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.,
285 2009; Clayton et al., 2011; Cross et al., 2016) with the Butterworth filter being the
286 most commonly utilised.
287
288 Some studies reported the main findings as peak rein tensions i.e. the maximum
289 that was recorded (Clayton et al., 2005; Eisersiö et al., 2013; Egenvall et al.,
290 2015, 2016). In contrast, others based their conclusions on average rein tension
291 (Warren-Smith et al., 2007; Heleski et al., 2009; Kuhnke et al., 2010; Christensen
292 et al., 2011; Eisersiö et al., 2015).
293
294 Discussion
295
296 There was unanimous agreement across the reviewed studies that individual
297 horse and rider characteristics significantly influence rein tension. However,
298 authors suggested different influencing characteristics including the horse, the
299 rider or equipment, or a combination of the three factors; consequently, no
300 specific aetiology to explain variation in rein tension has been proposed to date
301 (Figure 2). Nevertheless, the general consensus reported that rein tension
302 increased with the gait of the horse, increasing from 6.9 - 43 N in walk to 10.8 -
303 51 N in trot and 1.5 - 104 N in canter (Clayton et al., 2005; Kuhnke et al., 2010;
304 Eisersiö et al., 2015; Egenvall et al., 2016).
305
306 In addition to changes in gait, increased tensions could be related to training
307 practices where horses are taught to yield at higher pressures (McLean and
308 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.
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
collection 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


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


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.


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

Initial Search Results (154)

- Rejection due to language barriers (12)
- Non-related results rejected = 115 (19 equine reviews; 72 unrelated equine studies; 18 non-equine studies and 6 books)

Results to review (142)

- Abstract only papers rejected (5)

Peer reviewed primary research on Rein Tension (22)

End result: 17 peer reviewed, full primary research articles for the systematic review
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.
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<thead>
<tr>
<th>Description</th>
<th>Justification</th>
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<tr>
<td><strong>Participant</strong></td>
<td>Equine; any breed, age, height, sex, discipline, experience.</td>
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<td>Human; all riders, all experience levels.</td>
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<td><strong>Intervention</strong></td>
<td>Rein tension; ridden and non-ridden trials</td>
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<tr>
<td><strong>Outcome</strong></td>
<td>Corresponds to reports of all recorded rein tension measurements collected via quantitative data collection. Qualitative reports from riders or observers within studies also included.</td>
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<tr>
<td><strong>Study design</strong></td>
<td>Primary research; experimental studies with quantitative data collection. Peer-reviewed. Full papers (post 2001).</td>
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Table 1. Inclusion criteria adapted from PICO(S) Cochrane Handbook (Higgins and Green, 2011)
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<td></td>
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<td>3</td>
<td>Warren-Smith et al. (2007)</td>
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<td>Heleski et al. (2009)</td>
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<tr>
<td>8</td>
<td>Clayton et al. (2011)</td>
</tr>
<tr>
<td>Page</td>
<td>Study/Method</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>12</td>
<td>Hawson et al. (2014)</td>
</tr>
<tr>
<td>13</td>
<td>Christensen et al. (2014)</td>
</tr>
<tr>
<td>17</td>
<td>Egenvall et al. (2016)</td>
</tr>
</tbody>
</table>
Table 2. Overview of included study characteristics.

<table>
<thead>
<tr>
<th>RT</th>
<th>N</th>
<th>HNP</th>
<th>IMU</th>
<th>R</th>
<th>NR</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>rein tension</td>
<td>Newtons</td>
<td>Head and Neck Position [of the horse]</td>
<td>inertial measurement unit [IMU &amp; SMA mini S-beam force gauge &amp; Futek = rein tension devices]</td>
<td>ridden</td>
<td>non-ridden</td>
<td>mixed interventions</td>
</tr>
</tbody>
</table>

Influence of rider position and horse experience on RT minima and maxima measured bilaterally.
<table>
<thead>
<tr>
<th>Device</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Maximum Load (N)</strong></td>
</tr>
<tr>
<td>Strain gauge transducers (Transducer Technologies, Temecula, CA)</td>
<td>2002</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>333</td>
</tr>
<tr>
<td></td>
<td>445</td>
</tr>
<tr>
<td></td>
<td>333</td>
</tr>
<tr>
<td>ReinCheck™ (Crafted Technology, Sydney, Australia)</td>
<td>50 or 100</td>
</tr>
<tr>
<td>Custom made IMU (IMU, x-io Technologies Limited, UK)</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>500</td>
</tr>
<tr>
<td>Futek (2357 JR S-Beam mini load cell force sensor,)</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 3. Overview of rein tension devices used in the included review studies.

<p>| SMA mini S-beam force gauges (Interface, Scottsdale, Arizona) | - | Calibrated to 60N (150% overload capacity) | 200 | Cross et al. (2016) |</p>
<table>
<thead>
<tr>
<th>Study</th>
<th>Participant Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayton et al. (2005)</td>
<td>Equine: (n=1) no description</td>
</tr>
<tr>
<td>Manfredi, Clayton &amp; Rosenstein (2005)</td>
<td>Equine: (n=8) (4-15yrs; 152-160cm; 450-586kg). 4 WB, 4 TB, basic DR training.</td>
</tr>
<tr>
<td>Warren-Smith et al. (2007)</td>
<td>Equine: (n=22) (13.1± 1.2 yrs.) 10 geldings, 4 stallions, 8 mares. Various breeds/experience</td>
</tr>
<tr>
<td>Heleski et al. (2009)</td>
<td>Equine: (n=4) (16.2± 2.1yrs) 3 geldings, 1 mare. Riding school horses.</td>
</tr>
<tr>
<td>Manfredi et al. (2010)</td>
<td>Equine: (n=6) (4–16 years; 152–161 cm; 475–523 kg) 1x Oldenburg, Trakehner, Andalusian, 3 TB. Novice level DR.</td>
</tr>
<tr>
<td>Kuhnke et al. (2010)</td>
<td>Equine: (n=2) Trakehner geldings. 19yrs, German DR level M, right lateraled. 14yrs German DR level L, left lateraled.</td>
</tr>
<tr>
<td>Christensen et al. (2011)</td>
<td>Equine: (n=15) 2yrs, mares Danish WB, naive to bridles</td>
</tr>
<tr>
<td>Clayton et al. (2011)</td>
<td>Equine: (n=8) (13.7 ± 2.9 yrs. 154 ± 9 cm; 484 ± 92 kg.)</td>
</tr>
<tr>
<td>Egnenvall (2012)</td>
<td>Equine: (n=4) (3-4yrs), 2 geldings, 2 mares Swedish WB, 3-7 months ridden training</td>
</tr>
<tr>
<td>Eisersiö et al. (2013)</td>
<td>Equine: (n=7) (1.70± 0.07m), Warmbloods, competing at Grand-Prix/ Intermediare DR. (n=3) used in RT results.</td>
</tr>
<tr>
<td>Von Borstel and Glibman (2014)</td>
<td>Equine: (n=46) (n=33 mares, n=13 stallions. 3-4yrs). German Riding Horses</td>
</tr>
<tr>
<td>Hawson et al. (2014)</td>
<td>Equine: NA*</td>
</tr>
<tr>
<td>Christensen et al. (2014)</td>
<td>Equine: (n=15) (5-18yrs) 7 mares, 7 geldings, 1 stallion Danish WB, Grand Prix DR level.</td>
</tr>
<tr>
<td>Eisersiö et al. (2015)</td>
<td>Equine: (n=24) Advanced to basic DR training.</td>
</tr>
<tr>
<td>Study</td>
<td>Participant Characteristics</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Egenvall et al. (2015)</td>
<td>n=18 Advanced to basic DR training</td>
</tr>
<tr>
<td></td>
<td>n=6 professional riders</td>
</tr>
<tr>
<td></td>
<td>(172 ± 8 cm; 68 ± 12 kg)</td>
</tr>
<tr>
<td>Cross et al. (2016)</td>
<td>No description</td>
</tr>
<tr>
<td></td>
<td>n=1 rider (no description)</td>
</tr>
<tr>
<td>Egenvall et al. (2016)</td>
<td>n=23 Advanced to young DR training. Direction of preferred bend reported.</td>
</tr>
<tr>
<td></td>
<td>n=8 professional riders, handedness,</td>
</tr>
<tr>
<td></td>
<td>(173 ± 6 cm; 66 ± 10 kg)</td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th>Study</th>
<th>Title</th>
<th>Results: Primary/Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayton et al. (2005)</td>
<td>Strain gauge measurement of RT during riding: a pilot study</td>
<td>Peak RT: walk 43N; trot 51N; canter 104N. <em>Biphasic spikes in RT per stride in walk + trot and one spike in canter.</em></td>
</tr>
<tr>
<td>Warren-Smith et al. (2007)</td>
<td>Rein contact between horse and handler during specific equitation movements</td>
<td>RT: long-reining 10.7 N &gt; ridden movements 7.4N. <em>P=0.025. RT for halt response &gt; other movements P&lt;0.001</em></td>
</tr>
<tr>
<td>Heleski et al. (2009)</td>
<td>Effects on behaviour and RT on horses ridden with or without martingales and rein inserts</td>
<td>Mean RT: plain reins and rein inserts 3.53± 0.53 N &lt; martingales 4.10± 0.62N. Mean no. of CB exhibited per trial: martingale &lt; plain rein &lt; rein inserts. <em>Significant variation of CB between horses P&lt;0.0001.</em></td>
</tr>
<tr>
<td>Manfredi et al. (2010)</td>
<td>Fluoroscopic study of oral behaviours in response to the presence of a bit and the effects of RT</td>
<td>Significant effects for ‘horse X tension’ but not ‘horse X bit.’ <em>RT applied increased time spent mouthing the bit &amp; retracting the tongue vs loose reins.</em></td>
</tr>
<tr>
<td>Kuhnke et al. (2010)</td>
<td>A comparison of RT of the rider’s dominant and non-dominant hand and the influence of the horse’s laterality</td>
<td>Mean RT: walk 0.7kg &lt; trot 1.1kg &lt; 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. <em>More RT applied to outside rein when clockwise versus counter clockwise P&lt;0.05.</em></td>
</tr>
<tr>
<td>Christensen et al. (2011)</td>
<td>RT acceptance in young horses in a voluntary situation</td>
<td>Mean RT: first day 10.2N &gt; second day 6.0N &gt; third day 5.7 N. Significantly more CB with shorter reins. <em>Peak RT recorded ~40N on first day.</em></td>
</tr>
<tr>
<td>Clayton et al. (2011)</td>
<td>Length and elasticity of side reins affect RT at trot</td>
<td>Min, max, mean RT greatest in short length of all rein types, P&lt;0.05. <em>Elasticity of reins caused minimum RT to increase and maximum RT to decrease in neutral and short rein lengths.</em></td>
</tr>
</tbody>
</table>
| 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*
<table>
<thead>
<tr>
<th>Study</th>
<th>Methodology</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eisersio et al. (2013)</td>
<td>Horses using 2 methods of making trot to walk transitions</td>
<td>Against the bit responses and higher frequency of decelerating behavior from the horse.</td>
</tr>
<tr>
<td>Von Borstel and Glibman</td>
<td>Movements of the horse's mouth in relation to horse-rider kinematic variables</td>
<td>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.</td>
</tr>
<tr>
<td>Hawson et al. (2014)</td>
<td>Alternatives to Conventional Evaluation of Ride-ability in Horse Performance Tests: Suitability of RT and Behavioural Parameters</td>
<td>Ride-ability scores dropped with increasing mean, maximum and RT variability, P&lt;0.05. Horse<em>rider effect (P&lt;0.05) for mean and difference in RT indicate horse</em>rider pairing affects RT. Mean RT differed between stations, P&lt;0.0001.</td>
</tr>
<tr>
<td>Christensen et al. (2014)</td>
<td>Riders' application of RT for walk-to-halt transitions on a model horse</td>
<td>Deceleration cue: right rein 6.24±4.1N &lt; left rein 8.58±5.15N, P&lt;0.001. Deceleration cue was 51% and 59% higher than resting RT for right and left reins, respectively, (P &lt; 0.001). Left rein deceleration cue ranged 3.14-28.92N, right rein ranged 2.27-16.17N.</td>
</tr>
<tr>
<td>Egenvall et al. (2015)</td>
<td>Effects of hyperflexion on acute stress response in ridden dressage horses</td>
<td>RT significantly lower (P&lt;0.001) in loose frame, with less CB versus competition frame and hyperflexion, which saw significantly higher cortisol levels.</td>
</tr>
<tr>
<td>Egenvall et al. (2015)</td>
<td>Stride-related RT patterns in walk and trot in the ridden horse</td>
<td>RT peaked at hind limb stance in walk &amp; suspension phase at trot. Significant difference between diagonal mid-stance phases in rising trot, not in sitting trot.</td>
</tr>
<tr>
<td>Cross et al. (2016)</td>
<td>Application of a Dual Force Sensor System to Characterise the Intrinsic Operation of Horse Bridles and Bits</td>
<td>Snaffle bit acts in a 'pulley system' creating modest poll pressure. Curb chain diverts cheek piece tension to the chin rather than the poll.</td>
</tr>
<tr>
<td>Egenvall et al. (2016)</td>
<td>Maximum and minimum peaks in rein tension within canter strides</td>
<td>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&lt;0.0001). Right circle had lower values than left or no circle. Maximum and minimum RT</td>
</tr>
</tbody>
</table>
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]