.49	<0.001
		2–3	0.46	0.30	−0.27	1.18	0.290
	Behavior	Looking at something	2.16	0.40	1.34	2.97	<0.001
		Investigating	2.66	0.63	1.37	3.95	<0.001
		Turning toward handler	2.09	0.50	1.05	3.12	<0.001
		Head upward	1.34	0.28	0.78	1.91	<0.001
		Head forward	1.82	0.52	0.76	2.88	0.002
		Open mouth	1.05	0.36	0.32	1.79	0.007
Rein tension	Headstall	Bridle-halter	−4.88	1.64	−8.19	−1.58	0.005
	Age group	Adult-young	2.62	2.11	−1.74	6.98	0.226
	Number of steps	1–2	3.35	1.33	0.10	6.60	0.042
		1–3	3.32	1.84	−1.18	7.81	0.184
		2–3	−0.03	1.83	−4.45	4.38	1.000
	Behavior	Looking at something	9.02	2.3	4.34	13.70	<0.001
		Investigating	22.40	4.41	13.40	31.40	<0.001
		Turning away	6.71	2.24	2.14	11.30	0.005
		Head upward	4.72	1.57	1.52	7.93	0.005
		Head downward	19.40	4.02	11.20	27.60	<0.001
		Head forward	23.40	4.4	14.40	32.30	<0.001
		Open mouth	12.50	2.61	7.20	17.80	<0.001

Estimate is the estimated difference in response latency (s) and rein tension (N) between levels within the variables headstall, age group, number of steps, and presence/absence for each behavior, where presence is when only the listed behavior is present and absence is when no behavior is present. A positive value indicates longer latency or higher rein tension for the first alternative listed within each variable. For behavior, the contrasts show how much longer time (s) and higher rein tension (N) were when each behavior was present compared with absent. The variable number of steps is Tukey-adjusted for multiple comparisons. Each model includes the response to a rein tension signal by 20 horses, making eight repetitions of backing in response to a rein tension signal wearing a bridle and eight repetitions wearing a halter. R code and output can be found in ***Supplementary Material****.*

TABLE 4 | Back-transformed least square means from the response latency model (s) and the rein tension model (N) for headstall, age group, and number of steps when controlling for behavior, and presence/absence for behavior.

Model	Category	Variable	Estimate	SE	Lower CI	Upper CI
Response latency	Headstall	Bridle	0.59	0.24	0.13	1.09
		Halter	1.21	0.25	0.72	1.73
	Age group	Adult	1.13	0.30	0.55	1.77
		Young	0.65	0.27	0.12	1.25
	Number of steps	1	1.93	0.27	1.41	2.49
		2	0.66	0.24	0.20	1.17
		3	0.20	0.29	−0.34	0.82
	Behavior	Looking at something	3.04	0.46	2.17	4.00
		Investigating	3.55	0.68	2.29	4.96
		Turning toward handler	2.97	0.56	1.93	4.14
		Head upward	2.23	0.34	1.57	2.94
		Head forward	2.71	0.58	1.64	3.91
		Open mouth	1.94	0.40	1.18	2.78
Rein tension	Headstall	Bridle	9.59	1.35	7.07	12.50
		Halter	14.47	1.56	11.50	17.80
	Age group	Adult	13.30	1.68	10.00	17.00
		Young	10.60	1.53	7.71	14.00
	Number of steps	1	14.20	1.40	11.49	17.10
		2	10.80	1.36	8.27	13.70
		3	10.90	1.83	7.53	14.80
	Behavior	Looking at something	20.90	2.65	16.01	26.50
		Investigating	34.30	4.70	25.68	44.20
		Turning away	18.60	2.55	13.92	24.00
		Head upward	16.60	1.93	13.01	20.70
		Head downward	31.30	4.34	23.34	40.50
		Head forward	35.30	4.79	26.47	45.30
		Open mouth	24.40	2.91	19.02	30.50

*For headstall, age group, and number of steps, the column estimate shows the estimated response latency and rein tension when behavior was controlled for, i.e., none of the behaviors was present during the rein tension signal. For behavior, the estimate value shows the estimated response latency and rein tension when each behavior was present during the rein tension signal. Each model included the response to a rein tension signal by 20 horses, making eight repetitions of backing in response to a rein tension signal wearing a bridle and eight repetitions wearing a halter. R code and output can be found in **Supplementary Material**.*

the bridle treatment compared with the halter treatment, when controlling for behavior, confirming the starting hypothesis. However, the bridle treatment was associated with significantly more head/neck/mouth behaviors than the halter treatment, and the occurrence of head/neck/mouth behavior increased with increasing magnitude and duration of the rein tension signal. All behaviors in the head/neck/mouth category could be classified as evasive or resistance behaviors aimed at either escaping or resisting the pressure applied (**Table 1**). These results suggest that the bridle was perceived as more aversive by the horses, since they showed more of these evasive and resistance behaviors during the rein tension signals applied with the bitted bridle compared with the halter. Horses may also associate different equipment with different activities. Inattentive behaviors were significantly more common in the halter treatment and in young horses, indicating that young horses in particular may have associated the halter with non-training time and thus their attention was more on other things than on paying attention to rein tension signals.

Interestingly, there was no significant difference between young and adult horses in magnitude of rein tension or response latency. There was, however, a tendency for the young horses to respond faster and to a lighter rein tension signal (see estimates in **Table 4**), indicating that perhaps the adult horses had habituated to the rein tension signal to some extent and were thus less responsive. Nevertheless, habituation to the bit is not necessarily a consequence of having more years being trained with a bit, but is rather a consequence of how the horse's training has been conducted. The horses in our study were all school horses and were thus teaching riders to refine their skills in equitation on a daily basis. It is likely that their different riders have diverse skills in always beginning with a light rein tension signal (before gradually increasing) and releasing rein tension promptly, both of which are important skills to maintain lightness and avoid habituation to rein tension (23). By scrutinizing data on rein tension signals in relation to horse behavior and ridden exercise, more can be learnt about the horse's experience of the pressures applied and riders' timing of the release. This can assist in developing ways to evaluate rein tension in relation to the correct use of negative reinforcement and can ultimately increase the welfare of horses during training.

When a horse responded immediately to a light rein tension signal during the course of the experiment, the handler raised the criterion and applied rein tension for an additional step. Accordingly, rein tension applied for two or three steps had a shorter response latency and rein tension was lowest when the horse responded already during picking up the reins. This suggests that a quick response to a rein tension signal is crucial for keeping rein tension at a minimum (**Figure 2**). By focusing on making sure that the horse understands each rein tension signal, rein tension is more likely to be kept at low levels during a training session (23). The mean maximum amount of rein tension during the picking up the reins phase was $\sim$9 N (sum of left and right rein) and in 18% of the rein tension signals the horse was backing already during picking up the reins. This amount of rein tension, or less, was thus enough to elicit a response.

All behaviors recorded except biting on the bit, head toss, and head backward were associated with a significant increase in rein tension and/or response latency when present compared with when absent (**Figure 2**). The behavior investigating, which increased both magnitude of rein tension and response latency, implied that the horse's attention was on investigating the environment, rather than responding to the rein tension signal. The behaviors head forward and head downward significantly increased rein tension, since the horse moved its head in the opposite direction as the handler applied the rein tension signal. These behaviors were also recorded by Egenvall et al. (22) during riding when the release of rein tension was withheld until a complete correct response was obtained. It is thus likely that the horses in the present study moved their head forward/downward in an attempt to alleviate the pressure from the bit, as doing this forcefully could pull the reins out of the hands of a rider. This behavior was likely not performed for the first time in this study, but rather previously learnt by repeated success in getting relief from rein tension by the horse pushing their head and neck in the opposite direction. In this experiment, all behaviors recorded during the rein tension signal phase likely reflect the horse's understanding of what can lead to release of rein tension, and/or its motivation/eagerness to get relief from rein tension.

The type of halter used in this study is generally used for leading and grooming, and not primarily for riding horses. We chose the halter to compare with the bitted bridle because we wanted a headstall that would be as comfortable as possible for the horse, allowing us to compare the bit with no bit, rather than with other aversive equipment. The soft textile noseband of the halter used in this study likely created a more comfortable pressure on the horse compared with the pressure from the bit in the mouth, as the force was applied on a larger contact area (noseband of halter 35 mm, bit 13–20 mm in width), thus yielding a lower pressure, and on a less sensitive body part (the bridge of the nose compared with the mouth). However, it is difficult to estimate the pressure applied to these two anatomical regions, as both are irregularly shaped and consequently small pressure points are created (24). In other words, bitless headstalls in general are not necessarily more comfortable for horses.

The reason for choosing backing from a standstill, by the unridden horse, was to reduce the number of variables that could lead to fluctuations in rein tension, i.e., gait, stride, and/or (un)steadiness of the rider's hands/handling of the reins. This approach was intended to isolate the actual rein tension signal, in order to learn more about the appearance and features of rein tension signals, knowledge that could later be applied to study rein tension signals during movement.

The plots of rein tension signals revealed that the peaks of rein tension were distributed along the time axis (x-axis), while the magnitude and frequency of the peaks (y-axis) differed between the horses (**Figures 3–5**). It should be noted that all signals were given by the same handler in a consistent position. There were a few common features in all rein tension signals. The most obvious was that rein tension increased gradually during the rein tension signal, but returned to zero the moment that rein tension signal was released. During repetitions where the rein tension signal was applied for two or three steps back, a reduction in rein tension magnitude accompanied each step (**Figures 4**, **5**).

During data collection in this study, lifting of the first front hoof to step back was the feedback to the handler that the horse had responded to the rein tension signal. The timing of the release was thus coupled with lifting of the front hoof, i.e., the onset of backing. It is often stated that the release of pressure/tension has to be given immediately once the horse gives the correct response (5–7). How "immediate" is defined in this context is not clear, but we believe that releasing rein tension within one second of the horse's response would be immediate enough for the horse to make an association between its behavior (backing) and the following consequences (relief from pressure on the mouth/nose).

The results in this study show the rein tension signals given by one single handler, and thus reflect between-horse variation in response to a particular rein tension signal, rather than the traits of rein tension signals in general. It would be interesting to investigate further the variables that influence understanding and motivation among horses to respond to rein tension signals and the variation in application of rein tension signals among riders. Future studies should focus on developing methods to identify rein tension signals in a rein tension dataset of horse-rider interaction in movement.

The position of the handler is another factor to consider when interpreting the results from this study. Tension on the right rein was consistently slightly higher than on the left rein (**Table 2**), most likely due to the handler's position on the horse's left side. The horse was more inclined to turn toward the handler and the more open area on their left side, so the handler had to direct the horse's head straight from time to time using the right rein, thus increasing tension primarily on the right rein. Another issue to consider when interpreting the results from this study is that all the horses were from the same equestrian center, and thus trained under similar conditions and following similar procedures and training ideologies.

In rein tension studies, it is common to present the magnitude of rein tension as either a mean value for the left and right rein, or as separate values for the left and right rein. However, it is important to remember that when two forces are pulling on an object in the same direction, these forces should be added to show the resultant force. If, e.g., there is 5 N on the left rein and 5 N on the right rein, the resultant tension that the horse is experiencing as pressure applied is 10 N (**Figure 1**). In this study, we decided to use the resultant force for our computations and the reader should take this into consideration when comparing the magnitude of rein tension in this and other rein tension studies.

It should be borne in mind that when escalating pressure signals are used as a means of communication, there is always a risk of causing the horse discomfort, pain, and even physical injury (25). Bridles with bits and bitless alternatives both press on sensitive structures of the horse's head and mouth when rein tension is applied (26). Further, mouth injuries connected to use of bridles are common in horses (27, 28). Scrutinizing the characteristics of rein tension signals may thus yield clues to improving horse welfare during training and riding, ultimately increasing awareness of signals and how the horse perceives these. It is likely that horses would benefit from riders learning to use negative reinforcement in a more sophisticated way, e.g., by reducing the magnitude of rein tension signals, being more prompt in releasing rein tension, and recognizing how little rein tension is actually needed to elicit a response.

CONCLUSIONS

This study of rein tension in unridden horses at a standstill had the advantages of removing variables such as gait, stride, and the rider's influence, and provided a rein tension dataset that was used to scrutinize rein tension signals. Quantification of rein tension signals and the horse's response revealed a wide range in both magnitude of rein tension and response latency (time to response) between the horses. The most prominent finding was that horse behavior during the rein tension signal was significantly associated with both magnitude of rein tension and response latency. Horses that had their attention on other things or moved their head forward and/or downward during the rein tension signal had the greatest magnitude of rein tension and the longest response latency. Likewise, occurrence of head/neck/mouth behavior increased with increasing duration and magnitude of rein tension, and the bridle treatment was associated with significantly more head/neck/mouth behaviors than the halter treatment. The horses that responded quickly to the rein tension signal had the lowest rein tension. In future studies of rein tension signals, we suggest measuring three key variables: response latency, timing of release of the rein tension signal, and behavior of the horse during the rein tension signal. In particular, the horse's behavior needs to be considered when interpreting rein tension data, as the numerous behaviors a horse can perform will affect the magnitude of rein tension. Scrutinizing data on rein tension signals in relation to horse behavior and training exercise can help in developing ways to evaluate rein tension and promote correct use of negative reinforcement.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The animal study was reviewed and approved by the Animal Ethics Board, Uppsala district court, in Uppsala, Sweden.

AUTHOR CONTRIBUTIONS

The research objectives and the experimental setup were initiated by ME. Data collection was performed by ME, JY, PB, and AE. Video recordings were made by ME. Data analysis and statistical analysis were performed by ME, AE, and AB. ME wrote the manuscript. All authors contributed to improving the manuscript and refining the experimental design.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2021.652015/full#supplementary-material

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A rein tension signal can be reduced by half in a single training session

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A R T I C L E I N F O

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A B S T R A C T

Rein tension signals are, in essence, pressures applied on the horse's mouth or nose, via the bit/noseband, by a rider or trainer. These pressures may feel uncomfortable or even painful to the horse and therefore it is important to reduce rein tension magnitude to a minimum. The aim of this study was to investigate the magnitude of a rein tension signal for backing up, using negative reinforcement. We wanted to assess how much the magnitude of rein tension could be reduced over eight trials and if the learning process would differ depending on headstall (bridle/halter). Twenty Warmblood horses were trained to step back from a rein tension signal with the handler standing next to the horse, holding the hands above the horse's withers. As soon as the horses stepped back, rein tension was released. The horses were either trained with a bridle first (first treatment, eight trials) and then with a halter (second treatment, eight trials), or vice versa in a cross-over design. All horses wore a rein tension meter and behavior was recorded from video. The sum of left and right maximum rein tension from onset of the rein tension signal to onset of backing (signaling rein tension) was determined for each trial. Mixed linear and logistic regression models were used for the data analysis. In both treatments, signaling rein tension was significantly lower in trial 7–8 than the first trial ($p < 0.02$). Likewise, signaling rein tension was significantly lower ($p < 0.01$), and the horses responded significantly faster, ($p < 0.001$) in the second treatment compared to the first, regardless of headstall. The maximum rein tension was reduced from 35 N to 17 N for bridle (sum of left and right rein) and from 25 N to 15 N for halter in the first eight trials. Rein tension was then further reduced to 10 N for both bridle and halter over the eight additional trials in the second treatment, i.e. to approximately 5 N in each rein. There was no significant difference in learning performance depending on headstall, but the bitted bridle was associated with significantly more head/neck/mouth behaviors. These results suggest that it is possible to reduce maximum rein tension by half in just eight trials. The findings demonstrate how quickly the horse can be taught to respond to progressively lower magnitudes of rein tension through the correct application of negative reinforcement, suggesting possibilities for substantial improvement of equine welfare during training.

1. Introduction

At present, training horses to perform various tasks is mainly accomplished through the use of pressure signals to elicit desired responses from the horse. Pressure signals used in horse riding are generally rein tension creating mouth/nose pressure, leg pressure on the horse's belly, weight shifts in the saddle, and/or tapping with the whip.

The structures of the horse's mouth and head are sensitive and mouth injuries related to bridles and bits are common in horses (Björnsdóttir et al., 2014; Uldahl and Clayton, 2019; Tuomola et al., 2021). Whereas the noseband and the type of bit have been found to influence the occurrence of mouth injuries (Björnsdóttir et al., 2014; Uldahl and Clayton, 2019), it is likely that the magnitude of rein tension is an even more important factor for the development of oral lesions (Mellor, 2020). Likewise, research suggests that even naive horses may find pressure from the bit in the mouth aversive (Christensen et al., 2011)

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and it seems that horses prefer lower levels of rein tension than what riders generally apply (Piccolo and Kienapfel, 2019).

Well-informed horse trainers are aware of the principles of operant conditioning (McLean and Christensen, 2017) and systematically use pressure and timely release to train and maintain responses through negative reinforcement (Brown and Connor, 2017), i.e. releasing the pressure at the moment the horse performs the correct behavior, which increases the likelihood that the behavior appear again if the same stimulus is repeated (Pearce, 2008). Likewise, well-informed horse trainers will be aware of the associative learning principles of classical conditioning. In essence, by being consistent in starting each pressure signal with a light pressure, the initial light pressure becomes a conditioned stimuli, a signal, predicting the arrival of the increasing pressure (Baragli et al., 2015). Over repetitions, the horse will make an association between the initial, light pressure and the subsequent escalating pressure and will respond already at the light pressure signal (McGreevy and McLean, 2007). There are, however, knowledge gaps regarding the correct application of the learning principles among riders and horse trainers (Warren-Smith and McGreevy, 2008; Brown and Connor, 2017), e.g. the importance of the timing of the release of pressure and of always starting with a light signal (McLean and Christensen, 2017). Relentless pressure or unpredictable pressure signals can cause stress and discomfort for the horse (McLean and McGreevy, 2010) and therefore further education of equestrians in the principles of operant and classical conditioning is needed (Telatin et al., 2016). Moreover, it has been found that training horses through negative reinforcement can lead to a negative perception of humans (Sankey et al., 2010) and stress related behaviors (Hendriksen et al., 2011; Freymond et al., 2014). Subsequently, training horses to respond to rein tension signals using negative reinforcement, may pose welfare risks, and is important to investigate further.

While negative reinforcement is an operant learning principle that has been recognized and quantified since the experiments conducted by Skinner (1938), Ahrendt et al. (2015) was, to our knowledge, the first to conduct a standardized test for investigating negative reinforcement learning in horses. They trained horses to yield the hindquarters by applying pressure on the horses' hindquarters using an algometer. Inspired by Ahrendt et al. (2015), this study was designed to learn more about negative reinforcement learning of rein tension signals in horses.

Our hypothesis was that through the correct application of negative reinforcement, the magnitude of a rein tension signal can be substantially reduced over the course of a single training session. Further, it was hypothesized that the type of headstall used (bridle/halter) would not affect learning performance. The aim of this study was therefore to investigate the magnitude of a rein tension signal over repeated trials. We wanted to assess how much the magnitude of a rein tension signal could be reduced over eight trials of a backing up exercise and if the learning process would be similar regardless if the horse was trained with a bitted bridle or a halter.

2. Materials and methods

This study was carried out over three days in May 2019 at an Equestrian Center in Sweden. The Animal Ethics Board in Uppsala, Sweden, had given an ethical approval for the study, Dnr 5.8.18-02567/2019.

A study describing the characteristics of the rein tension signal has been published previously using the same data collection. Materials and methods will thus be summarized, and further details can be found in Eisersiö et al. (2021).

Twenty Warmblood horses participated in the study: 10 young horses (4–5 years old, five mares, five geldings) and 10 mature horses (>7 years old, mean 10.3 years ± 2.65, four mares, six geldings). The young horses had been in training under saddle 1–2 years. The mature horses had been trained in dressage and jumping more than 4 years. The horses were school horses at an Equestrian Center. The horses had all been backed up before, as part of normal handling and training, but the riding exercise rein back had not been specifically trained in the young horses. All horses were checked for soundness and health by a veterinarian and the staff at the Center on a regular basis. Oral exams of all horses were conducted two weeks prior to the data collection by a veterinarian with expertize in equine dentistry. The veterinarian considered all horses fit to participate in the experiment.

In brief, the experiment was conducted in an aisle (7 * 2 m) in a grooming area at the Equestrian Center. The order in which the horses entered the experiment was based on the daily activities of that horse, e.g. participation in riding lessons. Every other horse was placed in Group 1 (four young, six mature horses) and every other in Group 2 (six young, four mature horses). Group 1 was first fitted with the bridle and then the halter, and Group 2 was tested with the opposite order of headstalls. Each horse was tested once and on one day. For the bridle treatment, the horses wore their own bridle and bit (noseband removed). Eleven horses wore three-piece snaffles, five horses wore two-piece snaffles, and four horses had straight bits. The bits had a diameter of 13–20 mm close to the bit-rings. The halter treatment used the same full size, standard, nylon halter for all horses (noseband 35 mm wide) (Fig. 1). The staff at the Equestrian Center and the research team were in agreement that the bridles, bits and the halter fitted the horses properly.

2.1. The rein tension meter

To collect rein tension data, a custom-made rein tension meter was used. The rein tension meter for each rein consisted of a load cell (Futek, CA, USA) wired to amplifiers and an IMU (x-io technologies, Bristol, UK). The load cell had a measuring range of 0–500 N and weighted 20 g. The IMU had 10 bit resolution, 3.1 V battery and weighed 46 g. The sampling rate was 100 Hz. The load cells were attached to flat leather reins, with leather stoppers (15 mm wide), close to the bit. The amplifier and IMU were taped together and fastened on the crown piece of the headstall using tape (Fig. 1). The rein tension meter was attached to the headstall before it was fitted on the horse. The reins were attached to the side rings of the halter to exert pressure on the bridge of the nose during the halter treatment and to the rings of the bit to exert pressure on the oral tissues during the bridle treatment. Before and after the experiment, the rein tension meter was calibrated using ten known weights ranging from 0 to 10 kg suspended from each meter to confirm stability of voltage output.

2.2. Experimental setup

During the treatments (bridle and halter), the handler (author M.E., right-handed) was standing on the horse's left side near the horse's withers. Each treatment began with a 2 min rest period where the horse was standing still on the aisle with the handler next to the withers. After 2 min had passed, the handler shortened the reins while lifting the arms and positioned the hands above the horse's withers. Rein tension was then gradually increased, by the handler closing the hands to exert tension on the reins, until the horse took a step back. The handler stepped back along with the horse, staying next to the horse's withers. The handler released rein tension by opening and lowering the hands. The release of rein tension was given immediately when the horse stepped back with a front leg. For each horse and in each treatment, the criterion for release of rein tension started with one step backwards. During the course of the treatment, if the handler felt that the horse was responding immediately to a light rein tension signal, the criterion was raised to one additional step. Rein tension was released for each step back by the handler slightly lowering or moving the hands forward. The criterion was lowered again (to fewer steps) if the horse resisted, hesitated or seemed to have difficulty stepping back. After each backing event, the horse and handler stood still on the aisle until one minute had passed since the onset of the previous rein tension signal. The rein tension signal and rest period were repeated eight times. After the eighth

Fig. 1. The headstalls. The headstalls used in data collection with the rein tension meter attached. Bitted bridle to the left and halter to the right. The horses also wore a halter underneath the treatment headstall.

time, there was a 2 min recovery period standing still on the aisle. The horse was then led to a grooming stall to change headstall and the above described procedure was repeated.

2.3. Data extraction

The horse was video recorded from a left side view during the treatments (25 Hz, Canon Legria HF R806, Canon Inc, Tokyo, Japan). Each treatment began and ended by synchronizing the rein tension meter with the video camera. This was done by pulling on the left rein tension meter five times (not affecting the horse's mouth) while counting out load.

From the video, the different events within each treatment were annotated on a frame-by-frame level using the video editing program Adobe Premiere Elements (Adobe, CA, USA). The point in time when the handler had shortened the reins and positioned the hands above the horse's withers was recorded as the onset of the rein tension signal, while the release of the rein tension was annotated when the handler started to lower the hands. The moment when the horse's chest started to move backwards, i.e. a weight shift to the rear, was noted in the protocol as the beginning of the backing response. The onset of backing was recorded at the moment when the horse's first front hoof was lifted off the floor to step back. The number of front limb steps back that the handler applied the rein tension signal was recorded.

An equine ethologist (author ME) recorded the horse's behavior from the video. Behavior was recorded in the form of one-zero sampling (Martin and Bateson, 2009) during the time interval between onset of the rein tension signal and onset of backing as well as between onset of the rein tension signal and the release of rein tension. The ethogram can be found in Table 1. The horse's backing responses were defined as successful or unsuccessful. A successful response being one where the horse started to back within two seconds, to a light rein tension signal (visible slack in the rein) without showing any other behaviors. Videos 1–4 show the experimental setup and the application of rein tension signals. All videos show the same mature horse who started with the bitted bridle as first treatment.

Table 1
The ethogram used for behavioral observations during the application of the rein tension signal. Originally

Behavioral category		Behavior	Description
Backing response	Performance	Successful	Backing within two seconds, slack rein, no reluctant behaviors shown
	Backing	Steps	Number of steps back the handler applied the rein tension signal
Inattentive behavior	Attention	Looking at something	Directed gaze, pointed ears and immobile posture
		Investigating	Investigating the environment with nose and/or mouth
	Turning head/neck	Away	Turning the head and neck away from handler
		Towards	Turning the head and neck towards the handler for contact
Head/neck/mouth behavior	Head/neck movement	Upward	Head/neck is raised upward
		Downward	Head/neck is lowered downward
		Forward	Nose is pushed forwards
		Backward	Nose is drawn in towards the chest
		Toss	Quick upward vertical movement of the head
	Mouth behavior	Biting on bit	The bit is pulled up inside the mouth and horse is biting on it
		Open mouth	Visible gap between upper and lower jaw

Source:(a) Modified from Eisersiö et al. (2021). (b) Adapted from Egenvall et al. (2012) and Fenner et al. (2017).

3. Data analysis

Behavior, event records and rein tension data were imported into Matlab (2019b, MathWorks Inc., MA). Descriptive variables were calculated using custom-written code. Response latency was determined by calculating the time duration from onset of the rein tension signal to the onset of backing. Signaling rein tension was taken as the sum of left and right maximum rein tension during the response latency period. Response rein tension was taken as the sum of left and right maximum rein tension during the time period between the beginning of the backing response and onset of backing. If the horse started to back when the handler shortened the reins, before the rein tension signal was given, only response rein tension was recorded for that trial, and response latency had a negative value. The resulting dataset was imported into RStudio (version 1.2.5019, RStudio, MA, USA) for statistical analysis.

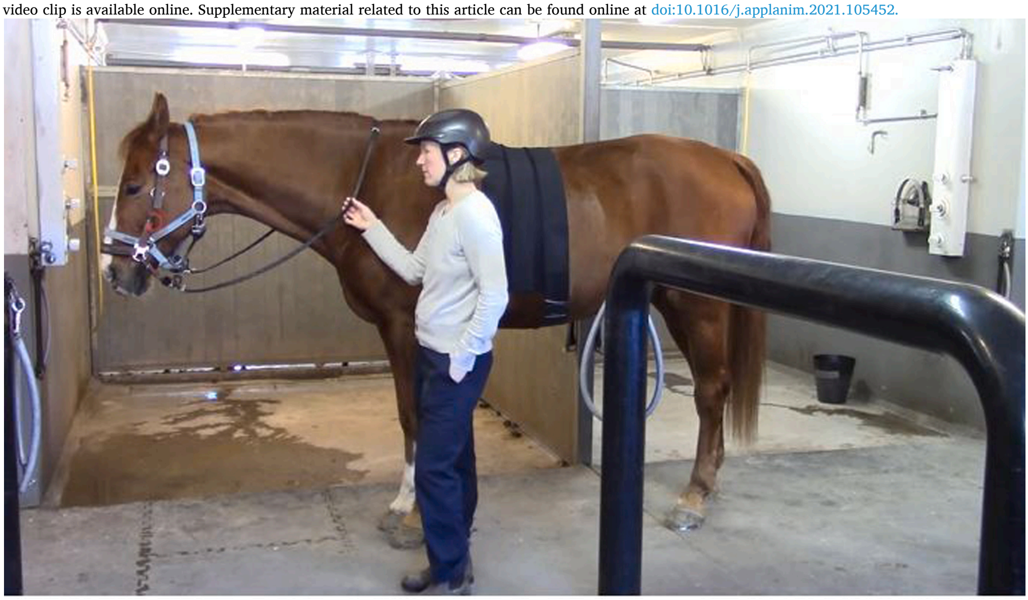
Video S1. The first trial in the first treatment (in this case bridle). Rein tension applied for one step back. The behavior head forward is present. All videos are of the same mature horse.
A video clip is available online. Supplementary material related to this article can be found online at doi:10.1016/j.applanim.2021.105452.

Video S2. The seventh trial of the first treatment (bridle). Rein tension applied for two steps back. Head forward and open mouth are present.
A video clip is available online. Supplementary material related to this article can be found online at doi:10.1016/j.applanim.2021.105452.

To describe the horses' learning process, descriptive statistics (median, IQR) were calculated for response latency, signaling rein tension, response rein tension, and number of behaviors other than backing that the horses showed during the application of the rein tension signal, by headstall, trial number, and order of treatment. The horses' behaviors were divided into two categories: head/neck/mouth behavior and inattentive behavior (Table 1). Additionally, the number of trials and horses with successful responses were summarized.

Linear mixed models were used for the statistical analysis of rein tension and response latency (RStudio, packages lmerTest, lme4). The three outcome variables, response latency, signaling rein tension, and response rein tension were not normally distributed and therefore transformed along the ladder of powers; i.e. response latency and signaling rein tension (sum of left and right rein) were log-transformed, and response rein tension was sqrt-transformed (sum of left and right rein).

Video S3. The first trial of the second treatment (in this case halter). Rein tension applied for one step back. The behavior head upward is present.
A video clip is available online. Supplementary material related to this article can be found online at doi:10.1016/j.applanim.2021.105452.



Video S4. The seventh trial of the second treatment (halter). Rein tension applied for three steps back. No other behaviors present.
A video clip is available online. Supplementary material related to this article can be found online at doi:10.1016/j.applanim.2021.105452.

The explanatory variables were headstall (bridle/halter), age group (young/mature), order of treatment (first treatment/second treatment) and trial (1−8). All explanatory variables were analyzed as categorical variables. Horse was included as a random variable. Plotting of Pearsons residuals was used for normality check of the models. Interactions between the four explanatory variables, headstall, age group, order of treatment, and trial number, were tested. Non-significant interactions were sequentially removed based on the type III *p*-value of < 0.05. Non-significant explanatory variable main effects were forced into the models.

Logistic regression models were used for statistical analysis of behaviors with head/neck/mouth behavior and inattentive behavior (present/absent) as outcome and headstall, order of treatment and trial number as explanatory variables. Horse was included as a random variable. The model with inattentive behavior as outcome did not converge with all the explanatory variables included and trial number was therefore omitted. Model fit was evaluated using ROC and AUC (RStudio, package pROC).

4. Results

All horses completed the experiment and met the criterion for a backing response to the rein tension signal in each trial. Twenty horses backing up eight times with the bridle and eight times with the halter resulted in a total of 320 observations, 20 observations for each trial number (1–8) and order of treatment (first, second). For the outcome variable signaling rein tension, there were no data to be recorded for 56 rein tension signals since in those trials the horse started backing before the rein tension signal was applied (18% of the observations, distributed among 17 horses). To avoid missing values for these observations, signaling rein tension was substituted by response rein tension for the same trial, in both analytical and descriptive statistics. This was deemed adequate since the response rein tension was recorded during the initiation of the backing response, and thus equivalent to signaling rein tension in these cases.

Descriptively, the median response latency was reduced from 6 s for bridle and 5 s for halter in the 1st trial in the first treatment (IQR 5–6 s bridle, 3–7 s halter) to 2.6 s for bridle and 2.3 s for halter in the 8th trial of the first treatment (IQR 0.25–5 s bridle, −0.05 to 3 s halter). In the 8th trial of the second treatment median response latency was 1.6 s for bridle and 1.6 s for halter (IQR 0.3–3.5 s bridle, 0.1–4 s halter) (Fig. 2).

The median maximum rein tension (sum of left and right rein) during application of the rein tension signal (signaling rein tension) was 35 N for bridle and 25 N for halter in the 1st trial of the first treatment (IQR 28–46 N for bridle, 19–36 N for halter). In the 8th trial of the first treatment, it was 17 N for bridle and 15 N for halter (IQR 4–25 N bridle, 12–19 N halter) and then further decreased to 10 N for bridle and 10 N for halter in the 8th trial of the second treatment (IQR 3–16 N bridle, 3–27 N halter) (Fig. 3). See supplementary materials for more details on signaling rein tension magnitude.

In the 1st trial of the first treatment median response rein tension (sum of left and right rein) was 24 N for bridle and 23 N for halter (IQR 21–27 N bridle, 13–25 N halter). In the 8th trial of the first treatment response rein tension was 12 N for bridle and 13 N for halter (IQR 4–20 N bridle, 12–17 N halter) and in the 8th trial of the second treatment response rein tension had decreased to 10 N for bridle and 7 N for halter (IQR 3–12 N bridle, 3–22 N halter).

Of all the backing responses (total 320), 36% (115) were successful (Table 2). In 95% of the responses labeled as successful, rein tension was below 20 N (sum of left and right rein). A higher percentage of the trials generated a successful response in the second treatment, 43%, (46% bridle, 40% halter) compared to the first treatment, 29% (both treatments). Overall, each horse responded within one second from the onset of the rein tension signal in at least two trials (mean 5 ± 3). When the criterion was raised to two or three steps, other behaviors than backing, were present in 41% of these trials (52/126 trials), i.e. the horses showed head/neck/mouth behavior in a total of 38 trials and inattentive behavior in 25 trials when taking two or three steps back (Table 2).

The results from the linear models are shown in Table 3, with further details in the supplementary materials. From the 5th trial onward, the horses responded significantly faster to the rein tension signal than during the first trial. Also, the horses responded significantly faster in the second treatment compared to the first treatment, regardless of headstall (Table 3).

At the 7th and 8th trials signaling rein tension was significantly lower than during the first trial, regardless of headstall (Table 3, Signaling RT). Likewise, signaling rein tension was significantly lower in the second treatment compared to the first treatment.

Response rein tension was significantly lower during the second treatment (Table 3, Response RT) than the first treatment. Compared to the first trial, response rein tension tended to be lower from the 5th trial onward and from the 7th trial, response rein tension was significantly lower.

The logistic regression model of head/neck/mouth behavior demonstrated that these behaviors were significantly less common in the 7th and 8th trials compared to the first trial and during the second treatment compared to the first treatment. Head/neck/mouth behavior was also less common during the halter treatment compared to the bridle treatment (Table 4). Inattentive behavior was less common in the second treatment.

5. Discussion

Our results support our hypotheses, i.e. rein tension magnitude could be substantially reduced during a single training session, regardless of headstall used. By the 7th trial of the first treatment, both response

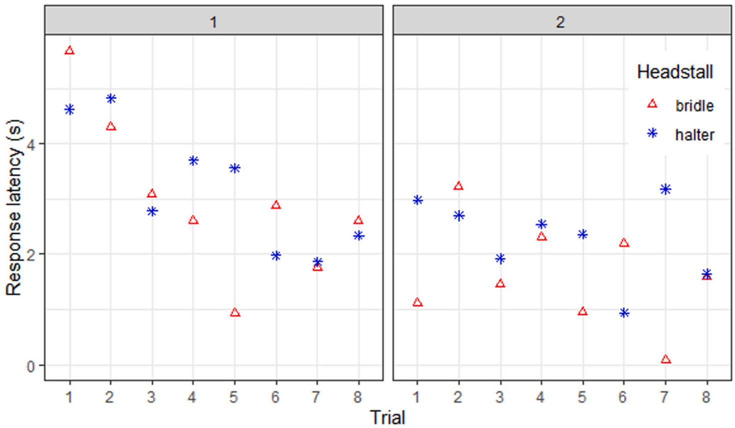


Fig. 2. Response latency across trials. Group median response latency (s) for the eight trials of the rein tension signal in the first (left) and second (right) treatment, color and shape by bridle and halter. Data are from 20 horses responding to a rein tension signal for backing up (eight times with a bridle and eight times with a halter, generating 320 rein tension signals in total).

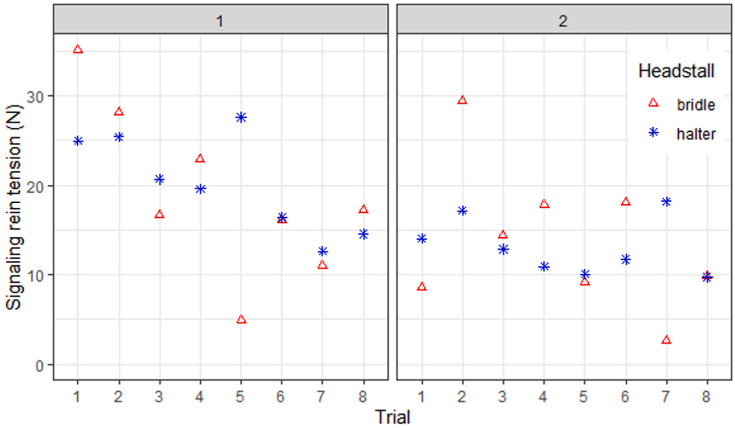


Fig. 3. Signaling rein tension across trials. Group median signaling rein tension (rein tension during the time interval from onset of the rein tension signal to onset of backing) for the eight trials of the rein tension signal in the first (left) and the second (right) treatment, color and shape by bridle and halter. Data for 20 horses responding to a rein tension signal for backing up (eight times with a bridle and eight times with a halter, generating 320 rein tension signals in total).

Table 2
Number of trials/rein tension signals (RTS) and number of horses where the handler asked for one, two or three steps back. The number of RTS followed by a successful backing response and the number of horses that responded successfully in at least one trial. The number of RTS where head/neck/mouth behavior and/or inattentive behavior was shown and the number of horses that showed those behaviors in at least one trial. The experiment included 20 horses, responding to eight RTS with a bitted bridle and eight RTS with a halter resulting with a total of 320 RTS. Group 1 (four young, six mature horses) started with the bridle and group 2 (six young, four mature horses) started with the halter.

		One step		Two steps		Three steps		Successful	
		RTS	horses	RTS	horses	RTS	horses	RTS	Horses
Group 1	Bridle	55	10	21	8	4	4	23	8
	Halter	38	10	32	9	10	5	32	10
Group 2	Halter	51	10	21	8	8	4	23	9
	Bridle	50	10	16	6	14	5	37	10
Total no of RTS		194		90		36		115	
Behavior	Head/neck/mouth	96	19	30	12	8	4	n.a.	n.a.
	Inattentive	64	16	20	10	5	3	n.a.	n.a.

latency and magnitude of the rein tension signal were reduced by half compared to at the first trial, with further reduction during the second treatment. This was consistent regardless of whether the bridle or the halter was the first treatment. In other words, the horses generalized the learning between the first and second treatment and the order of the treatments, i.e. the total number of trials, turned out to be far more important than the headstall used. Further, head/neck/mouth behaviors were significantly less common at the end of treatment than at the beginning of each treatment, and both head/neck/mouth behavior and inattentive behavior were significantly less common during the second treatment. The reduction of head/neck/mouth and inattentive behaviors was likely a key factor in reducing rein tension, as it was shown in Eisersiö et al. (2021) that horse behavior has a large influence on the magnitude of rein tension.

Rein tension was higher before the onset of backing compared to when the horse commenced the backing response. This relates to the lag between the application of pressure by the handler, the horse perceiving the pressure and deciding to step back, and the handler noting that the horse is responding and releasing the pressure. In fact, the pressure motivating the horse to step back occurs some time before the horse starts to shift their weight back. It is interesting to elaborate on if this lag can be reduced and to what extent this influences the horse's learning. Perhaps the horse can achieve a reduction in rein tension by shifting the weight back, despite that the handler had not yet initiated the release of rein tension.

The experimental design used was selected to study the learning process of rein tension signals while keeping other influential variables like gait, stride and rider influence at a minimum. Our decision to use eight trials of the rein tension signal in each treatment was based on data from two pilot studies, using four different horses who all reached the learning criterion of backing up promptly to a light rein tension signal within eight trials (unpublished data). Fenner et al. (2017) used a similar design in their study and also used eight trials of backing up using rein tension signals. Other experiments on equine learning have used between 5 and 20 trials per session (McCall et al., 1993; Ahrendt et al., 2015; Valenchon et al., 2017). It is, to our knowledge, not known how many trials a horse needs to form a conditioned response, but based on the statistical results, perhaps seven or eight trials on average is an appropriate number for teaching horses a new criterion or signal. The number of trials of an exercise will of course have to be adjusted depending on the level of physical and mental exertion the horse is subjected to. Moreover, as horses have various backgrounds, different temperamental traits and emotionality, as well as a diverse level of motivation to respond to negative reinforcement, learning performance will differ considerably between individuals (Lansade and Simon, 2010; Valenchon et al., 2017).

The structures of the horse's head and mouth are sensitive (Mellor, 2020) and warrant the usage of light rein tension signals during training

Table 3
Results for mixed linear models of response latency, signaling rein tension (Signaling RT) and response rein tension (Response RT). The Estimate and SE are on the log scale for response latency and signaling RT and on the square root scale for response RT. A negative estimate indicates that this level of the explanatory variable predicted a decrease in the outcome variable value. The models each include data from 20 horses, responding to eight rein tension signals fitted with a bitted bridle and eight rein tension signals fitted with a halter (320 observations total). Bold p-values are considered significant ($p < 0.05$). Baseline categories and estimates from trial 2–4 have been omitted. Model output and R code can be found in the supplementary materials.

Dependent variable	Explanatory variable	Estimate	SE	p-value
Response latency	(Intercept)	1.74	0.14	< 0.001
	Halter	0.10	0.07	0.145
	Young horses	-0.09	0.15	0.546
	Second treatment	-0.25	0.07	**< 0.001**
	Trial 5	-0.32	0.13	**0.017**
	Trial 6	-0.29	0.13	**0.028**
	Trial 7	-0.41	0.13	**0.002**
	Trial 8	-0.37	0.13	**0.005**
Signaling RT	(Intercept)	2.99	0.29	< 0.001
	Halter	0.14	0.13	0.298
	Young horses	-0.09	0.30	0.765
	Second treatment	-0.40	0.13	**0.003**
	Trial 5	-0.41	0.27	0.128
	Trial 6	-0.30	0.27	0.265
	Trial 7	-0.66	0.27	**0.014**
	Trial 8	-0.64	0.27	**0.018**
Response RT	(Intercept)	4.31	0.42	< 0.001
	Halter	0.20	0.18	0.277
	Young horses	-0.04	0.45	0.936
	Second treatment	-0.57	0.18	**0.002**
	Trial 5	-0.65	0.36	0.075
	Trial 6	-0.71	0.36	0.052
	Trial 7	-0.87	0.36	**0.018**
	Trial 8	-0.86	0.36	**0.019**

Table 4
Odds ratios (OR) and 95% confidence intervals from the logistic regression models with head/neck/mouth behavior or inattentive behavior as outcomes. Bold p-values indicate that the explanatory variable had a significant influence ($p < 0.05$) on the outcome. The results presented are presence/absence of behavior from onset rein tension signal to onset backing (20 horses, 2 treatments, 8 trials in each treatment). Baseline categories and estimates from trial 2–4 (non-significant) have been omitted. Model output and R code can be found in the supplementary materials.

Model	Variable	OR	2.5%	97.5%	p-value
Head/neck/mouth behavior	Halter	0.52	0.30	0.87	**0.013**
	Second treatment	0.55	0.32	0.93	**0.025**
	Trial 5	0.36	0.13	0.97	**0.045**
	Trial 6	0.41	0.15	1.11	0.080
	Trial 7	0.19	0.06	0.55	**0.003**
	Trial 8	0.31	0.11	0.85	**0.024**
Inattentive behavior	Halter	1.23	0.71	2.14	0.458
	Second treatment	0.50	0.29	0.87	**0.014**

sessions. While it may be necessary to escalate rein tension in the first few trials when teaching the horse a new exercise, horse trainers should aim to quickly reduce rein tension magnitude by proper use of negative reinforcement (pressure is released with the correct timing) and classical conditioning (a light signal predictably precedes escalating pressure). This study demonstrates that rein tension can be reduced substantially over the course of eight trials in a single training session. Given that horses find pressure from the bit aversive (Christensen et al., 2011) and since horses seem to prefer lower rein tension than what riders generally apply (Piccolo and Kienapfel, 2019), this finding is important from an equine welfare perspective as it demonstrates how quickly the horse can be taught to respond to progressively lower magnitudes of pressure. The fact that the horses in our study generalized the exercise between bridle and halter emphasizes that it is the proper application of the learning principles that is crucial for successful training and not the equipment used.

Training a horse successfully, using negatively reinforced pressure signals, rely on clear communication through timely and frequent release of pressure. As the release of pressure provides information to the horse about what behavior pays off, timely and consistent releases are most informative to the horse. In this experiment, the release of rein tension was given within one second from the first front hoof lifting to step back (see Eisersiö et al., 2021). However, an often forgotten variable in animal training is the criteria the trainer has set up. Low criteria, i.e. simple tasks and low requirements for precision, are more likely to be met by the horse (McCall, 1990), while increasing the demands too quickly, without a sufficient number of successful attempts at the initial level, will inevitably make it more difficult for the horse to figure out what behavior that pays off/leads to release of pressure. Releases will then be less frequent as it takes longer time for the horse to figure out the correct response. One could argue that with a too high criterion, information about the correct response is withheld from the horse, prolonging the duration from the onset of the signal to its release. This is unfortunate since lengthy application of the rein tension signal may disassociate the aimed conditioned stimuli, the initial light pressure, and the reinforcing release and thus associative learning of the light rein tension signal will fail (McGreevy and McLean, 2007).

In our study, the criterion for release of rein tension was one step back. In hindsight, the learning process would probably have benefitted from applying a lower criterion to begin with. Even in the second treatment only 43% of rein tension signals resulted in a successful response, i.e. in 57% of the trials it took longer than 2 s before the horse responded to the rein tension signal or the horse showed evasive behavior before stepping back (Table 2). Some of the horses seemed to struggle to understand how to get relief from the pressure applied. Particularly in the bridle treatment, several horses performed numerous head/neck/mouth behaviors before taking the first step back. Perhaps the learning process would have been more effective if the criterion was gradually increased from shifting the weight back to a step back, as suggested by McCall (1990). Further, it is possible that the criterion was raised too soon for some horses. To be able to sustain a continuous learning process throughout the eight trials in each of the two treatments in all horses, the handler was given the possibility to ask the horse for an additional step back, above the one step back that was asked initially. Even though the handler only applied the rein tension signal for additional steps if the horse responded with a short latency to a light signal and showed no other behaviors during signaling rein tension, the additional steps included other behaviors than backing in 41% of the trials. This finding indicates that the horses were still searching for what behavior would lead to the release, even though they were already backing or had started to step back. By staying longer on the criterion of one step back, the backing response would likely have been more firmly established and less other behaviors would probably have been shown when the criterion was raised. The head/neck/mouth behaviors did, however, decrease over trials for the horses as a group, implying that the experimental setup was effective in training the horses to respond correctly to the rein tension signal. In future research on equine learning it would be interesting to study criteria levels in relation to learning efficacy.

5.1. Practical applications

The results from this study show that the correct use of the learning principles; negative reinforcement and classical conditioning, can lead to a reduction in magnitude of a rein tension signal in a single training session. These results can likely be applied to other (ridden) exercises as well and are thus applicable for the average rider. Horse may, however, try several other behaviors before making the correct response and it seems that the bitted bridle provokes more trial and error behavior than a plain halter. During initial training of a new response it may thus be an advantage to use a soft, non-aversive headstall to avoid complicating the learning process. Reducing rein tension magnitude, in combination with a timely release, is crucial to avoid stress and discomfort due to uncomfortable sensations from the bit or bridle. A broad application of the results from this study, when training responses to rein tension signals, would largely benefit equine welfare.

5.2. Conclusion

Investigating the magnitude of a rein tension signal (with a timely release) training the horse to step back, it was found that both response latency and magnitude of rein tension could be significantly reduced during a single training session consisting of eight trials. The reduction in rein tension magnitude likely reflects the increased frequency of the horses promptly stepping back, instead of trying other behaviors, in response to the rein tension signal. There was no significant difference between the bitted bridle and the halter in terms of learning performance. However, the bitted bridle was associated with significantly more head/neck/mouth behaviors regardless if the bridle was the first or the second treatment. Both response latency and maximum rein tension were reduced by half over the first eight trials and then further reduced during the second treatment. The findings demonstrate how quickly horses can be taught to respond to progressively lighter rein tension signals through the correct application of negative reinforcement. These results are important from a horse welfare point of view as pressures applied on the horse's mouth and/or nose can cause discomfort or even pain.

Contributions to study

The idea for the study was initiated by M.E. All authors contributed in refining and improving the experimental design. M.E., J.Y. P.B. and A. E. conducted the data collection. The rein tension analysis was performed by A.E. and the behavioral recordings were done by M.E. The statistical analysis was performed by M.E., A.E. and A.B. The manuscript was drafted by M.E. and all authors contributed to improving the content.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest, no competing interests, and no financial interests..

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2021.105452.

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Gaping for relief? Rein tension at onset and end of oral behaviors and head movements in unridden horses

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ABSTRACT

Pressure from the bit in the horse's mouth, rein tension, likely feels unpleasant to the horse due to sensitive oral tissues. Through trial and error, the horse may learn how to adjust their behavior in order to avoid, diminish or cease uncomfortable sensations from the bit. We hypothesized that oral behaviors and head movements in response to rein tension have the function to avoid or escape the rein tension. The study objective was to assess in what way oral behaviors and head movements affect rein tension and determine the magnitude of rein tension at the onset and end of these behaviors. Twenty Warmblood horses were fitted with a bitted bridle and subjected to 8 trials of backing up in response to a rein tension signal with the handler standing next to the horse's withers. The rein tension signal was gradually increased and then immediately released when the horse stepped back. A rein tension meter and video recordings were used for data collection. Linear mixed models were used for the statistical analysis. There was a decrease in mean rein tension (sum of left and right rein) from onset to end for open mouth ($P < 0.001$, from 19 to 11 Newtons (N), biting on the bit ($P = 0.004$, from 11 to 5 N), and head upward ($P = 0.024$, from 16 to 12 N), while there was an increase in rein tension associated with head forward ($P = 0.015$, from 27 to 37 N) and head downward ($P < 0.001$, from 17 to 46 N). Our results suggest that horses will open their mouth, or bite on the bit, to alleviate the oral tissues from pressure; move the head upward to avoid rein tension and move the head forward or downward to increase rein tension, likely in a presumed attempt to break free from the pressure applied. The horse's oral behaviors and head movements during training can be used to gain a greater understanding of how the horse perceives the magnitude of rein tension.

Introduction

Research suggests that horses may show evasion or escape behavior in response to rein tension, or pressure in the mouth from the bit (Quick and Warren-Smith, 2009; Christensen et al., 2011; Górecka-Bruzda et al., 2015). The function of evasive and escape behavior are to avoid or escape a situation that is perceived as threatening, that is, one that is making the horse feel mentally and/or physically uncomfortable (Hall and Heleski, 2017). Escape behavior has the function to get away from, or diminish, the influence of aversive stimuli. If escape behavior is negatively reinforced, by definition, the behavior leads to a reduction of the aversive stimulus, and it will become a learned avoidance behavior performed to avoid the aversive stimulus (McGreevy and McLean, 2010). For example, a horse pulling on the reins is likely a learned avoidance behavior attempted by the horse to gain more freedom of movement through longer/looser reins (Górecka-Bruzda et al., 2015).

Rein tension can cause discomfort and stress for the horse since applying tension on the reins means that the bit is pressing on sensitive oral tissues (McLean and McGreevy, 2010b; Hall and Heleski, 2017; Mellor, 2020). One way to determine if the magnitude of rein tension applied is compromising the horse's welfare is to study rein tension in relation to behavioral parameters

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(König von Borstel et al., 2017). Christensen et al (2011) found a correlation between a mean rein tension of 10 Newtons (N) and frequencies of conflict behavior (e.g., open mouth in combination with lifting/tilting the head) when the horses were pulling against short side reins to reach a food bucket (maximum rein tension 40 N). Likewise, Piccolo and Kienapfel (2019) reported that the horses displayed less conflict behavior without a rider when the horses' (voluntary) mean maximum rein tension was approximately 7.5 N on each side rein compared to with a rider (mean maximum 24 N in each rein). These studies give an idea about how much rein tension horses are willing to accept, but to date we do not know what magnitude of rein tension the horse is comfortable with and what magnitude will trigger oral or head/neck behaviors. Likewise, it is, to our knowledge, not determined which behaviors function to reduce pressure from the bit. It is likely that certain behaviors will decrease rein tension, while some actions taken by the horse appear to potentially increase rein tension.

Nosebands are extensively used within the equestrian sport and, if fitted tightly, may sensitize the horse's mouth, making the horse more responsive to rein tension signals (Randle and McGreevy, 2013), and also prevent the horse from performing oral behaviors like opening the mouth (McGreevy, 2011). A tight noseband thus makes it difficult for the horse to move the jaw (McLean and McGreevy, 2010a) thereby diminishes the possibility of the horse to manipulate the bit. Giving the horse the opportunity to perform oral behavior may, to some extent, allow the horse to control where in the mouth bit pressure is applied. Hence, oral behavior can potentially prevent and alleviate the development of sore oral tissue. This is particularly important when considering that several studies have revealed that oral injuries connected to the use of bits, bridles, and nosebands are common in riding horses (Björnsdóttir et al, 2014; Uldahl and Clayton, 2019; Tuomola et al, 2021).

Our hypothesis was that oral behavior and head movements in response to a rein tension signal will be associated with either an increase or a decrease in rein tension and that behaviors decreasing rein tension will be more frequently displayed than behaviors increasing rein tension. The aims of the study were therefore to investigate how oral behavior and head movements affect rein tension and to determine the magnitude of rein tension at the onset and end of these behaviors.

Materials and method

Twenty Warmblood horses (7.5 years ± 3.4), used as school horses at an Equestrian Centre in Sweden, were included in the study. The horses were mainly used for dressage and jumping and were regularly checked for soundness and health by the staff veterinarian. Two weeks prior to data collection, all horses had an oral examination. Following intravenous sedation with 10-15 microgram /kg detomidine hydrochloride (Domosedan, Orion Pharma), a Haussmann gag was fitted and the oral cavity was thoroughly inspected by a veterinarian with expertise in equine dentistry. All horses passed the oral examination and were included in the study.

An aisle (7 × 2 m) in a grooming area of the Equestrian Centre was used for the study. All horses were tested once with a bitted bridle and once with a halter in a randomized order. For this study, only data from the bridle treatment were used. All horses wore their own bridle with a correctly fitted snaffle bit in terms of length, thickness, and tightness of side pieces. Four horses had straight bits, 5 horses had single jointed snaffles, and 11 horses had double-jointed snaffles. The diameter of the bits was between 13-20 mm closest to the bit rings. The noseband of the bridle was removed completely.

The rein tension meter

Rein tension data were collected using a custom-made rein tension meter consisting of 1 load cell for each rein (Futek, CA, USA) that was wired to amplifiers and an inertial measurement unit (IMU, x-io technologies, Bristol, UK). The measuring range of the load cell was 0-500 N and the weight was 20 g. The IMU weighed 46 g, had a resolution of 10 bit and a 3.1 V battery. Rein tension data were sampled at 100 Hz. The load cells of the rein tension meter were fastened on the reins (flat leather reins with leather stoppers, 15 mm wide) by pinching the rein between metal plates using screws and bolts. Before bridling the horse, the reins with the rein tension meter were attached to the bit, and the amplifier box and IMU were taped onto the crown piece of the bridle. To confirm that the voltage output from the rein tension meter was stable, the rein tension meter was calibrated before and after the experiment, using ten known weights ranging from 0.2-10 kg.

Experimental setup

The study was initially designed for studying the characteristics of rein tension signals (Eisersiö et al, 2021a) and the learning process of a rein tension signal for backing up the horse (Eisersiö et al, 2021b). Therefore, the study design involved the application of a rein tension signal to elicit a backing response, using the principles of negative reinforcement (i.e., instant removal of bit pressure for stepping back reinforces this behavior and increases the likelihood of the horse stepping back again).

During data collection, the handler (first author, right-handed) stood on the left side of the horse, near the horse's withers (Figure 1). The trial began with a 2 minutes rest period with the handler and horse standing still on the aisle. The handler then picked up the reins, lifting the arms and placing the hands above the horse's withers while shortening the reins. The handler then gradually increased rein tension, closing the hands, exerting pressure on the reins, until the horse stepped back with at least 1 front leg. If the horse performed other behaviors than stepping back, rein tension was sustained (and gradually increased) until the horse stepped back. The handler stayed next to the horse's withers by stepping back along with the horse. As soon as the horse

Figure 1. Handler position. Horse standing with loose reins in the picture to the left, and rein tension signal applied in the picture to the right.

Table 1
The ethogram used for behavioral annotation describing the onset and end for each behavior.

Category	Behavior	Onset of behavior	End of behavior
Head movement	Upward	Head begins to elevate	Head stops moving upward
	Downward	Head begins to lower	Head stops moving downward
	Forward	Nose begins to move forward	Nose stops moving forward
	Backward	Nose begins to move towards the chest	Nose stops moving towards the chest
	Toss	A quick upward movement begins	Head is returned to start position
Oral behavior	Biting on bit	Horse begins to bite on the bit	Horse stops biting on the bit
	Open mouth	Visible gap between upper and lower jaw begins	Upper and lower jaw closes

stepped back, rein tension was immediately released by the handler opening and lowering the hands. The rein tension signal to step back was repeated 8 times with 1 minute-intervals. In between the backing events, the horse, and handler stood still on the aisle. After the 8 backing up trials, the horse and handler stood still on the aisle for 2 minutes.

A video camera recorded the horse's behavior and horse-handler interactions from the left side of the horse during treatment (Canon Legria HF R806, Canon Inc, Tokyo, Japan, 25 Hz). The rein tension meter was synchronized with the video recordings at the beginning and end of the treatment by pulling on the left rein tension meter 5 times (not affecting the horse's mouth) in front of the camera to create tension peaks that could be identified both in the video and in the rein tension data set.

Data extraction

Using the video recordings, the time intervals representing the rein tension signals and the horse's behavior were annotated at video frame level. The onset of the rein tension signal was annotated when the handler had shortened the reins and held the hands in place above the horse's withers. The moment when the handler started to lower the hands was annotated as the release of the rein tension signal.

The oral behaviors recorded were open mouth and biting on the bit, while head movements recorded were head upward, head downward, head forward, head backward, and head toss (Table 1). The onset and end of each behavior was annotated during each rein tension signal. The video sequence for each rein tension signal was first viewed at normal speed to register behaviors. The video was then viewed again and the frames at onset and end of each behavior were identified (Table 1). The onset of a behavior was the point in time when the horse started making the first movement that initiated the subsequent behavior, while the end of a behavior was when the behavior stopped. For example, the onset of head backward was the point in time when the horse's nose started to move inward, towards the horse's chest, and the end of head backward was when the nose started to move forwards again, even if the horse's nasal plane was still behind the vertical. Head upward, head downward, and open mouth can be seen in Video 1.

Data analysis

The protocols from the video recordings and the rein tension data were imported into Matlab (MathWorks Inc, MA, USA) and analyzed using a custom-written code. Descriptive statistics (mean, median, range, interquartile range (IQR)) of rein tension data (in N) were calculated for each of the 8 rein tension signals and each behavior, including extraction of the magnitude of rein tension at the onset and end of each behavior as well as the time duration (in s) of each behavior. The data were then imported into R Studio (version 1.2.5019, R Studio, MA, USA) for statistical analysis (R packages tidyverse, lme4, lmerTest, emmeans). The sum of left and right rein tension was used for analysis.

In order to determine if there was a significant difference between the onset and end rein tension for each behavior, linear mixed models were applied for each of the behaviors (onset to end models). The outcome variable was rein tension and the explanatory variable was time point with onset and end on different levels, modelled as a fixed effect. Horse and the interaction between horse and trial were included as random variables. For the open mouth model, the biting on the bit model, and the head upward model, only the interaction between horse and trial was included as a random variable to avoid overfitting those models. The R code can be found in the supplementary material.

Linear mixed models were also used to compare the magnitude of rein tension at the onset of the rein tension signal with the onset of the registered behaviors, as well as comparing onset rein tension between the behaviors. Linear mixed models were likewise applied, to determine if there was a significant difference in end rein tension among behaviors. Thus, the outcome variables were the rein tension at the onset of behaviors and the rein tension signal in one model (onset model) and rein tension at the end of behaviors in another model (end model). The explanatory variables were behavior (oral and head movement), and the rein tension signal in the onset model, and only behavior in the end model. The explanatory variables were fixed effects with behavior and the rein tension signal on different levels within the same variable for the onset model and only behavior on different levels within the same variable in the end model. Horse and the interaction between horse and trial were modelled as random variables in both models.

Rein tension data were not normally distributed and plots of Pearson's residuals were used to determine whether log-transformation or square root transformation was most suitable for each model. The transformation for each model can be found in Tables 3 and 4. Least square means and contrast P-values were computed for all level combinations. Contrasts were Tukey adjusted for multiple comparisons and the P-value limit was set to <0.05.

Results

Behavior was analyzed for 20 horses, subjected to 8 rein tension signals each, yielding 160 rein tension signals and 199 behaviors in total. Oral behavior and/or head movement during the rein tension signal was displayed by 18 of the 20 horses. Open mouth and head upward were the most common behaviors; displayed 77 times (17 horses) and 38 times (15 horses), respectively. Head backward was the least common behavior; displayed 15 times (8 horses). Head forward was shown 24 times (11 horses), head downward 22 times (9 horses) and biting on the bit 23 times (9 horses). The behavior head toss only appeared twice and was excluded from further analysis. Open mouth was shown in 34 % of the rein tension signals (in 54 of 160 rein tension signals) and head upward in 23 % of the rein tension signals . Head backward was shown in 9 %, head forward in 13 % and head downward and biting on the bit in 14 %

Table 2
Descriptive statistics of the sum of left and right rein tension (N) at the onset and end of each behavior and the rein tension signal. Data include behavior from 18 horses responding to 8 trials of a rein tension signal for backing up.

Behavior	Minimum		1st Quartile		Median		Mean		3rd Quartile		Maximum	
	Onset	End	Onset	End	Onset	End	Onset	End	Onset	End	Onset	End
Open mouth	5	0	12	5	18	10	21	15	28	19	82	104
Biting on bit	3	0	6	2	8	4	12	6	15	7	36	29
Head upward	2	1	7	7	12	11	18	13	31	16	49	47
Head backward	5	0	8	8	12	14	22	15	20	19	89	34
Head forward	6	10	18	23	25	36	29	40	37	51	95	92
Head downward	6	14	13	30	16	46	20	56	23	85	52	155
Rein signal	0	0	3	1	4	2	5	3	6	4	33	19

of the rein tension signals. Open mouth or biting on the bit was sometimes displayed simultaneously with one of the head movements. Likewise, head forward and head downward did to some extent overlap, but generally only 1 head movement at the time was present.

Biting on the bit had the lowest median onset rein tension, followed by head upward and head backward (Table 2). Biting on the bit also had the lowest median end rein tension, while head forward and head downward had the highest median end rein tension (Table 2). Figure 2 shows the difference in rein tension between onset and end for each of the behaviors. The median duration was less than 1 second for all behaviors (IQR 0.5-1.5 s) except biting on the bit that had a median duration of 2.5 s (IQR 1.5-3.5 s).

The onset to end models, comparing rein tension at the onset and end of each behavior, showed that rein tension decreased significantly from the onset to the end during the behaviors open mouth, biting on the bit, and head upward (Table 3). On the contrary, rein tension increased significantly from the onset to the end during head downward and head forward. There was no significant difference in rein tension between the onset and end for head backward.

The onset model showed that there was a significant difference between rein tension at the onset of the rein tension signal and the onset of each behavior (Table 4). The rein tension at the onset of the behavior biting on the bit was significantly lower than at the onset of head forward and open mouth. The rein tension at the onset of head upward was also significantly lower than the rein tension at the onset of head forward. The end model showed

Table 3
Least square means and confidence intervals for rein tension (N) at the onset and end of each behavior, calculated from each of the onset to end models. Rein tension was square root transformed in the open mouth, biting on the bit, head upward, and head forward models and log transformed in the head backward, and head downward models. Data include behavior from 18 horses responding to 8 trials of a rein tension signal for backing up. R code and output (including random effects) can be found in the supplementary materials.

Behavior	Event	Estimate	SE	lower CI	upper CI	*P*-value
Open mouth	Onset	19	2	16	23	<0.001
	End	11	1	9	14	
Biting on bit	Onset	11	2	7	14	0.004
	End	5	1	3	7	
Head upward	Onset	16	2	12	20	0.024
	End	12	2	8	15	
Head backward	Onset	13	5	6	29	0.381
	End	10	4	4	22	
Head downward	Onset	17	3	12	24	<0.001
	End	46	7	33	64	
Head forward	Onset	27	5	17	38	0.015
	End	37	6	26	50	

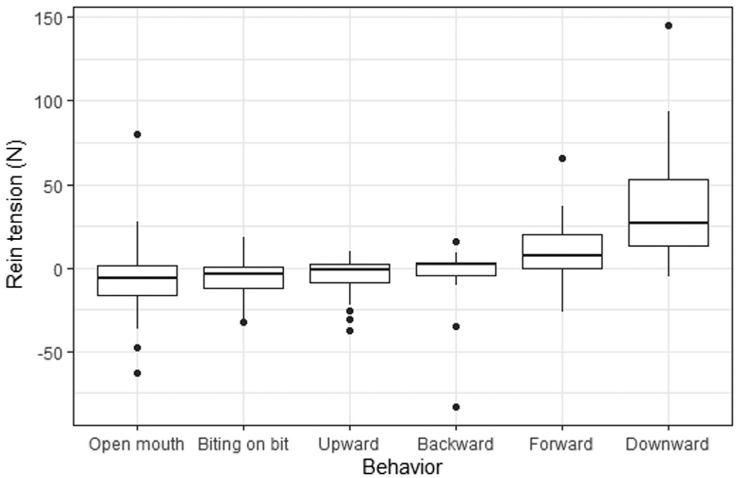

Figure 2. The mean rein tension (N) difference between end and onset of behavior. The onset rein tension has been subtracted from the end rein tension. A negative rein tension value indicates that end rein tension was lower than the onset rein tension, while a positive rein tension value signifies that end rein tension was higher than the onset rein tension. Number of horses displaying the behavior and number of observations were: Open mouth 77 times/17 horses, biting on the bit 23 times/9 horses, head upward 38 times/15 horses, head backward 15 times/8 horses, head forward 24 times/11 horses and head downward 22 times/9 horses.

Table 4
Significant contrasts from the onset model and the end model. Estimates are back-transformed and show the estimated difference in rein tension (N) between the variables. Rein tension was log transformed in the onset model and square root transformed in the end model. The first alternative listed has a higher rein tension. *P*-values have been Tukey-adjusted for multiple comparisons. Data include behavior from 18 horses responding to 8 trials of a rein tension signal for backing up. R code and output (including random effects) can be found in supplementary materials.

Model	Contrast		Estimate	SE	lower CI	upper CI	*P*-value
Onset	Head upward	Rein signal	8	1	4	13	<0.001
	Head backward	Rein signal	9	2	2	16	0.008
	Head downward	Rein signal	11	2	4	19	<0.001
	Head forward	Rein signal	20	3	9	30	<0.001
	Biting on bit	Rein signal	5	1	1	9	0.017
	Open mouth	Rein signal	12	1	7	16	<0.001
	Head forward	Head upward	11	4	1	22	0.033
	Head forward	Biting on bit	15	4	4	26	0.001
	Open mouth	Biting on bit	7	2	2	12	0.003
End	Head downward	Head upward	36	6	20	53	<0.001
	Head downward	Head backward	37	6	21	54	<0.001
	Head downward	Biting on the bit	43	5	27	59	<0.001
	Head downward	Open mouth	38	5	22	54	<0.001
	Head forward	Head upward	24	5	10	37	<0.001
	Head forward	Head backward	25	5	10	39	<0.001
	Head forward	Biting on the bit	30	5	17	44	<0.001
	Head forward	Open mouth	25	4	12	38	<0.001

that the rein tension at the end of head downward and head forward was significantly higher than at the end of all other behaviors (Table 4).

Discussion

The behaviors open mouth, biting on the bit, and head upward were associated with a significant decrease in rein tension from onset to end, while head downward and head forward were associated with a significant increase in rein tension from onset to end. Open mouth and head upward were the most common behaviors, displayed by most horses, and thus, behaviors decreasing rein tension were more common than behaviors increasing rein tension. Rein tension at the onset of the rein tension signal was significantly lower than at the onset of each of the recorded behaviors, that is, rein tension had to increase significantly, to about 10 N (approximately 5 N in each rein), before an oral behavior (biting on the bit onset median rein tension 8 N) or head movement (head upward/backward onset median rein tension 12 N) was displayed. This suggests that the behaviors were indeed provoked by the rein tension signal. Certain behaviors were elicited at a lower magnitude of rein tension than other behaviors; biting on the bit and head upward were initiated at significantly lower rein tension than head forward. Since the behaviors head forward and head downward increased rein tension, the rein tension as these behaviors ended was significantly higher compared to when the other behaviors ended.

Pressure from the bit can cause discomfort and pain (Mellor, 2020) and, therefore, it may seem puzzling why horses sometimes perform behaviors that increase rein tension. The behaviors head downward and head forward both increased rein tension, yet most likely with the presumed expectation that these behaviors would lead to a longer/looser rein. When a horse moves the head forward and/or downward in a quick motion, it can result in the rider losing the grip on the reins (Górecka-Bruzda et al., 2015). Thus, moving the head forward and/or downward have likely been manifested through previous successful trial-and-error learning in getting relief from rein tension by pushing against the bit. In other words, it is plausible that the function of these behaviors is to try to alleviate the pressure from the bit. It should also be noted that the behavior head forward commenced at a higher rein tension than the other behaviors. This could indicate that rein tension had to reach a certain magnitude before the horses were motivated to briefly increase mouth pressure in order to potentially completely release it.

Head upward and head backward showed intermediate levels of rein tension both at onset and end (Tables 2 and 3). Since the rein tension signal was gradually increased, these behaviors may reflect the horses' attempts to avoid being subjected to excessive bit pressure by altering their head carriage before stepping back. Our results suggest that if the horse is moving the head upward or backward, away from the pulling force on the mouth, the function of those behaviors is likely to avoid or decrease rein tension. Similarly, it seems that open mouth and biting on the bit either had the function to reduce the pressure from the bit or that these behaviors appeared when rein tension reached a certain magnitude and then terminated as rein tension magnitude was lowered again. Nevertheless, our results suggest that the function of these behaviors was to alleviate the oral structures from bit pressure.

The rein tension at the onset of the behavior open mouth had an IQR of 12-28 N (sum of left and right rein, Table 2), or an IQR of approximately 6-14 N in each rein. This magnitude of rein tension is fairly low when compared with results from rein tension studies of ridden horses (median 22-40 N, sum of left and right rein) at the trot (Kuhnke et al., 2010; Eisersiö et al., 2015). This result is comparable to the magnitude of voluntary rein tension measured during trotting in unridden horses (Piccolo and Kienapfel, 2019), stationary unridden horses (Christensen et al, 2011) and unridden horses backing up from a single rein (Fenner et al., 2017). When a rider has contact on the reins, rein tension is constantly varying due to the horse's gait and stride cycle (Egenvall et al., 2015; Piccolo and Kienapfel, 2019), and perhaps a mean rein tension of 10 N in each rein is a fairly accurate limit of how much mouth pressure the horse can be comfortable with. Yet, individual differences among horses have to be considered as, for example, temperamental traits like tactile sensitivity and reactivity/fearfulness differ among horses and have been found to have a significant effect on learning performance, specifically responsiveness to negative reinforcement (Lansade and Simon, 2010). It is also likely that rein tension signals may need to escalate beyond 10 N to elicit a desired response from the horse in, for example, a fear-eliciting situation like the encounter of a fear-inducing stimulus or in a new environment.

The horse opening the mouth in response to bit pressure has been suggested by earlier research to be an indicator of discomfort when performed in response to excessive rein tension

(Manfredi et al, 2010; Christensen et al., 2011). Given that rein tension decreased during open mouth, the function of this behavior is likely to gain comfort or, at least, reduce discomfort. However, many riders choose to fit the noseband of the bridle tightly to inhibit horses from opening their mouth (McGreevy et al., 2012), likely in an attempt to make the horse more responsive to the bit and hide unwanted mouth behavior during dressage competition (Fenner et al., 2016). In other words, a tight noseband may mask pain and discomfort and may also give an unfair competitive advantage to riders relying on sustained and restrictive pressures in place of appropriate and ethical training methods. The horses in our study did not wear nosebands and could freely open their mouth. Considering that the magnitude of rein tension measured at the onset of open mouth was lower than measured rein tension in ridden horses (e.g., Kuhnke et al., 2010; Eisersiö et al., 2015), it is likely that also ridden horses may feel a need to open their mouth to reduce discomfort on the oral structures while the noseband is restricting them.

A limitation of this study is that the horses' intra-oral behaviors could not be recorded. Manfredi et al (2010) conducted a fluoroscopic study of unridden horses' intra-oral behaviors when standing in stocks and being subjected to a steady contact of 25 ± 5 N rein tension in each rein. They recorded the behaviors lifting the bit, retracting the tongue, and bulging the tongue over the bit using fluoroscopic images. In future rein tension studies it would be interesting to investigate rein tension at the onset and end of different types of intra-oral behaviors in more detail using fluoroscopic technique.

When interpreting the results from this study it should be kept in mind that the rein tension applied was not constant. The handler increased rein tension to motivate the horse to step back and then immediately released rein tension as the horse stepped back. Thus, if an oral behavior and/or head movement coincided with the handler's actions, the magnitude of rein tension partly reflects the handler's application and release of rein tension. However, an advantage of our study design, that is, of gradually increasing the rein tension, was that it provided a large spectrum of rein tension magnitudes. Furthermore, it enabled recording of onset rein tension for several behaviors and allowed to determine which behaviors were more frequently initiated at lower and higher magnitudes, respectively.

It would be interesting to perform a similar study in ridden and unridden horses comparing rein tension at the onset and end of different behaviors for horses wearing a bitted bridle with and without a noseband or different bits, including bitless bridles. Studying rein tension at the onset and end of different behaviors reveals the potential function of the behavior and thus provides an indication of how the horse experiences the rein tension applied.

Conclusion

Open mouth or biting on the bit was associated with a decrease in rein tension from onset to end, suggesting that these behaviors were performed to alleviate the oral tissues from the bit pressure. The head moving upward decreased rein tension, indicating that the horses avoided the escalating rein tension by altering their head carriage. Conversely, the head moving forward or downward was associated with an increase in rein tension from onset to end, suggesting that the horses tried to push against the bit pressure to escape. The results from this study yield information about how different magnitudes of rein tension affect horse behavior and how the horse's behavior affects rein tension. Thus, the horse's behavior provides an indication of how the horse experiences rein tension and can potentially reflect the magnitude of rein tension the horse may be comfortable with. Monitoring horse behavior in response to rider and handler signals should be addressed throughout all training.

Authorship statement

The idea for the paper was conceived by Marie Eisersiö. The experiments were designed and performed by Marie Eisersiö, Agneta Egenvall and Jenny Yngvesson. All authors contributed to the data analysis. The paper was written by Marie Eisersiö. All authors contributed to improve the paper and approved the final version.

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Ethical considerations

The study was approved by the Animal Ethics Board in Uppsala, Sweden, Dnr 5.8.18-02567/2019.

Conflict of Interest

There are no conflicts of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jveb.2022.11.009.

Video 1. The application of the rein tension signal and the horse's behavioral response. Behaviors shown are head upward, head downward, and open mouth. The magnitude of rein tension can be seen below the video. The playback speed was reduced for improved perception of the events.

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This thesis evaluated the association between rein tension and the horse's behaviour. The results show that less than 10 N (1 kg) rein tension in each rein was enough to elicit a response from the horse to perform an exercise, while more than 10 N led to evasive head/neck/mouth behaviour. The release should be emphasized more in horse training and rein tension magnitude should not exceed the level that the individual horse is comfortable with, judging from the horse's behaviour.

Marie Eisersiö received her postgraduate education at the Department of Clinical Sciences, Swedish University of Agricultural Sciences (SLU). She obtained her Master degree in Animal Science and Biology at SLU.

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