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A systematic literature review to evaluate the tools and methods used to measure rein tension

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A B S T R A C T

The use of pressure via a bit in the horse's mouth is part of training methods throughout equine disciplines. Rein tension refers to the force exerted on the reins between the horse and human during ridden and in-hand training. Understanding the effects of these forces has the potential to inform both rider performance and equine welfare research. The methodological protocols of current rein tension research appear inconsistent, and to date, a review on rein tension has not been published. This study uses a systematic literature review to evaluate the tools and methods used to measure rein tension within current literature to establish whether their findings were reliable. The review also suggests improvements to study protocols, where appropriate, to enable the standardized measurement of rein tension. A search protocol was developed and inclusion criteria defined with the aid of independent subject specialists, including 2 published equestrian authors, an equine industry professional and a librarian. Inclusion criteria determined that only full peer-reviewed articles available via Google Scholar and published in the previous 15 years were included in the review. Articles also had to include the following key words: rein tension AND "horse/s" OR "rider/s" OR "equine/s" OR "equestrian." The literature search returned 154 initial results, and the inclusion criteria rejected 137 results. Seventeen primary research articles (after 2002) from peer-reviewed journals were subsequently reviewed. The articles reviewed found rein tension to be influenced by the horse, the rider, and the training equipment used. Rein tension studies have multivariable foci and methodological limitations and frequently report their methods and results inconsistently. Future rein tension research should aim to improve the consistency of reporting horse-related, rider-related, and performance-related factors that may affect rein tension, as well as reporting data handling and analysis approaches to increase comparability between studies.

Introduction

The modern horse is predominantly regarded as a companion or sporting animal in Western Europe, where high-profile equestrian events account for at least half of the top 10 paid attendance sporting events in the UK in 2016 and 2017 (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 where both members are athletes, it is important to counteract long-held perceptions of equestrianism epitomizing 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 that minimize risks to human and equine athletes and maximize efforts to ensure equine welfare is a top

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priority in sporting and training environments (FEI, 2017a). Central to achieving safe interaction and harmony between horses and humans is understanding how the 2 species can communicate. As well as having socioeconomic 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 absence, researchers are increasingly trying to use perceived objective measures of the horse-human interaction to assess how the horse and rider can perform together rather than focusing on the horse and rider separately (Clayton and Hobbs, 2017; Randle and Waran, 2017). As the only Olympic sport where 2 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/well-being (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 toward 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 standardized 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 newton (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 have evolved 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 can result secondarily from negative reinforcement involving the removal of an aversive stimulus such as pressure (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 among 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/stress 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 commercialized 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 standardized 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 used for this systematic literature review was determined by a panel including 2 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 center the research aims (Dundar and Fleeman, 2014). The panel defined the search method including key words, 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 Type guidelines (Higgins and Green, 2011). The decision to include literature over a 15-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 15-year period also aligned with these noteworthy dates.

The purpose of the current systematic review was to analyze 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, or methods of quantitative data collection were implemented (Maber-Aleksandrowicz et al., 2016). A comprehensive evaluation of full articles was deemed necessary by the panel of subject specialists to meet

Table 1
Inclusion criteria adapted from Participants, Interventions, Comparisons, Outcomes, and Study Type (PICOS) Cochrane Handbook (Higgins and Green, 2011)

Criteria	Description	Justification
Participant	Equine: any breed, age, height, sex, discipline, experience. Human: all riders, all experience levels.	Expert panel and adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)
Intervention	Rein tension: ridden and nonridden 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 and adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)
Study design	Primary research; experimental studies with quantitative data collection. Peer-reviewed and full articles (after 2001).	Adapted from the PICOS used in Maber-Aleksandrowicz et al. (2016)

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 articles 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 articles were included within this review to ensure that the content was not misreported due to inaccurate translation. While 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 articles. When a language inclusion criterion is applied, it is considered best practice to report how many potential articles were excluded for language reasons, and this approach was adopted within the present 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 using 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 key words across full articles on “Google Scholar” returned 154 initial search results. Of those, 154 results and 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), nonequine studies (18), equine reviews (19), and books (6). Furthermore, 5 studies were rejected at this point because abstracts were published without access to the full study. Figure 1 illustrates the study selection process by a flow diagram. As a result of the selection process, 17 primary research articles (after 2001) were selected for review.

Study characteristics

The study characteristics in the 17 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 4 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 4 horses; however, in this study, behavioral observations were related to rider influences (2 methods of trot-walk transitions) rather than the horse's behavior associated with use of riding equipment as in Heleski et al. (2009).

Studies used 3 main genres of rein tension intervention: (1) ridden, (2) nonridden, 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. Subthemes 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 11 studies focused on ridden rein tension, 4 on nonridden rein tension, and 2 better suited a mixed category including both ridden and nonridden measures.

Rein tension was investigated as a secondary measure to the primary focus in 24% of reviewed studies. This resulted in

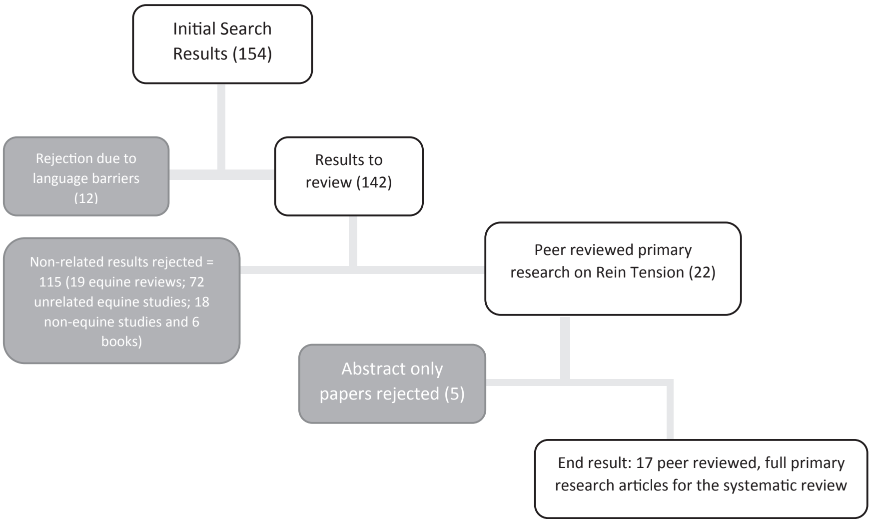

Figure 1. Flow diagram of the study selection process for key words “rein tension” AND “horse/s” OR “rider/s” OR “equine/s” OR “equestrian,” in Google Scholar (>2001) = 154.

Table 2
Overview of included study characteristics

	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 and 3 Mylers/strain gauge transducer	[NR] Reins attached to handler via roller, 25± 5N bilaterally.
3	Warren-Smith et al. (2007)	Rein contact between the horse and handler during specific equitation movements	Long reining and 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 nondominant hand and the influence of the horse's laterality	Rider handedness and horse laterality/ReinCheck	[R] Three circles of walk, sitting trot, canter, 4 halt transitions, RT recorded bilaterally; left and 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. Horses encouraged to stretch forward 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 horses using 2 methods of making trot-to-walk transitions	Trot-to-walk transition method/ReinCheck	[R] 1: RT relief at first attempt to perform correct response (walking). 2: RT relief at completed response.
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 a treadmill.
11	Von Borstel and Glibman (2014)	Alternatives to conventional evaluation of rideability in horse performance tests: Suitability of RT and behavioral parameters	Behavior and RT versus 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 155-cm live horse.
13	Christensen et al. (2014)	Effects of hyperflexion on acute stress response in ridden dressage horses	Stress response, RT and HNP: (1) Competition frame, (2) long deep round/hyperflexion, (3) loose frame/ReinCheck	[R] Standardized 10-minute DR plan in 3 HNP. Heart rate, heart rate variability, behavior, salivary cortisol, and 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 characterize 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 and cheekpiece 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.

RT, rein tension; N, newton; HNP, head and neck position [of the horse]; IMU, inertial measurement unit [IMU and SMA mini S-beam force gauge and Futek, rein tension devices]; R, ridden; NR, nonridden; M, mixed interventions.

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 used across the studies in this review (Table 3). All 17 studies named which device they used, although variations included "strain gauge transducers," "ReinCheck," "custom-made Inertial Measurement Units," "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 Inertial Measurement Units 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

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

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. (2015)
Futek (2357 JR S-Beam mini load cell force sensor,)	-	Weight: 28 g	140	Egenvall et al. (2015)
SMA mini S-beam force gauges (Interface, Scottsdale, Arizona)	-	Calibrated to 60N (150% overload capacity)	200	Egenvall et al. (2015)

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 2 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).

Most 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 that measured tension exerted on the reins and the cheekpiece 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). Most studies (94%) included some details of participant characteristics, except Cross et al. (2016), who reasoned participant information was not required in the study. Most (87%) reviewed studies used both equine and human participants, and the remaining 2 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 17 studies, a mean (±standard deviation) of 12 (±12.0) (Table 4). Within individual studies, the sample size used 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 was 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 years), 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 most studies (76%). Most 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 were 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 17 studies, encompassing 98 riders and 3 handlers, a mean (± standard deviation) of 16 (±4.9) (Table 4). Individual study populations of human participants were smaller than equine study populations ranging from 1 to 15 participants. Twenty nine percent of studies involved a single participant, 41% of studies included 3-9 participants, and 30% had greater than 10 participants. Human demographics were stated in most 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, the 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 12 of the 17 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 newton. Although Kuhnke et al. (2010) reported rein tension in kilogram force (kgF), these data can be converted using a simple equation (formula: XX kg $\times$ 9.81 = N) to enable comparisons to be made. Rein tension data processing was only reported in 4 articles (Clayton et al., 2005; Heleski et al., 2009; Clayton et al., 2011; Cross et al., 2016) with the Butterworth filter being the most commonly used.

Some studies reported the main findings as peak rein tensions, that is, the maximum that was recorded (Clayton et al., 2005;

Table 4
Overview of participant characteristics

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

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

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 3 factors; consequently, no specific etiology 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 or desensitization (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 6 different bits, representing bits considered by industry to have a mild through to severe action (McGreevy et al., 2005; Randle and Wright, 2013). Interestingly, the 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 or responses commonly exhibited when experiencing difficulty in coping with mental or physical discomfort. 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 versus 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 nonridden) 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

Table 5
Overview of study outcomes included in the review

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 1 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 behavior 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 behaviors 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 and retracting the tongue versus loose reins.*
Kuhnke et al. (2010)	A comparison of RT of the rider's dominant and nondominant hand and the influence of the horse's laterality	Mean RT: walk 0.7 kg < trot 1.1 kg < canter 1.65 kg and halt transitions 1.62 kg. Significantly higher RT applied to left rein of left lateralized horse versus any rein of right lateralized horse. *More 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 the 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 behavior responses in young riding horses using 2 methods of making trot-to-walk transitions	Average transition time = (1) 5.5 ± 1.1 seconds; (2) 4.4 ± 0.7 seconds. Time spent over 30N: (1) 19 ± 16%; (2) 38 ± 23%. *Mean RT: (1) 13.5N < (2) 23N. 1 displayed fewer "pushing 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 midstance 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 rideability in horse performance tests: Suitability of RT and behavioral parameters	Rideability scores dropped with increasing mean, maximum, and RT variability, $P < 0.05$. Horse*rider effect ($P < 0.05$) for mean and difference in RT indicates 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 lowers ($P < 0.001$) 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 and 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 and suspension phase at trot. *Significant difference between diagonal midstance phases in rising trot not in sitting trot.*
Cross et al. (2016)	Application of a dual force sensor system to characterize the intrinsic operation of horse bridles and bits	Snaffle bit acts in a "pulley system" creating modest poll pressure. *Curb chain diverts cheekpiece 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.

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

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, most ridden studies in the review failed to include specific details on the 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 has 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

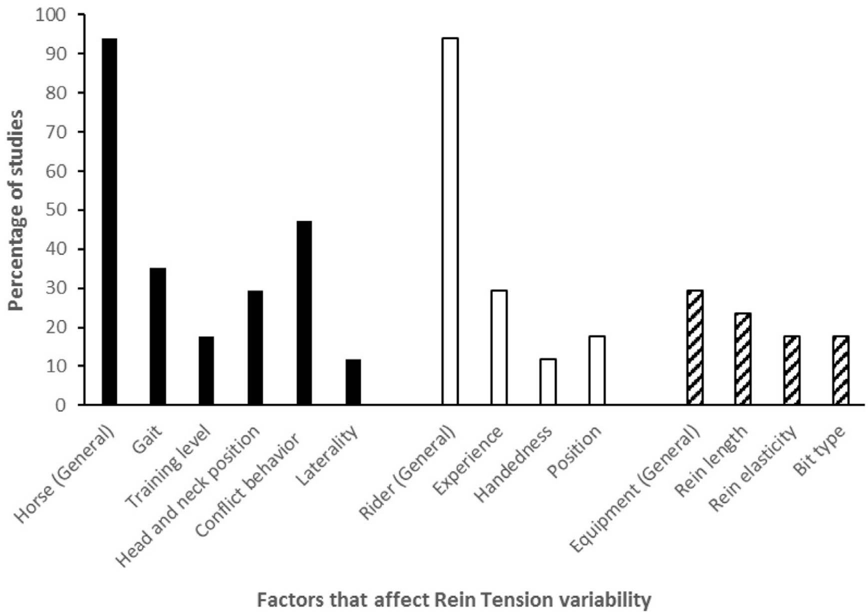

Figure 2. Incidence of factors that are associated with rein tension variability reported by the 17 reviewed studies.

tension, future research should include description of the 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 synchronization 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 minimize 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 4 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 maneuvres and transitions with the nondominant 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 most 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 most of the human population (Faurie et al., 2012). Equine sidedness is the equivalent of human handedness, and as rein tension is derived from both horses and humans, a study investigating the interaction between human handedness and equine sidedness would increase understanding of rein tension. These 2 factors should be consistently reported in rein tension studies.

Given rein tension derived 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 3 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 generalized 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. While a detailed discussion of experimental design is outside the scope of this article, Randle et al. (2017) provide 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, that is, the cause of rein tension, but aim to define the case, that is, 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 focusing on the horse's experience, it would be better to measure the pressure experienced by the horse. Pressure is the force acting on a defined area; therefore, the size of the area that the pressure acts on will influence the magnitude and

Figure 3. Factors that can affect rein tension in the ridden horse. White text: horse-related factors; green text: performance-related factors; yellow text: rider-related factors. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

effect observed. Future rein tension studies should consider this within their design and report rein tension as a force in newton, or ideally a pressure in Nm^{-2}. Future research could use 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 standardization, 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), while 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 that 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 because they can easily be distorted by outliers (Tong, 2014).To improve comparability between present and future studies, the approach used by Clayton et al. (2011) is advocated across a minimum of 10-15 strides with due consideration of gait phasing (ideally by conducting digitally synchronized kinematic analysis). This approach measures the entirety of the force patterns that 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 individualized 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-subject research framework and consider relative differences in rein tension rather than strive to identify baseline measures across horses that 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 that find statistically “significant” results compared to nonsignificant findings (O'Connor and Sargaent, 2015).

Within equestrian research, small study samples are common due to the difficulty of accessing horses and riders that are managed under the same conditions (Pierard et al., 2015). The samples in the reviewed studies followed this pattern and as such risk overestimating 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 horses and humans (whether as a 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 refocus 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 and 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.

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