Introduction

The modern horse is predominantly regarded as a companion or sporting animal in Western Europe with high profile equestrian events accounting for at least half of the top ten sporting events in the UK in 2016 and 2017 with paid for attendance (Deloitte, 2016, 2017). In 2015 the equestrian sector was responsible for £4.3 billion of consumer spending in Great Britain alone (BETA, 2017). To maintain this consumer interest and attract new audiences the future of equestrianism is reliant on the public's perception of the sport (Fletcher and Dashper, 2013). As such presenting the horse and human as a team, with both members athletes, is important to counteract long held perceptions of equestrianism epitomising social inequality and elitism with the horse being an expensive 'tool' to achieve success (Krishna and Haglund, 2008).

There have been recent high profile questions around the welfare of the horse and the safety of the human during sporting performance and associated training, such as the occurrence of rotational falls (injuring both the horse and the rider) in eventing and blood in the saliva of dressage horses (Jones, 2017; Bryan, 2017). Decision makers within equestrian sport are therefore required to cultivate techniques which minimise risks to human and equine athletes, and maximise efforts to ensure equine welfare is a top priority in sporting and training environments (FEI, 2017a). Central to achieving safe interaction and harmony between horse and human is understanding how the two species can communicate. As well as having socio-economic implications for the future of equestrian sport, this topic is central to the field of Equitation Science (FEI, 2017b; International Society for Equitation Science, 2017).

There is still a paucity of evidence-based practice and objective performance analysis measures underpinning practices commonly undertaken in equestrianism (Cornelisse, 2001; Williams, 2013) despite the potential improvements in competitive success these can facilitate. To address this researchers are increasingly trying to utilise perceived objective measures of the horse-human interaction to assess how the horse and rider can perform together, rather than focussing on the horse and rider separately (Clayton and Hobbs, 2017; Randle and Waran, 2017). As the only Olympic sport where two species compete in partnership (De Haan and Dumbell, 2016) the complexity of studying equestrian sport should not be underestimated. Technology can be used to measure horse-human interactions with the aim of producing objective parameters to define and assess if riding and training practices promote equine welfare / wellbeing (Williams, 2013; Randle *et al.*, 2017). Data obtained can also be used to advance equestrian performance analysis by understanding what expert equestrians do and producing models that less experienced equestrians can train towards reproducing, an approach that is fundamental to sport technique analysis (Lees, 2002). However for both of these outcomes to be judged as accurate, reliable, precise and valid measures, data need to have been collected using validated research equipment. It is also important that a standardised research framework and experimental protocols are applied across studies to enable worthwhile comparison to be made between projects and to develop an objective evidence base for advancing equitation practice (Cornelisse, 2001; Pierard *et al.*, 2015; Randle *et al.*, 2017).

An emerging area of investigation is the interface between the horse and the rider, with communication between the rider’s hands and the horse’s bit commonly evaluated by rein tension as a proxy measure of the resulting forces. Rein tension is defined as the force exerted along the reins via a mouthpiece or ‘bit’ in the horse’s mouth, as an aid to control direction, speed and head position of the horse and is typically measured in Newtons (N) (Clayton et al. 2003). The bit and the (rein) tension applied on it are fundamental in horse-rider communication and control during ridden and in-hand training (McGreevy and McLean, 2007; McGreevy, 2007; McLean and McGreevy, 2010; Hawson et al., 2014). Behavioral responses of horses originate from neurological motivation to avoid pain, discomfort and predation (McGreevy, 2007) and it is common practice for animal trainers to make use of such innate responses and to provide rewards for desired behaviors. Rewards can take the form of praise or negative reinforcement involving the removal of an aversive stimulus such as pressure etc. (Terada *et al.*, 2006; McGreevy and Boakes, 2006). Precisely timed pressure signals from the rider are transferred through the reins to the horse to control the direction and speed at which the horse travels, and the position of its head and neck carriage. It is the timing of these pressure signals and particularly the timing of the release of pressure that is an important determinant of their success (Heleski *et al.*, 2009; Manfredi *et al.*, 2010).

The application of ‘excessive’ rein tension during equestrianism is central to debates on rein tension and equine welfare amongst equine professionals (McLean and McGreevy, 2010; ISES, 2017). Inadequate timing of rein signals or unintentional pulls on the reins have been identified to cause poor welfare and a negative stress response in the horse (Waran and Randle, 2017) and can result in the exhibition of undesirable or conflict behaviors (McLean and McLean 2002; Heleski *et al.*, 2009; Manfredi *et al.*, 2010; McLean and McGreevy, 2010), which may then result in rider injuries (Newton and Neilson, 2005). In addition to this, standard equipment worn by horses such as bits and nosebands, are designed to reduce the extent that horses can physically exhibit undesirable behaviors, which may be associated with uncomfortable or excessive bit pressure (McGreevy *et al.*, 2005; Randle and McGreevy, 2013). Being able to measure the forces exerted by the rider and experienced by the horse, especially if evidence-based ranges of acceptable rein tension can be produced, would enable objectively based interventions to be made to improve horse welfare and rider training and ultimately reduce the risk of horses demonstrating potentially dangerous behaviors.

The development of technology capable of measuring the forces associated with differing rein tensions has led to an emergence of research in recent years measuring rein tension. This technology is rapidly being commercialised to make it accessible to all levels of equestrian however this raises concerns as to whether it is supported by reliable, evidence-based research (Randle *et al.*, 2017). This study uses a systematic literature review to evaluate the tools and methods currently used to measure rein tension within published literature to establish whether their findings were reliable. The systematic literature review also aimed to identify improvements to study protocols, where appropriate, to enable the standardised measurement of rein tension to be used to inform decision makers, commercial developments and good practice guidance in the future

Materials and Methods

A systematic literature review uses explicitly stated search methods determined by a panel of subject specialists and library professionals to systematically approach a literature review and reduce the inherent bias in any literature search (Centre for Reviews and Dissemination, 2001; Sargeant *et al.*, 2006; Dundar and Fleeman, 2014; Gough et al. 2017). The search strategy employed for this systematic literature review was determined by a panel including two independent academic professionals who have published in the area of performance analysis within equestrianism, a librarian for assistance in identifying relevant databases, and a Fellow of the British Horse Society to provide an industry perspective, in addition to the researchers to centre the research aims (Dundar and Fleeman, 2014). The panel defined the search method including keywords, literature sources and inclusion criteria and decided that ‘Google Scholar’ should be the search engine used due to the breadth of material that it contains. This review adapted inclusion criteria (Table 1) from the Cochrane Participants, Interventions, Comparisons, Outcomes and Study Types guidelines (Higgins and Green, 2011). The decision to include literature over a fifteen year period, resulted from discussions with the subject specialists during the search strategy development process to reduce the risk of the search being inadvertently influenced by author convenience issues, a common literature review bias (McCrae *et al.*, 2015). Much of the investigation of rein tension has resulted from the field of Equitation Science that has been the focus of the International Society of Equitation Science since it was founded in 2007 and first proposed in 2002 (ISES, 2018).. Inclusion of literature from a fifteen year period also aligned with these noteworthy dates.

The purpose of the current systematic review was to analyse all available rein tension literature, regardless of human or equine demographics and therefore strict participant criteria were not required. No exclusions to the number of participants, their age, nor methods of quantitative data collection were implemented (Maber-Aleksandrowicz et al., 2016). A comprehensive evaluation of full papers was deemed necessary by the panel of subject specialists in order to meet the research objectives of this review. Abstract only and non-peer reviewed publications (including student theses) were excluded due to the reported lack of consistency between abstracts and full papers in the reporting of results (Snedeker *et al.*, 2010), and the lack of independent professional appraisal in the scientific quality of the work produced (Lee *et al.*, 2012). Only English language papers were included within this review to ensure that the content was not misreported due to inaccurate translation. Whilst rejection of results due to language barriers is not recommended in systematic reviews, Smith *et al.* (2011) acknowledged a lack of accessible translation services as a reasonable cause for the rejection of papers. When a language inclusion criterion is applied it is considered best practice to report how many potential papers were excluded for language reasons, and this approach was adopted within the current study (Smith *et al.*, 2011)

Data extraction was conducted by the review team; an inductive content analysis was adopted from Keegan et al. (2014) performed utilizing tags (‘open-coding’) to create themes (‘focused coding’) which were then organized to demonstrate their relationship to key areas within rein tension research, study characteristics, rein tension devices, participant characteristics and outcomes related to measured rein tension. To strengthen the review an iterative consensus validation process was conducted by the authors to ensure tags were placed under appropriate themes and a peer debrief was undertaken to debate the validity and reliability of the results obtained (Dundar and Fleeman, 2014; O’Connor and Sargeant, 2015).

Results

A search of the keywords across full articles on ‘Google Scholar’ returned 154 initial search results. Of those 154 results 12 publications were rejected as they were not available in the English language. A further 115 publications were rejected including: equine studies unrelated to the review (72), non-equine studies (18), equine reviews (19) and books (6). A further five studies were rejected at this point because abstracts were published without access to the full study. Figure 1 illustrates the study selection process by flow diagram. As a result of the selection process, seventeen primary research papers (post 2001) were selected for review.

Study Characteristics

The study characteristics in the seventeen studies selected for final review varied (Table 2). Even studies that appear similar differ in important characteristics. Heleski *et al.* (2009) examined changes in behavior and rein tension in four horses with and without martingales; thus investigating rein tension, behavior and riding equipment. Egenvall *et al.* (2012) similarly focused on equine behavior and rein tension in four horses, however, in this study behavioral observations were related to rider influences (two methods of trot-walk transitions) rather than the horse’s behavior associated with use of riding equipment as in Heleski *et al.* (2009).

Studies utilised three main genres of rein tension intervention: (1) ridden, (2) non-ridden or (3) mixed interventions. Methodologies within the main genres varied and investigated the relationship of one (or more) variable(s) and their association with rein tension. Sub-themes included: equine behavior, equine welfare and rider influence/performance, with a small amount of literature also testing riding equipment such as bits and leatherwork. A total of eleven studies focused on ridden rein tension, four on non-ridden rein tension and two better suited a mixed category including both ridden and non-ridden measures.

Rein tension was investigated as a secondary measure to the primary focus in 24 % of reviewed studies. This resulted in incomplete measures in some cases, for example Eisersiö *et al.* (2013) did not record rein tension for 80% of the study population (n=15).

Rein Tension Devices

There were variations in the rein tension devices utilized across the studies in this review (Table 3). All seventeen studies named which device they used, although variations included: 'strain gauge transducers,' 'ReinCheck™,' 'custom made Inertial Measurement Units (IMU),' 'Futek' and 'SMA mini S-beam force gauges.' Differences in the sensitivity of tension measurements and maximum load capacities were reported between devices and should be considered in the comparison of results accordingly (Eisersiö *et al.*, 2015). For example, the strain gauge transducer used by Clayton *et al.* (2005) had a maximum load of 2002 N which exceeds the maximum range of 500 N in the custom made IMU used by both Eisersiö *et al.* (2015) and Egenvall *et al.* (2015 and 2016), and the 50 N maxima of the ReinCheck™ system (Kuhnke *et al.*, 2010; Egenvall *et al.*, 2012; Christensen *et al.*, 2014). A number of limitations were reported with the ReinCheck™ including its inability to accurately record peak rein tension due to insufficient maximal capacity (Christensen *et al.*, 2014) and there were also two reports of kit failure in this system (Egenvall *et al.*, 2012; Von Borstel and Glibman, 2014). Overall, studies presented device specifications inconsistently and 18 % of studies failed to report the maximum load capacities of their devices (Manfredi *et al.*, 2005; Eisersiö *et al.*, 2013; Cross *et al.*, 2016).

The majority of studies (88 %) recorded rein tension bilaterally. The exceptions to this were case studies by Clayton *et al.* (2005) and Cross *et al.* (2016) where unilateral left and right rein tensions were investigated respectively. These studies tested pioneering equipment during riding; either generic rein tension (Clayton *et al.*, 2005) or more recently Cross *et al.* (2016) created a dual-force measuring device, which measured tension exerted on the reins and the cheek-piece of the bridle (to quantify poll-pressure).

Participant characteristics

There was a lack of consistency in how participant characteristics were reported across the studies reviewed for human and equine participants (Table 4). The majority of studies (94 %) included some details of participant characteristics, except Cross *et al.* (2016), who reasoned participant information was not required in the study. The majority (87 %) of reviewed studies used both equine and human participants and the remaining two studies (13 %) either used equine or human participants. However, only 41 % of studies included descriptive demographics for both the equine and human participants (41 %). The detail of the participants' descriptions was also variable with less detail often reported about the equine participants.

The literature reviewed represented 203 equine participants across seventeen studies, a mean (± s.d.) of 12 (± 12.0) (Table 4). Within individual studies, the sample size utilised ranged between 1 and 46 horses. Sample sizes of less than 10 horses were used in 59 % of studies, 18 % included 11 to 20 horses and 23 % used more than 21 horses. Equine demographic information were provided by 88 % of studies. These reported a range of variables including age, breed, sex, height, weight and training experience, although not all were described in every study. Age (range: 2-18 yrs), breed (variable) and sex (24 geldings, 66 mares, 18 stallions) of the horses were reported in 71 %, 47 % and 41 % of the literature respectively. In contrast horse height (range: 1.45 -1.70 m) and weight (range: 392 -586 kg) were only recorded in 18 % of studies respectively. Equine training experience and the discipline the horse was being trained for were included in the majority of studies (76 %). The majority of the reviewed studies measured rein tension in older, experienced horses. Where specified, the most common discipline investigated appeared to be dressage, although horses within this discipline where trained from preliminary level up to Grand-Prix. Only Christensen *et al.* (2011) used young horses naïve to bitting.

A total of 101 human participants were included across the seventeen studies, encompassing 98 riders and 3 handlers, a mean (± s.d.) of 16 (± 4.9) (Table 4). Individual study populations of human participants were smaller than equine study populations ranging from one to fifteen participants. Twenty nine % of studies involved a single participant, 41 % of studies included 3 to 9 participants and 30 % had greater than 10 participants. Human demographics were stated in the majority of the reviewed studies although 29 % of studies failed to include further details of the human participants beyond stating the sample size used (Manfredi *et al.*, 2005; Manfredi *et al.*, 2010; Clayton *et al.*, 2011; von Borstel and Glibman, 2014; Cross *et al.*, 2016). The consistency of what variables were included between the studies was poor. For example, level of rider experience (novice to Grand Prix), weight (range: 56 – 95 kg), height (range: 1.59 -1.8 m), sex, human handedness and age (range 14 - 50 years) of riders were reported in 59 %, 35 %, 29 %, 24 %, 18 % and 12 % of studies, respectively.

Data Collection

The preparation of equipment is a key stage in reporting data collection protocols but calibration was only reported in twelve of the seventeen studies. Five studies (Manfredi *et al.*, 2005; Warren-Smith *et al.*, 2007; Kuhnke *et al.*, 2010; Manfredi *et al.*, 2010; Cross *et al.* 2016) did not refer to this critical stage. Across the studies sampling rates varied, with ranges between 100 Hz (Christensen et al., 2011; Egenvall et al., 2012), 140 Hz (Eisersio et al., 2013) and 240 Hz (Clayton et al., 2011; Heleski et al., 2009) reported.

Data handling between reviewed studies was inconsistent (Table 5). Forces are usually reported in Newtons. Although Kuhnke *et al.* (2010) reported rein tension in kilograms Force (kgF) these data can be converted using a simple equation (formula: XXkg x 9.81 = N) to enable comparisons to be made. Rein tension data processing was only reported in four papers (Clayton et al., 2005; Heleski et al., 2009; Clayton et al., 2011; Cross *et al.*, 2016) with the Butterworth filter being the most commonly utilised.

Some studies reported the main findings as *peak* rein tensions i.e. the maximum that was recorded (Clayton *et al.*, 2005; Eisersiö *et al.*, 2013; Egenvall *et al.*, 2015, 2016). In contrast, others based their conclusions on *average* rein tension (Warren-Smith *et al.*, 2007; Heleski *et al.*, 2009; Kuhnke *et al.*, 2010; Christensen *et al.*, 2011; Eisersiö *et al.*, 2015).

Discussion

There was unanimous agreement across the reviewed studies that individual horse and rider characteristics significantly influence rein tension. However, authors suggested different influencing characteristics including the horse, the rider or equipment, or a combination of the three factors; consequently, no specific aetiology to explain variation in rein tension has been proposed to date (Figure 2). Nevertheless, the general consensus reported that rein tension increased with the gait of the horse, increasing from 6.9 - 43 N in walk to 10.8 - 51 N in trot and 1.5 - 104 N in canter (Clayton *et al.*, 2005; Kuhnke *et al.*, 2010; Eisersiö *et al.*, 2015; Egenvall *et al.*, 2016).

In addition to changes in gait, increased tensions could be related to training practices where horses are taught to yield at higher pressures (McLean and McLean, 2002), or the threshold where bit pressure becomes excessive could have increased due to habituation i.e. desensitisation (McLean and McGreevy, 2010; Christensen *et al.*, 2011). Learning theory recommends training self-carriage during locomotory responses without habituation to pressure signals (McLean and McGreevy, 2015). If the horse is trained to accept more pressure in the mouth, it could increase the risk of injury, negatively affect equine welfare, and perpetuate the need for increasingly stronger pressures. The horse's individual training may also determine whether undesirable behavior is associated with increasing rein tension (Warren-Smith *et al.*, 2007; Christensen *et al.*, 2011).

Manfredi *et al.* (2010) found a significant increase in undesirable behavior indicative of increased equine stress levels as rein tension was progressively increased. The study used six different bits, representing bits considered by industry to have a mild through to severe action (McGreevy *et al.*, 2005; Randle and Wright; 2013). Interestingly individual bit type demonstrated no association with undesirable behaviors (Manfredi *et al.*, 2010) perhaps suggesting it is how the bit is used and learning theory is applied within this use, which could trigger the expression of conflict behaviors. A wide range of bits are available for use in horses, with reported actions on different parts of the horse's head potentially affected to different extents by increasing rein tension. Technological advances now permit dual-force rein tension measurements that quantify rein *vs.* poll pressure and offer insights into actual bit mechanism (Cross *et al.*, 2016). As a result, rein tension could be used to design equipment based on scientific evidence.

Rein tension and head and neck position

Equine head and neck position can be influenced by riders and the use of training aids (Clayton *et al.*, 2011; Eisersiö *et al.*, 2013; Egenvall *et al.*, 2015). Studies (ridden and non-ridden) agreed that as rein length becomes shorter, measured rein tension and the frequency of evasive behavior increases (Clayton *et al.*, 2011; Eisersiö *et al.*, 2013; Christensen *et al.*, 2014). However, research suggests rein material and noseband tightness may also significantly affect rein tension (Randle et al., 2011; Randle and McGreevy, 2013). However, with the exception of Warren-Smith *et al.* (2007) where length, weight and thickness of material was reported, the majority of ridden studies in the review failed to include specific details on rein type.

Similarly, studies in the review inconsistently reported noseband tightness or type. For example, Eisersiö *et al.* (2013) reported horses wore standard bridles, some wore cavesson nosebands and some flash nosebands. Additional research reported that when cavesson nosebands were fitted loosely greater rein tensions were measured than when fitted tightly (Randle and McGreevy, 2013). To date, the effect of flash nosebands on rein tension have not been investigated. Flash nosebands are designed to restrict the horse from opening the mouth (Casey *et al.*, 2013) comparing horses subjected to different noseband conditions is likely to yield incomparable rein tension data. To confirm the relationship between rein length, horse head and neck position, and measured rein tension, future research should include description of noseband type and tightness, and rein type, material, length and weight.

Rein tension and the participants

The riders used across the research reviewed were all experienced equestrians, able to anticipate locomotory movements and remain in synchronisation with the horse (Terada *et al.*, 2004; LaGarde *et al.*, 2005). Riders with previous experience may have preconceptions about socially desirable equitation practices and therefore minimise the force they exert on the reins (Terada *et al.*, 2004; Heleski *et al.*, 2009). The prevalence of the ‘participant effect’ is reasonably high in experimental studies causing test participants to subconsciously alter their behavior and respond in a way they assume the researcher expects (Nichols and Maner, 2008). Therefore rein tension research may not represent riders outside studies or beginner riders (McLean and McGreevy, 2010). The fact however that rein tension was not the primary focus of four studies may actually be beneficial here and reduce this ‘participant effect’.

Only 13% of studies reported human handedness preferences although these saw bilateral rein tension asymmetries during turning manoeuvres and transitions with the non-dominant hand applying higher rein tension than the dominant hand (Kuhnke *et al.*, 2010; Hawson *et al.*, 2014; Eisersiö *et al.*, 2015). Laterality preferences are reported to increase grip strength by up to 10% on the dominant side of the body in the majority of the general population (Steele, 2000; Oppewal *et al.*, 2013) which could explain the bilateral asymmetries observed. Where handedness bias was reported, the studies predominantly used right-handed participants reflecting the majority of the human population (Faurie *et al.*, 2012). Equine sidedness is the equivalent of human handedness and as rein tension is derived from both horse and human a study investigating the interaction between human handedness and equine sidedness would increase understanding of rein tension. These two factors should be consistently reported in rein tension studies.

Given rein tension derives from human and equine interaction few studies included descriptive demographics for both the equine and human participants (41 %) and the detail of that reporting was highly variable. Clear reporting of the characteristics of both human and equine participants in a published study is essential to enable the reader to understand the limits to the validity of the findings. Pierard et al. (2015) outlined an extensive list of factors that should be included in equitation research and its key features are applicable to research measuring rein tension. These factors can be grouped into three groups, horse-related, rider-related and performance-related factors. For rein tension research they should also include handedness preferences in rider-related factors and tack descriptions in horse-related factors. Figure 3 displays the factors that should be reported in future rein tension research.

Study design

Care should be taken to avoid forming false-positive assumptions from the results of studies that cannot be generalised to the wider population (Hackshaw, 2008; Holmes and Jeffcott). This is a serious concern in equestrian research, where identifying large samples that share sufficient characteristics to be considered similar is difficult and sourcing funding for the frequently expensive data collection is often challenging. Despite this it is important that studies follow accepted study design principles to produce valid, reliable, accurate and precise results. Whilst a detailed discussion of experimental design is outside the scope of this paper Randle *et al.* (2017) provides an accessible overview.

The purpose of case studies is to investigate single-units with the aim to generalize across a larger set of units (Gerring, 2004). Therefore, the findings of Clayton *et al.* (2005) and Cross *et al.* (2016) do not model causal relationships i.e. the cause of rein tension, but aim to define the case, i.e. to infer what happens during rein tension, and as case studies the results obtained are only applicable to the subjects under investigation.

Data collection, processing and analysis

Rein tension gauges tend to sit between the bit and the reins, and as such are not an absolute measure of the force acting upon the horse’s mouth. For studies focussing on the horse’s experience it would be better to measure the pressure experienced by the horse. Pressure is the force acting upon a defined area, therefore the size of the area that the pressure acts upon will influence the magnitude and effect observed. Future rein tension studies should consider this within their design and report rein tension as a force in Newtons, or ideally a pressure in Nm^{-2}. Future research could utilise pressure sensitive film or fabric to determine how rein tension relates to what the horse is experiencing on the lips, the bars of the mouth, the poll and other anatomical areas (Pierard *et al.*, 2015).

Experimental studies should aim to demonstrate reproducibility and as such report their materials and methods in a detailed manner, including giving precise descriptions of equipment used (Randle *et al.*, 2017). Inconsistencies in reporting create barriers to developing a generic, valid and reliable approach within future rein tension research. Devices to measure rein tension should be described consistently and in detail, with manufacturer's details and product references. The maximum load capacities of devices and the levels of precision and accuracy that they are validated to provide should be clearly stated. From the studies reviewed the device must be capable of measuring forces in excess of the 104 N recorded by Clayton *et al.*, (2005). To ensure the rein tension device can perform as published it is important that it is maintained and set-up as per the manufacturer's instructions, including calibration and standardisation, as discussed in Randle *et al.* (2017). Reporting of these activities was not consistent and complete within the reviewed studies.

Rein tension data may also integrate spurious data points related to extraneous noise, therefore data processing is required to remove noise and ensure the validity and reliability of the data obtained. A number of studies documented data processing approaches undertaken (such as use of the Butterworth filter), whilst others only report sampling rates and neglect to detail filtering, and how rein tension data were processed. We advocate that data processing and analysis should be reported in full as in Clayton et al. (2005), to facilitate more accurate comparison of results obtained. Reporting should include details of calibration, sampling rate and filtering protocols for rein tension data.

A consistent approach to data analysis is also recommended, within the constraints of the individual investigation and its associated hypothesis(es). There were a small number of studies which clearly presented minimum, maximum and average rein tensions providing a *holistic* understanding to measured rein tension comparable to different studies (Clayton *et al.*, 2011; Von Borstel and Glibman, 2014). Reporting solely minimum and maximum, or average rein tension is unlikely to represent true rein tension since they can easily be distorted by outliers (Tong, 2014).To improve comparability between current and future studies, the approach utilised by Clayton et al. (2011) is advocated across a minimum of 10-15 strides with due consideration of gait phasing (ideally by conducting digitally synchronised kinematic analysis). This approach measures the entirety of the force patterns which occur during different equitation movements enabling a rein tension profile to be constructed. This would support the development of reference values for optimum and excessive rein tension levels across a range of equestrian disciplines, activities and experience levels, as McGreevy (2007) advocated.

The variability in rein tension within the reviewed studies suggests it is an individualised measure. Similar patterns are observed in electromyography with reliability and consistency demonstrated within individuals rather than across cohorts (Williams et al., 2014). Future research should apply a within-subjects research framework and consider relative differences in rein tension rather than strive to identify baseline measures across horses which may not truly exist (Williams, 2018). Future research should also evaluate the impact of transitions (changes of gait) within rein tension assessment. Studies exploring pressure differentials during transitions compared to riding consistently within the gaits are warranted to fully elucidate the contribution of transitions to pressure variables commonly measured. Using kinematic analysis and rein tension assessment together would provide more accurate results and a holistic view of the role of rein tension within equitation.

Limitations of this systematic literature review

The inclusion criteria rejected student theses and abstract only publications. Consequently this resulted in omission of recent research and potentially increases the effects of publication bias (Riis, 2006; Blackhall, 2007), the increased likelihood of publication for studies which find statistically ‘significant’ results compared to non-significant findings (O’Connor and Sargaent, 2015).

Within equestrian research small study samples are common due to the difficulty of accessing horses and riders which are managed under the same conditions (Pierard et al., 2015). The samples in the reviewed studies followed this pattern and as such risk over-estimating the effect of an association (Hackshaw, 2008; Blundell, 2014).

Conclusions

The tools and methods used to measure rein tension within published literature were frequently inconsistently reported leading to difficulty in establishing whether their findings were reliable. Reporting the characteristics of the human and equine participants comprehensively, combined with using and systematically reporting robust methods of data collection, processing and analysis should support comparisons and future meta-analysis being completed. To fully understand rein tension and the effects it may have on horse and human (whether as handler or rider), larger scale studies need to be conducted.

There is a clear need for decision makers within the equine industry and research communities to consider theoretical versus actual mechanisms of standard riding equipment, in relation to rein tension. Therefore, future studies should re-focus to establish how measured rein tension equates to pressure in the equine mouth. It is important to consider the relevance of rein tension research to equestrian performance as well as equine welfare. Rein tension research will be improved by the use of consistent and robust methodologies with the aim to objectively evaluate communication between horse and human.

Authorship statement

The idea for the paper was conceived by J Williams, in discussion with C Lemon and L Dumbell

The experiments were designed by all, with C Lemon performing the initial search.

The experiments were performed by n/a

The data were analyzed by all

The paper was written by L Dumbell, with input from J Williams and C Lemon

References

British Equestrian Trade Association, 2017. Market Information. Available from: http://www.beta-uk.org/pages/industry-information/market-information.php [Accessed 29 April 2017]

Blackhall, K., 2007. Finding studies for inclusion in systematic reviews of interventions for injury prevention the importance of grey and unpublished literature. Inj. Prev. 13 (5), 359–359.

Blundell, M., 2014. Understanding and Synthesizing My Data. In: Angela (Ed) Doing a Systematic Review A Student's Guide. Los Angeles, CA: SAGE Publications.

Bryan, P., 2017. Three horses eliminated under blood rules at European Dressage Championships. Available from: http://www.horseandhound.co.uk/news/three-horses-eliminated-blood-rules-european-dressage-championships-630320 [Accessed 1st December 2017]

Casey, V., McGreevy, P.D., O'Muiris, E. and Doherty, O., 2013. A preliminary report on estimating the pressures exerted by a crank noseband in the horse. J. Vet. Behav. 8 (6), 479–484.

Centre for Reviews and Dissemination, 2001. Undertaking Systematic Reviews of Research on Effectiveness. CRD's Guidance for those Carrying Out or Commissioning Reviews. 2nd ed. York: York Publishing Service Ltd.

Christensen, J.W., Beekmans, M., van Dalum, M. and VanDierendonck, M., 2014. Effects of hyperflexion on acute stress responses in ridden dressage horses. Physiol. Behav. 128, 39–45.

Christensen, J.W., Zharkikh, T.L., Antoine, A. and Malmkvist, J., 2011. Rein tension acceptance in young horses in a voluntary test situation. Eq. Vet. J. 43 (2), 223–228.

Clayton, H.M. and Hobbs, S.J., 2017. The role of biomechanical analysis of horse and rider in equitation science. Appl. Anim. Behav. Sci. 190, 123-132.

Clayton, H.M., Larson, B., Kaiser, L.J. and Lavagnino, M., 2011. Length and elasticity of side reins affect rein tension at trot. Vet. J. 188 (3), 291–294.

Clayton, H.M., Singleton, W.H., Lanovaz, J.L. and Cloud, G.L., 2005. Strain gauge measurement of rein tension during riding: A pilot study. Eq. Comp. Ex. Physiol. 2 (3), 203–205.

Clayton, H.M., Singleton, W.H., Lanovaz, J.L. and Cloud, G.L., 2003. Measurement of rein tension during horseback riding using strain gauges. Exp. Tech. 27 (3), 34-36.

Cook, W.R., 1999. Pathophysiology of bit control in the horse. J. Eq. Vet. Sci. 19 (3), 196–204.

Cornelisse, C.J., Holcombe, S.J., Derksen, F.J., Berbey, C., Jackson, C.A., 2001. Effect of a tongue-tie in horses during exercise. Am. J. Vet. Res. 62, 775–778.

Cross, G.H., Cheung, M.K.P., Honey, T.J., Pau, M.K. and Senior, K.-J., 2016. Application of a dual force sensor system to characterise the intrinsic operation of horse bridles and bits. J. Eq. Vet. Sci. 48, 129-135e.

De Haan, D. and Dumbell, L., 2016. Equestrian Sport at the Olympic Games from 1900 to 1948. Int. J. Hist. Sp. 33 (6-7), 648-665.

Deloitte, 2016. Almost 70m tickets sold for UK sports events in 2016. Available from: https://www2.deloitte.com/uk/en/pages/press-releases/articles/70m-tickets-sold-for-uk-sports-event.html [Accessed 1st March 2018]

Deloitte, 2017. Almost 75m tickets sold for UK sports events in 2017. Available from: https://www2.deloitte.com/uk/en/pages/press-releases/articles/almost-75m-tickets-sold-for-uk-sports-events-in-2017.html [Accessed 1st March 2018]

Dundar, Y. and Fleeman, N., 2014. Developing my search strategy and applying my inclusion criteria. In: Boland, A., Cherry, M.G. and Dickson, R., (Ed), Doing a Systematic Review A Student's Guide. London: SAGE Publications Ltd, pp. 35–60.

Egenvall, A., Eisersiö, M. and Roepstorff, L., 2012. Pilot study of behavior responses in young riding horses using 2 methods of making transitions from trot to walk. J. Vet. Behav. 7 (3), 157–168.

Egenvall, A., Roepstorff, L., Eisersiö, M., Rhodin, M. and Van Weeren, R., 2015. Stride-related rein tension patterns in walk and trot in the ridden horse. Acta Vet. Scand. 57–89.

Egenvall, A., Roepstorff, L., Rhodin, M., Eisersio, M. and Clayton, H.M., 2016. Maximum and minimum peaks in rein tension within canter strides. J. Vet. Behav. 13, 63-71.

Eisersiö, M., Rhodin, M., Roepstorff, L. and Egenvall, A., 2015. Rein tension in 8 professional riders during regular training sessions. J. Vet. Behav. 10 (5), 419–426.

Eisersiö, M., Roepstorff, L., Weishaupt, M.A. and Egenvall, A., 2013. Movements of the horse's mouth in relation to horse–rider kinematic variables. Vet. J. 198, e33–e38.

Faurie, C., Llaurens, V., Hegay, T. and Raymond, M., 2012. Handedness and socioeconomic status in an urban population in Uzbekistan. Evol. Hum. Behav. 33 (1), 35–41.

FEI, 2017a. Code of Conduct for the Welfare of the Horse. Available from: http://inside.fei.org/system/files/Code_of_Conduct_Welfare_Horse_1Jan2013.pdf [Accessed 29th April 2017]

FEI, 2017b. FEI Values. Available from: http://inside.fei.org/fei/about-fei/values [Accessed 29th April 2017]

Finneran, A. and O'Sullivan, L., 2013. Effects of grip type and wrist posture on forearm EMG activity, endurance time and movement accuracy. Int. J. Ind. Ergon. 43 (1), 91–99.

Fletcher, T. and Dashper, K., 2013. 'Bring on the dancing horses!': Ambivalence and class obsession within British media reports of the Dressage at London 2012. Sociol. Res. Online. 18 (2). DOI: 10.5153/sro.3040

Gough, D., Oliver, S. and Thomas, J., 2017. Introducing systematic reviews. In Gough,D., Oliver, S. and Thomas, J. (Eds.), An Introduction to Systematic Reviews. (pp. 1-16). 2nd ed. London: SAGE Publications Ltd, pp. 1–16.

Gough, D., Thomas, J. and Oliver, S., 2012. Clarifying differences between review designs and methods. Syst. Rev. 1 (1), 28.

Greenhalgh, J., Bagust, A., Boland, A., Martin Saborido, C., Oyee, J., Blundell, M., Dundar, Y., Dickson, R., Proudlove, C. and Fisher, M., 2011. Clopidogrel and modified-release dipyridamole for the prevention of occlusive vascular events (review of technology appraisal no. 90): A systematic review and economic analysis. Health Technol. Assess. 15 (31).

Hackshaw, A., 2008. Small studies: Strengths and limitations. Editor. 1 November. Available from: http://erj.ersjournals.com/content/32/5/1141doi:10.1183/09031936.00136408 [Accessed 24 February 2016].

Hawson, L.A., Salvin, H.E., McLean, A.N. and McGreevy, P.D., 2014. Riders' application of rein tension for walk-to-halt transitions on a model horse. J. Vet. Behav. 9 (4), 164–168.

Heleski, C.R., McGreevy, P.D., Kaiser, L.J., Lavagnino, M., Tans, E., Bello, N. and Clayton, H.M., 2009. Effects on behaviour and rein tension on horses ridden with or without martingales and rein inserts. Vet. J. 181 (1), 56–62.

Higgins, J.P.T. and Green, S., 2011. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0. Chichester, England: Wiley-Blackwell.

Hinnemann, J., van Baalen, C., van Andel, C., Bronkhorst, A. and Caremans, D., 2004. The Simplicity of Dressage. United States: Trafalgar Square.

Holmes, M. and Jeffcott, L., 2010. Equitation Science, rider effects, saddle and back problems in horses: can technology provide the answer? Vet. J. 184 (1), 5-6.

International Society of Equitation Science, 2017. ISES Mission and Aims. Available from http://equitationscience.com/ [Accessed 29th April 2017]

International Society of Equitation Science, 2018. About ISES. Available from http://equitationscience.com/ [Accessed 1st March 2018]

Jakovljevic, D.G. and McConnell, A.K., 2009. Influence of different breathing frequencies on the severity of Inspiratory muscle fatigue induced by high-intensity front crawl swimming. J. Strength Cond. Res. 23 (4), 1169–1174.

Jones, E., 2017. French event rider dies after rotational fall. Available from http://www.horseandhound.co.uk/news/eventer-maxime-debost-dies-rotational-fall-633119#brVlJqjLfQdfYTfu.99 [Accessed 10th October 2017]

Knicker, A.J., Renshaw, I., Oldham, A.R.H. and Cairns, S.P., 2011. Interactive processes link the multiple symptoms of fatigue in sport competition. Sp. Med. 41 (4), 307–328.

Krishna, A. and Haglund, E., 2008. Why do Some Countries Win More Olympic Medals? Lessons for Social Mobility and Poverty Reduction. Econ. Political Weekly. 43, 145.

Kuhnke, S., Johnson, J.L., Gauly, M., Borstel, U.K. von, Dumbell, L. and McDonald, K., 2010. A comparison of rein tension of the rider's dominant and non-dominant hand and the influence of the horse's laterality. Comp. Ex. Physiol. 7 (02), 57–63.

Lagarde, J., Peham, C., Licka, T. and Kelso, J.A.S., 2005. Coordination dynamics of the horse-rider system. J. of Mot. Behav. 37 (6), 418–424.

Lee, C.J., Sugimoto, C.R., Zhang, G. and Cronin, B., 2012. Bias in peer review. J. Am. Soc. Info. Sci. Tech. 64 (1), 2–17.

Lees, A., 2002. Technique analysis in sports: a critical review. J. of Sports Sci. 20, 813-828.

Ludewig, A.K., Gauly, M. and von Borstel, K.U., 2013. Effect of shortened reins on rein tension, stress and discomfort behavior in dressage horses. J. Vet. Behav. 8 (2), e15–e16.

Maber-Aleksandrowicz, S., Avent, C. and Hassiotis, A., 2016. A systematic review of animal-assisted therapy on psychosocial outcomes in people with intellectual disability. Res. Dev. Disabil. 49-50, 322–338.

Manfredi, J., Clayton, H. and Rosenstein, D., 2005. Radiographic study of bit position within the horse's oral cavity. Eq. Comp. Ex. Physiol. 2 (3), 195–201.

Manfredi, J.M., Rosenstein, D., Lanovaz, J.L., Nauwelaerts, S. and Clayton, H.M., 2010. Fluoroscopic study of oral behaviours in response to the presence of a bit and the effects of rein tension. Comp. Ex. Physiol. 6 (04), 143–148.

McCrae, N., Blackstock, M. and Purssell, E., 2015. Eligibility criteria in systematic reviews: A methodological review. Int. J. Nurs. Stud. 52 (7), 1269–1276.

McGreevy, P.D., 2007. The advent of equitation science. Vet. J. 174 (3), 492–500.

McGreevy, P.D. and Boakes, R.A., 2006. Carrots and sticks: Principles of animal training. Cambridge: Cambridge University Press.

McGreevy, P.D. and McLean, A.N., 2007. Roles of learning theory and ethology in equitation. J. Vet. Behav. 2 (4), 108–118.

McGreevy, P.D. and Rogers, L.J., 2005. Motor and sensory laterality in thoroughbred horses. Appl. Anim. Behav. Sci. 92 (4), 337–352.

McGreevy, P., McLean, A., Warren-Smith, A., Goodwin, D., Waran, N. and Botterrill, S., 2005. ISES Australia2005 proceedings [online]. Available from: http://www.equitationscience.com/documents/Proceedings/Australia2005_Proceedings.pdf [Accessed 12 March 2016].

McLean, A.N. and McGreevy, P.D., 2010. Horse-training techniques that may defy the principles of learning theory and compromise welfare. J. Vet. Behav. 5 (4), 187–195.

McLean, A. and McGreevy, P., 2015. ISES training principles poster 2015. Available from: http://www.equitationscience.com/documents/Equitation/ISES_Training_Principles_Poster_2015.pdf [Accessed 11 March 2016].

McLean, A. and McLean, A., 2002. Horse training the Mclean way: The science behind the art. Victoria: Australia Equine Behaviour Centre.

Meade, M.O. and Richardson, W.S., 1997. Selecting and appraising studies for a systematic review. Ann. Intern. Med. 127 (7), 531.

Murphy, J. and Arkins, S., 2008. Facial hair whorls (trichoglyphs) and the incidence of motor laterality in the horse. Behav. Process. 79 (1), 7–12.

Newton, A.M. and Nielsen, A.M., 2005. A review of horse-related injuries in a rural Colorado hospital: Implications for outreach education. J. Emerg. Nurs. 31 (5), 442–446.

Nichols, A.L. and Maner, J.K., 2008. The good-subject effect: Investigating participant demand characteristics. J. Gen. Psych. 135 (2), 151–166.

O'Connor, A. and Sargeant, J., 2015. Research synthesis in veterinary science: Narrative reviews, systematic reviews and meta-analysis. Vet. J. 206 (3), 261–267.

Oppewal, A., Hilgenkamp, T.I.M., van Wijck, R. and Evenhuis, H.M., 2013. The effect of handedness on grip strength in older adults with intellectual disabilities. Res. Dev. Disabil. 34 (5), 1623–1629.

Pierard, M., Hall, C., Borstel, U.K. von, Averis, A., Hawson, L., McLean, A., Nevison, C., Visser, K. and McGreevy, P., 2015. Evolving protocols for research in equitation science. J. Vet. Behav. 10 (3), 255–266.

Pinker, S., 2007. Steven Pinker - toward a Consilient study of literature - philosophy and literature 31: 1. Philos. Lit. 34, 1.

Pugh, T.J. and Bolin, D., 2004. Overuse injuries in equestrian athletes. Curr. Sports Med. Rep. 3 (6), 297–303.

Randle, H. and McGreevy, P., 2013. The effect of noseband tightness on rein tension in the ridden horse. J. Vet. Behav. 8 (2), e18–e19.

Randle, H. and Wright, H., 2013. Rider perception of the severity of different types of bits and the bitless bridle using rein tensionometry. J. Vet. Behav. 8 (2), e18.

Randle, H. and Waran, N., 2017. Breaking down barriers and dispelling myths: the need for a scientific approach to Equitation. Appl. Anim. Behav. Sci. 190, 1-4.

Randle, H., Abbey, A. and Button, L., 2011. The effect of different rein types on the rein tension applied when taking up a ‘medium contact’. J. Vet. Behav. 6 (5), 295.

Randle, H., Steenbergen, M., Roberts, K. and Hemmings, A., 2017. The use of the technology in equitation science: A panacea or abductive science? Appl. Anim. Behav. Sci. 190, 1-4.

Riis, J., 2006. *Cochrane handbook for systematic reviews of interventions 4.2.6* [online]. Available from: http://community-archive.cochrane.org/sites/default/files/uploads/Handbook4.2.6Sep2006.pdf [Accessed 13 March 2016].

Sandberg, J. and Alvesson, M., 2010. Ways of constructing research questions: Gap-spotting or problematization? Organ. 18 (1), 23–44.

Sargeant, J.M., Rajic, A., Read, S. and Ohlsson, A., 2006. The process of systematic review and its application in agri-food public-health. Prev. Vet. Med. 75 (s 3–4), 141–151.

Slingerland, E. and Collard, M., 2011. Creating Consilience: Integrating the sciences and the humanities. United States: Oxford University Press.

Smith, V., Devane, D., Begley, C.M. and Clarke, M., 2011. Methodology in conducting a systematic review of systematic reviews of healthcare interventions. BMC Med. Res. Method. 11 (1), 15.

Snedeker, K.G., Campbell, M., Totton, S.C., Guthrie, A. and Sargeant, J.M., 2010. Comparison of outcomes and other variables between conference abstracts and subsequent peer-reviewed papers involving pre-harvest or abattoir-level interventions against foodborne pathogens. Prev. Vet. Med. 97 (2), 67–76.

Steele, J., 2000. Handedness in past human populations: Skeletal markers. Laterality: Asymmetries of Body, Brain and Cognition 5 (3), 193–220.

Terada, K., Clayton, H.M. and Kato, K., 2004. Stabilization of wrist position during horseback riding at trot. Eq. Comp. Ex. Phys. 3(4), 179-184.

Tong, Z., 2014. Averages can be misleading: Try a Percentile. 23 October. Available from: https://www.elastic.co/blog/use-percentile [Accessed 11 March 2016].

von Borstel, U.K. and Gliβman, C., 2014. Alternatives to conventional evaluation of rideability in horse performance tests: suitability of rein tension and behavioural parameters. PLoS ONE. 9(1). e87285. doi: 10.1371/journal.pone.0087285

Waran, N. and Randle, H., 2017. What we can measure, we can manage: The importance of developing robust welfare indicators for use in Equitation. Appl. Anim. Behav. Sci. 190, 74-81.

Warren-Smith, A.K., Curtis, R.A., Greetham, L. and McGreevy, P.D., 2007. Rein contact between horse and handler during specific equitation movements. Appl. Anim. Behav. Sci. 108 (s 1–2), 157–169.

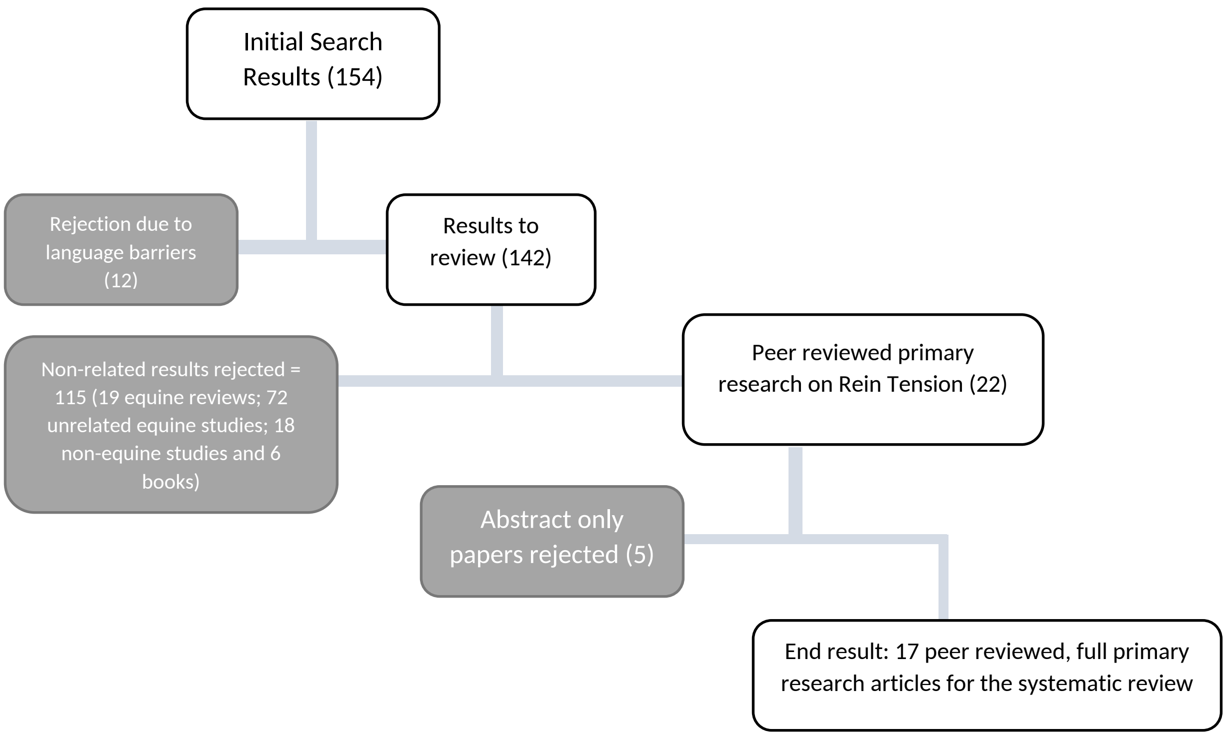
Williams, D.E. and Norris, B.J., 2007. Laterality in stride pattern preferences in racehorses. Anim. Behav. 74 (4), 941–950.

Williams, J., 2018. Electromyography in the horse: a useful technology. J. Eq. Vet. Sci. 60, 43-58e2.

Williams, J., 2013. Performance analysis in equestrian sport. Comp. Ex. Physiol. 9 (2), 67-77.

Williams, J.M., Johnson, C., Bales, R., Lloyd, G., Barron, L., Quest, D.,2014. Analysis of Temporalis and Masseter adaptation after routine dental treatment in the horse via surface electromyography. Comp. Ex. Physiol. 10 (4), 223-232.

Figure 1: Flow diagram of the study selection process for key words ‘rein tension’ AND ‘horse/s’ OR ‘rider/s’ OR ‘equine/s’ OR ‘equestrian’, in Google Scholar (>2001) = 154



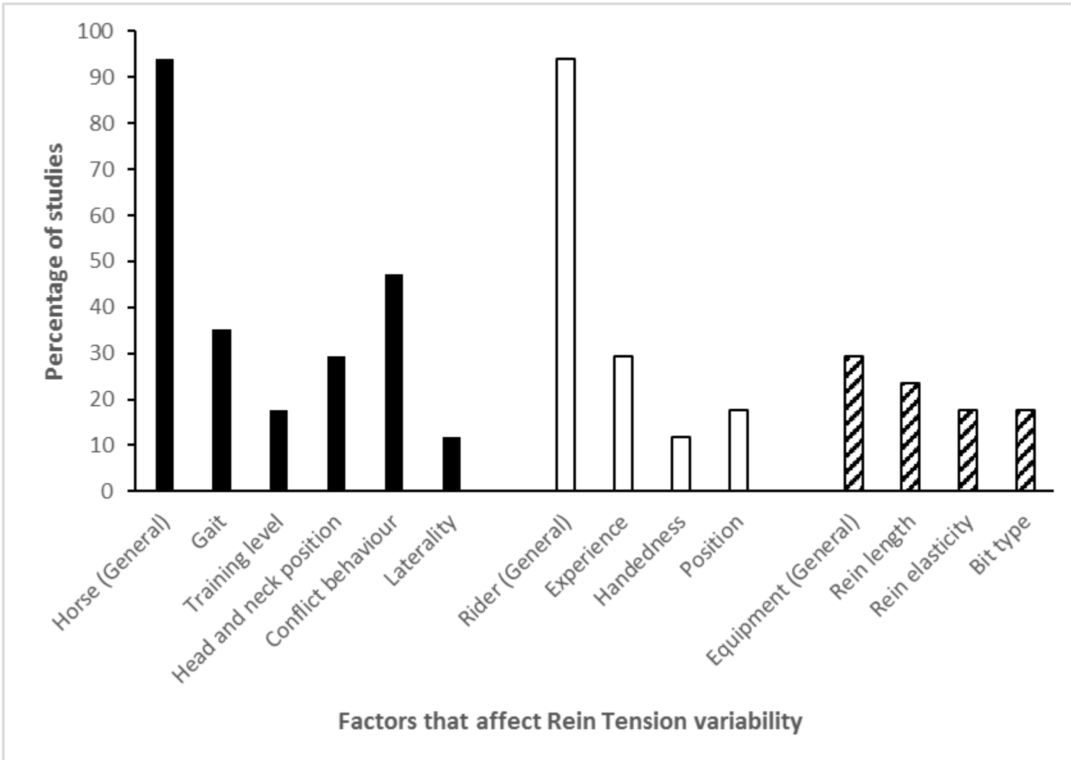


Figure 2 Incidence of factors which are associated with rein tension variability reported by the seventeen reviewed studies.

Tif heading submitted as a separate file:

Figure 3: Factors that can impact rein tension in the ridden horse. White text: horse related factors; Green text: performance related factors; Yellow text: rider related factors.

	Description	Justification
Participant	Equine; any breed, age, height, sex, discipline, experience. Human; all riders, all experience levels.	Expert panel & adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)
Intervention	Rein tension; ridden and non-ridden trials	Expert panel
Outcome	Corresponds to reports of all recorded rein tension measurements collected via quantitative data collection. Qualitative reports from riders or observers within studies also included.	Expert panel & adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)
Study design	Primary research; experimental studies with quantitative data collection. Peer-reviewed. Full papers (post 2001).	Adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)

Table 1. Inclusion criteria adapted from PICO(S) Cochrane Handbook (Higgins and Green, 2011)

Study		Study Characteristics		
		Title	Intervention/ Equipment	Method
1	Clayton *et al.* (2005)	Strain gauge measurement of RT during riding: a pilot study	Regular riding / Strain gauge transducer	[R] Walk trot and canter, both directions. Left rein measured.
2	Manfredi, Clayton & Rosenstein (2005)	Radiographic study of bit position within the horse's oral cavity	6 snaffle bits: 3 single jointed & 3 Mylers / Strain gauge transducer	[NR] Reins attached to handler via roller, 25± 5N bilaterally.
3	Warren-Smith *et al.* (2007)	Rein contact between horse & handler during specific equitation movements	Long-reining & riding / ReinCheck™	[M] RT bilaterally recorded for: turn left, turn right, going straight and halt.
4	Heleski et al. (2009)	Effects on behavior and RT on horses ridden with or without martingales and rein inserts	Plain reins, martingale, elastic rein inserts / ReinCheck™	[R] RT bilaterally recorded: sitting trot to walk, change of rein, walk to sitting trot
5	Manfredi *et al.* (2010)	Fluoroscopic study of oral behaviors in response to the presence of a bit and the effects of RT	3 snaffle bits: Single-jointed, KK Ultra & Myler comfort / Strain gauge transducer	[NR] Reins attached to handler via roller, 25± 5N bilaterally.
6	Kuhnke *et al.* (2010)	A comparison of RT of the rider's dominant and non-dominant hand and the influence of the horse's laterality	Rider handedness and horse laterality / ReinCheck™	[R] 3 circles of walk, sitting trot, canter, 4 halt transitions, RT recorded bilaterally. Left & right lateralized horses. Right handed riders.
7	Christensen *et al.* (2011)	RT acceptance in young horses in a voluntary situation	Degree of voluntary RT for food reward / ReinCheck™	[NR] Side reins attached to roller at: loose, intermediate and short rein length. Horse encouraged to stretch forwards to reach food reward.
8	Clayton *et al.* (2011)	Length and elasticity of side reins affect RT at trot	3 side reins at 3 lengths / Strain gauge transducer	[NR] Inelastic, stiff elastic, compliant elastic side reins attached to roller at long, neutral and short rein length. Trot in straight line with handler.
9	Egenvall *et al.* (2012)	Pilot study of behavior responses in young riding	Trot to walk transition method / ReinCheck™	[R] 1: RT relief at first attempt to perform correct response (walking). 2: RT relief at completed response.

		horses using 2 methods of making trot to walk transitions		
10	Eisersiö *et al.* (2013)	Movements of the horse's mouth in relation to horse-rider kinematic variables	Horse's HNP: 'on the bit' and unrestrained / RT meter (Futek)	[R] HNP1: loose reins, unrestrained. HNP2: neck raised, poll high, 'on the bit' as in dressage competitions. All horses and riders recorded in trot on treadmill.
11	Von Borstel and Glibman (2014)	Alternatives to Conventional Evaluation of Rideability in Horse Performance Tests: Suitability of RT and Behavioural Parameters	Behavior & RT vs Judges' evaluation of horse rideability / ReinCheck™	[M] Mare and stallion breeding station performance tests. RT and behavior measured in performance test and dressage training
12	Hawson *et al.* (2014)	Riders' application of RT for walk-to-halt transitions on a model horse	Walk to halt transition, rider handedness / ReinCheck™	[R] Model horse, built on measurements of a 155cm live horse.
13	Christensen *et al.* (2014)	Effects of hyperflexion on acute stress response in ridden dressage horses	Stress response, RT & HNP: (1) Competition frame, (2) Long Deep Round/hyperflexion, (3) loose frame / ReinCheck™	[R] Standardised 10-min DR plan in 3 HNP. Heart rate, Heart rate variability, behavior, salivary cortisol & RT recorded.
14	Eisersiö *et al.* (2015)	RT in 8 professional riders during regular training sessions	Regular riding during riding session / Custom made, IMU	[R] Rider-determined flatwork schooling session
15	Egenvall *et al.* (2015)	Stride-related RT patterns in walk and trot in the ridden horse	Stride phase related RT / Custom made, IMU	[R] Rider-determined flatwork schooling session
16	Cross *et al.* (2016)	Application of a Dual Force Sensor System to Characterise the Intrinsic Operation of Horse Bridles and Bits	Poll and rein pressure: 1 snaffle and 2 leverage bits / SMA mini S-beam force gauges	[R] Walk, trot, and canter. RT & cheek-piece measured.
17	Egenvall *et al.* (2016)	Maximum and minimum peaks in rein tension within canter strides	Stride phase related RT / Custom made, IMU, accelerometers on head and video analysis to assess head tilt and gait	R] Rider-determined flatwork schooling session: canter through circle, lateral work and during transitions within canter.

					Influence of rider position and horse experience on RT minima and maxima measured bilaterally.

Table 2. Overview of included study characteristics.

RT=rein tension; N=Newtons; HNP= Head and Neck Position [of the horse]; IMU=inertial measurement unit [IMU & SMA mini S-beam force gauge & Futek =rein tension devices]; R=ridden, NR=non-ridden, M= mixed interventions.

Device	Specification			Author (year)
	Maximum Load (N)	Other Factors Reported	Data sampling (Hz)	
Strain gauge transducers (Transducer Technologies, Temecula, CA)	2002	Weight: 85g	1000	Clayton (2005);
	-	N/A	-	Manfredi (2005);
	333	Weight: 21g	-	Heleski (2009);
	445	Weight: 21g	-	Manfredi (2010)
	333	Weight: 21g	240	Clayton (2011)
ReinCheck™ (Crafted Technology, Sydney, Australia)	50 or 100	Weight: 600g (data logger)	100	Warren-Smith (2007); Kuhnke (2010); Christensen (2011); Egenvall (2012); von Borstel (2014); Hawson (2014); Christensen (2014).
Custom made IMU (IMU, x-io Technologies Limited, UK)	500	Resolution: 0.11N	128	Eisersiö *et al.* (2015)
	500	Resolution 0.11N	128	Egenvall *et al.* (2015)
	500	Resolution 0.11N	128	Egenvall *et al.* (2016)
Futek (2357 JR S-Beam mini load cell force sensor,)	-	Weight: 28 g	140	Eisersiö *et al.* (2013)

SMA mini S-beam force gauges (Interface, Scottsdale, Arizona)	-	Calibrated to 60N (150% overload capacity)	200	Cross *et al.* (2016)

Table 3. Overview of rein tension devices used in the included review studies.

Study	Participant Characteristics	
	Equine	**Human**
Clayton *et al.* (2005)	n=1 no description	n=1 rider, experienced
Manfredi, Clayton & Rosenstein (2005)	n=8 (4-15yrs; 152-160cm; 450-586kg). 4 WB, 4 TB, basic DR training.	n=1 handler (no description)
Warren-Smith *et al.* (2007)	n=22 (13.1± 1.2 yrs.) 10 geldings, 4 stallions, 8 mares. Various breeds/experience	n=3 Advanced, intermediate & novice riders
Heleski et al. (2009)	n=4 (16.2± 2.1yrs) 3 geldings, 1 mare. Riding school horses.	n=9 females, novice riders (165.7± 6.2cm, 68.7± 11.3kg)
Manfredi *et al.* (2010)	n=6 (4–16 years; 152–161 cm; 475–523 kg) 1x Oldenburg, Trakehner, Andalusian, 3 TB. Novice level DR.	n=1 handler (no description)
Kuhnke *et al.* (2010)	n=2 Trakehner geldings. 19yrs, German DR level M, right lateralized. 14yrs German DR level L, left lateralized.	n=11 riders, 10 female, 1 male. 29± 15yrs 18.5±11.5yrs experience. All right handed. Trained A-M German DR level.
Christensen *et al.* (2011)	n=15 2yrs, mares Danish WB, naïve to bridles	NA*
Clayton *et al.* (2011)	n=8 (13.7 ± 2.9 yrs. 154 ± 9 cm; 484 ± 92 kg.)	n=1 handler (no description)
Egenvall (2012)	n=4 (3-4yrs), 2 geldings, 2 mares Swedish WB, 3-7 months ridden training	n=4 riders 1 advanced 1 intermediate, 2 novice. (167± 1.3cm; 63± 2kg),
Eisersiö *et al.* (2013)	n=7 (1.70± 0.07m), Warmbloods, competing at Grand-Prix/ Intermediare DR. n=3 used in RT results.	n=7 riders 3 males, 4 females (78± 17kg)
Von Borstel and Glibman (2014)	n=46 (n=33 mares, n=13 stallions. 3-4yrs). German Riding Horses	n=15 riders (no description)
Hawson *et al.* (2014)	NA*	n=12 riders 9 females, 2 males (36.8± 13.6 yrs.) 15.8± 10.1yrs riding experience. 10 right handed, 2 ambidextrous.
Christensen *et al.* (2014)	n=15 (5-18yrs) 7 mares, 7 geldings, 1 stallion Danish WB, Grand Prix DR level.	n=13, intermediate- Grand Prix DR
Eisersiö *et al.* (2015)	n=24 Advanced to basic DR training.	n=8 professional riders (173 ± 6 cm; 65.5 ± 10 kg)

Egenvall *et al.* (2015)	n=18 Advanced to basic DR training	n=6 professional riders (172 ± 8 cm; 68 ± 12 kg)
Cross *et al.* (2016)	No description	n=1 rider (no description)
Egenvall *et al.* (2016)	n=23 Advanced to young DR training. Direction of preferred bend reported.	n=8 professional riders, handedness, (173 ± 6 cm; 66 ± 10 kg)

Table 4 Overview of participant characteristics.

WB= Warmblood; TB=Thoroughbred; DR=dressage. Description of horse/rider/handler experience taken from study description. NA* not applicable for the study

Study	Title	Results: Primary/*Secondary*
Clayton *et al.* (2005)	Strain gauge measurement of RT during riding: a pilot study	Peak RT: walk 43N; trot 51N; canter 104N. *Biphasic spikes* in *RT per stride in walk + trot and one spike in canter.*
Manfredi, Clayton & Rosenstein (2005)	Radiographic study of bit position within the horse's oral cavity	RT causes bit position to move in the oral cavity. *Movement toward premolars, under RT: Myler bits < single jointed bits.*
Warren-Smith *et al.* (2007)	Rein contact between horse and handler during specific equitation movements	RT: long-reining 10.7 N > ridden movements 7.4N, P=0.025. *RT for halt response > other movements P<0.001*
Heleski et al. (2009)	Effects on behaviour and RT on horses ridden with or without martingales and rein inserts	Mean RT: plain reins and rein inserts 3.53± 0.53 N < martingales 4.10± 0.62N. Mean no. of CB exhibited per trial: martingale < plain rein < rein inserts. *Significant variation of CB between horses P<0.0001.*
Manfredi *et al.* (2010)	Fluoroscopic study of oral behaviours in response to the presence of a bit and the effects of RT	Significant effects for 'horse X tension' but not 'horse X bit.' *RT applied increased time spent mouthing the bit & retracting the tongue vs loose reins.*
Kuhnke *et al.* (2010)	A comparison of RT of the rider's dominant and non-dominant hand and the influence of the horse's laterality	Mean RT: walk 0.7kg < trot 1.1kg < canter 1.65kg and halt transitions 1.62kg. Significantly higher RT applied to left rein of left lateralized horse vs any rein of right lateralized horse. M*ore RT applied to outside rein when clockwise versus counter clockwise P<0.05.*
Christensen *et al.* (2011)	RT acceptance in young horses in a voluntary situation	Mean RT: first day 10.2N > second day 6.0N > third day 5.7 N. Significantly more CB with shorter reins. *Peak RT recorded ~40N on first day.*
Clayton *et al.* (2011)	Length and elasticity of side reins affect RT at trot	Min, max, mean RT greatest in short length of all rein types, P<0.05. *Elasticity of reins caused minimum RT to increase and maximum RT to decrease in neutral and short rein lengths.*
Egenvall (2012)	Pilot study of behaviour responses in young riding	Average transition time = (1) 5.5±1.1 secs; (2) 4.4±0.7 secs. Time spent over 30N: (1) 19± 16%; (2) 38± 23%. *Mean RT: (1) 13.5N < (2) 23N. 1 displayed fewer "pushing*

	horses using 2 methods of making trot to walk transitions	*against the bit" responses and higher frequency of decelerating behavior from the horse.*
Eisersiö *et al.* (2013)	Movements of the horse's mouth in relation to horse-rider kinematic variables	Peak RT: HNP1 mid stance phase; HNP2 emphasis in suspension phase, with increased lip movements and open mouth compared to stance phase. *HNP2: left rein tension significantly associated with increased frequency of lip and open mouth movements.*
Von Borstel and Glibman (2014)	Alternatives to Conventional Evaluation of Ride-ability in Horse Performance Tests: Suitability of RT and Behavioural Parameters	Ride-ability scores dropped with increasing mean, maximum and RT variability, P<0.05. Horse*rider effect (P<0.05) for mean and difference in RT indicate horse*rider pairing affects RT. *Mean RT differed between stations, P<0.0001.*
Hawson *et al.* (2014)	Riders' application of RT for walk-to-halt transitions on a model horse	Deceleration cue: right rein 6.24± 4.1N < left rein 8.58± 5.15N, P<0.001. Deceleration cue was 51% and 59% higher than resting RT for right and left reins, respectively, (P < 0.001). *Left rein deceleration cue ranged 3.14-28.92N, right rein ranged 2.27-16.17N*
Christensen *et al.* (2014)	Effects of hyperflexion on acute stress response in ridden dressage horses	RT significantly lower (P<0.001) in loose frame, with less CB versus competition frame and hyperflexion, which saw significantly higher cortisol levels.
Eisersiö *et al.* (2015)	RT in 8 professional riders during regular training sessions	RT: Walk 12N < Trot 14-19N< Canter 13-24N. Rider position (sitting or light seat) influences RT in trot & canter.
Egenvall *et al.* (2015)	Stride-related RT patterns in walk and trot in the ridden horse	RT peaked at hind limb stance in walk & suspension phase at trot. *Significant difference between diagonal mid-stance phases in rising trot, not in sitting trot.*
Cross *et al.* (2016)	Application of a Dual Force Sensor System to Characterise the Intrinsic Operation of Horse Bridles and Bits	Snaffle bit acts in a 'pulley system' creating modest poll pressure. *Curb chain diverts cheek piece tension to the chin rather than the poll.*
Egenvall *et al.* (2016)	Maximum and minimum peaks in rein tension within canter strides	RT: Canter minima 0 – 50 N, mean = 8.5 ± 8.3 N. maxima 1.5 – 284 N, mean = 56.1 ± 33 N. RT higher in seated canter than 2-point seat (P<0.0001). Right circle had lower values than left or no circle. Maximum and minimum RT

		increased as nose moved caudally relative to poll. Young horses had highest maximum and advanced horses had highest minimum RT. Horses and riders contributed to RT.

Table 5 Overview of study outcomes included in the review.

RT=rein tension; CB=conflict behavior; HNP=head and neck position [of the horse]


Rider behaviour & temperament
Rider symmetry
Rider experience: balance & training level
Rider handedness
Elbow-shoulder angle
Hand & wrist position
Consistency of rider contact
Rider's hand height
Riding position: seated, rising, 2 point seat
Wrist-elbow angle
Arm length
Horse's head & neck position
Gait: walk, trot, canter, gallop
Tack: bit type, bridle, martingale, length of reins, saddle, stirrup length
Horse symmetry
Horse experience: balance & training level
Gait: collected, free rein, medium, extended
Horse laterality
Horse behaviour & temperament
Speed
Phase of stride
Resistance
Environment
Impulsion
Movement being ridden