Journal of Veterinary Behavior 10 (2015) 419–426

Contents lists available at ScienceDirect

Journal of Veterinary Behavior

journal homepage: www.journalvetbehavior.com

Research

Rein tension in 8 professional riders during regular training sessions

Marie Eisersiö [a], Marie Rhodin [a], Lars Roepstorff [b], Agneta Egenvall [a,*]

[a] Department of Clinical Sciences, Faculty of Veterinary Medicine and Animal Husbandry, Swedish University of Agricultural Sciences, Uppsala, Sweden
[b] Department of Anatomy, Physiology and Biochemistry, Faculty of Veterinary Medicine and Animal Husbandry, Swedish University of Agricultural Sciences, Uppsala, Sweden

ARTICLE INFO

Article history:
Received 5 January 2015
Received in revised form
12 April 2015
Accepted 21 May 2015
Available online 17 July 2015

Keywords:
rein tension
dressage
gaits
equine welfare

ABSTRACT

Rein tension signals are commonly used to communicate the intended speed, direction, and head carriage to the horse during horseback riding. Rein tension has previously been recorded relative to gait, exercises, and turning maneuvers. The aim of this study was to target the between-gait and between-exercise variation in rein tension, controlling for riders and horses within riders, the between-rein variation, and the general within-gait or exercise variation, during entire riding sessions. Eight riders with 3 horses each were included in the study and each horse was fitted with a custom-made rein tension meter fastened on leather reins. Rein tension data and video films were collected during the riding session, and the video films were scrutinized and categorized according to ridden exercises. Statistics used to model rein tension in mixed models were "median", area under curve, averages of 2 and 25 percentiles ("low") and of 75 and 98 percentiles ("high"), and the difference between 98 and 2 percentiles ("range"). Fixed effects were rein, gait, rider's position, horse level, and type of ridden exercise, and random effects were horse-side, rider, horse, and trial within horse. The analyses demonstrate substantial variation between gaits, rider position within gait, and between riders and horses. Considering data on short reins, the major determinants found for amount of rein tension was gait (walk [median 12 N both reins] <trot [median 14-19 N left/right rein and sitting/posting] <canter [median 13-24 N left/right rein and sitting/light seat]) as well as the rider's position in the saddle for trot (posting [median 14 N both reins] <sitting [median 17 N/19 N left/right rein]) and canter (light seat [median 13-17 N left/right rein and left/right canter] <sitting [median 20-24 N left/right rein and left/right canter]). Regarding the 2 reins; the right rein was the highest in comparisons in the "high" and "range" models, whereas the inside rein was the highest in canter. Riders contributed to most of the variation in the "median" and "low" models, whereas horses contributed the highest relative variance estimates in the models associated with high rein tension ("high" and "range"). Our results suggest that variables to consider in rein tension studies are the gait of travel, the rider's position in the saddle, the ridden exercise performed, the educational level of horse, the rider and horse per se, and to some extent the left or right rein.

Introduction

The bit in the horse's mouth, connected to the reins in the rider's hand, is generally used to condition the horse to respond to pressure signals, that is, negative reinforcement; pressure and release of the bit against the tissues in the horse's mouth. Applying rein tension signals is commonly the means used for communicating speed, direction, and head carriage to the horse during horseback riding (Manfredi et al., 2010). Rein tension displays a constant variation of magnitude during horseback riding, partly as a results of the rider's cues, but also along with the horse's stride cycle (Clayton et al., 2003; 2011; Eisersiö et al., 2013), and depending on the horse's reaction to bit pressure (Clayton et al., 2011; Egenvall et al., 2012). Furthermore, the magnitude of rein tension has been found to be connected to gait (Clayton et al., 2005; Kuhnke et al., 2010) and the skill level of the rider (Warren-Smith et al., 2007). Earlier rein tension studies of horseback riding have recorded different gaits, exercises, and turning maneuvers (Clayton et al.,

* Address for reprint requests and correspondence: Agneta Egenvall, Department of Clinical Sciences, Faculty of Veterinary Medicine and Animal Husbandry, Swedish University of Agricultural Sciences, Box 7054, SE-750 07, Uppsala, Sweden, Tel: +46 70 3799544; Fax: 046-18-671201.

E-mail address: agneta.egenvall@slu.se (A. Egenvall).

http://dx.doi.org/10.1016/j.jveb.2015.05.004
1558-7878/

2003; Warren-Smith et al., 2007; Heleski et al., 2009; Egenvall et al., 2012; Egenvall et al., 2015), and the mean rein tension for walk, trot, and canter ranged from 7-43 N at the walk, 11-51 N at the trot, and 16-104 N for the canter (Clayton et al., 2005; Kuhnke et al., 2010).

The Fédération Equestre Internationale (FEI) states that one of the objectives of dressage is for the horse to accept the bit without any tension or resistance (Fédération Equestre Internationale, 2014), and rein tension have been studied as a variable to determine rideability (von Borstel and Glißman, 2014). The use of tension via the rein for controlling the horse raises some welfare concerns as it is likely that the pressure from the bit becomes uncomfortable for the horse at some point (Christensen et al., 2011). In Ludewig et al., (2013) shortening the reins by 10 cm resulted in an increase of rein tension of 10 N and the results suggested that horses comply with shorter reins, that is, more rein tension, by adapting their head position, step length and by putting more pressure on the bit, yet at the same time these horses' behavioral expressions (open mouth, flattened ears) indicated that this posture or the increase of rein tension was perceived as aversive. Furthermore, in Christensen et al., (2011) it was found that naive horses learn to avoid rein tension rather than habituate to it when encouraged to stretch for a food reward. In addition, pressure from the bit in the horse's mouth is associated with lesions in the horse's oral cavity (Tell et al., 2008) and conflict behavior (Egenvall et al., 2012). Magnitude and loading rate of rein tension are factors that largely contribute to intra-oral lesions (Clayton et al., 2011), yet there is still lacking information about these relationships.

Measured rein tension is a complex signal, where a number of components contribute to the resulting shape of the curve. Basically we expect between-horse, between-rider (von Borstel and Glißman, 2014), between-gait (Warren-Smith et al., 2007), between-exercise, between-rein, between-stride variation, between-session, within-stride (Clayton et al., 2003; 2011; Eisersiö et al., 2013), within-session variation, and variation related to specific signaling to the horse (Egenvall et al., 2012) or more extraneous circumstances. Some of these sources of variation will be difficult to discern from each other. However, we should strive to quantify and characterize the variation at each level.

The aim of this study was to target the between-gait and between-exercise variation controlling for riders and horses within riders, the between-rein variation, and the general within-gait or exercise variation, by illustrating the distribution for rein tension during entire and regular riding sessions performed by professional riders on familiar horses. Having identified, for example, gaits, rider positions, and ridden exercises in 8 riders riding 3 horses each (Eisersiö et al., 2015), measuring rein tension simultaneously, we wanted to relate these variables to the rein tension.

Material and methods

Riders and horses

Data were collected from 8 professional riders (mean ± standard deviation height 173 ± 6 cm and weight 65.5 ± 10 kg) riding 3 horses each (n = 24). The horses were either in training or owned by the rider and had regularly been trained by the riders between 1 month and 22 years, median 24 months before start of the study. All horses wore their own saddle and bridle with a snaffle bit. Further information on the horses and riders can be found in Eisersiö et al. (2015). The riders all worked in the horse industry as riding instructors (with the exception of 1, who was only 14 years old but was training horses in a professional enterprise) or horse trainers on various levels. Two riders competed at advanced level (as classified in the national Swedish system), 5 at intermediate level, and 2 at basic level. One rider was left-handed and the others were right-handed. Based on rider statement, 7 horses were easier to bend to the left, 15 horses were easier to bend right, 1 horse was equally easy to bend left and right, and 1 horse was easier to bend right at the trot and to the left at the canter. The educational level of the horse was stated by the riders as follows: basic (n = 6), young horse (n = 3), medium (n = 5), and advanced (n = 4). Advanced horses had competed at Prix St. George, Intermediaire or Grand Prix level; basic horses had entered low-level competitions only; and medium horses were in between. Young horses had been ridden for less than a year and had not competed.

Equipment

Data collection took place at each horse's current stable in an indoor (n = 4 riders) or outdoor (n = 4 riders) riding arena, depending on the weather conditions. Each horse was fitted with a custom-made rein tension meter (128 Hz), measuring range 0-500 N, resolution 0.11 N, fastened on leather reins. A cable from each tension meter ran forward along each rein and up along the side piece of the bridle, behind the horse's ear and to an Inertial Measurement Unit (IMU, x-io Technologies Limited, UK) attached right below the browband of the bridle using a custom made Velcro browband (Figure 1). The rein tension meter was calibrated before the riding sessions started for each rider by suspending 13 known weights between 0-20 kg from each meter. The rein tension meter was also successfully tested in a tensile test machine for stability and repeatability of results (data not shown). Further details on the rein tension meter can be found in Eisersiö (2013). All equipment was fitted on the horse in the riding arena, and each fitting took approximately 10 minutes including synchronization (see the following). Video recordings (Canon Legria HF200, 25 Hz; Canon Svenska AB, Solna, Sweden) were made of the entire riding session from the middle of one of the long sides of the arena. All horses were free from lameness based on visual assessment of the videos by a veterinarian.

Study design

The riders were asked to demonstrate their normal routine with each horse for flatwork or dressage and to ride in all gaits (walk, trot, and canter). The whole riding arena was used for the exercises, and the length of the riding session was determined by the rider.

Figure 1. The rein tension meter used in the study.

Synchronization of equipment

After the rider had mounted, and before dismounting in the end, the rein tension meter was synchronized with the video recordings by manual applied tension to the right tension meter 5 times twice in a row while counting out loud in front of the camera.

Data management

One investigator (M.E.) scrutinized the videos and categorized the data. Further information on this protocol can be found in Eisersiö et al. (2015). In short, the categories used in this study were gait (walk, trot, left lead canter, right lead canter), rider's position (sitting, light seat, posting), corners and turns (corner left/right, turn left/right), lateral movements (half-pass to the left/right, shoulder-in left/right, leg-yield left/right), or riding in collection or lengthening (trot, canter). The accuracy of the evaluator-determined video protocols (mainly gait) was examined by comparing protocols to head acceleration data and main categorizations were thus validated by a second researcher (A.E.) during the data management process. Rein tension data were downloaded to a personal computer and processed in MATLAB (MathWorks Inc., MA).

Statistics

Descriptive left or right rein tension statistics have been produced for the calibrated data by gait, exercises within gait, exercises within rider and within horse, making description using mean values of statistics (means, STDs, min, max, medians, 2 and 98% percentiles) based on horse-specific data. For the outcome statistics selected for modeling descriptive statistics have been done by rider position within gait and rein. The outcome in the multivariable modeling was rein tension in the left and right rein, each observation was a statistic based on various activity combinations in each horse. Outcome statistics used to model rein tension was median, area under curve ("auc"), averages of 2 and 25 percentiles and of 75 and 98 percentiles, "low" and "high," respectively, and the difference between 98 and 2 percentiles "range". The median statistic was selected as a measure of average tension. "Low" was selected to represent the lower basic tension and "high" to represent the higher pressure when the riders did the more definite signaling or horses experienced the higher tension values. "Range" was selected to demonstrate the range from "low" to "high" within the same statistic, all modified from Clayton et al. (2011). Models were combined for reins (both left and right rein tension in same model, but separated) and data on walk, trot, and canter were combined into the same model. Dependent data were checked for normality, that is, that the means and medians were deemed close, the standard deviations judged as small, and skewness and kurtosis close to zero, or otherwise suitably transformed. Fixed effects trial-level variables were rein (left/right), which was forced in, gait [gait], whether the horse-rider combination was turning (left/right) or passed through a corner (left/right) [turn/corner] compared to not doing any of this, performed lateral movements [lateral] (shoulder in left/right, half-pass left/right, leg yield left/right), or was riding in collection (all gaits) or lengthening (trot, canter) [collection/lengthening] versus not doing those. The activity was also categorized according to [position] trot (sitting/posting) and canter (sitting/light seat) which was modeled nested within gait. Horse level (young horse training/basic/medium/advanced level; also see Eisersiö et al., 2015) was also included. (Data from long reins were not included in modeling because it was early on found that the rein tension was lower, and hence the model could be simplified). Two-way interactions between fixed effect variables were tested, after main effects had been reduced to $P < 0.05$. Two-way interactions were kept at $P < 0.001$. Random effects were horse-side (basically including rein, and why rein was forced was to be able to evaluate fixed effect interactions with rein), rider, horse, and trial within horse, the choice of random effects guided by the Akaike criterion. Models were reduced based on the type III sums of squares. Using this reduced model left or right rein was exchanged for dominant rein and Akaikes criterion used to verify whether the model fit the data better. The correlation structure was variance component (compound symmetry was originally strived for, but either variance component was deemed superior based on the Akaike criterion or the compound symmetry models did not converge). For the variation levels the percent of the variation contributed was estimated, dividing by the sum of all sources of variation. In general the results from the median model have been presented in full, whereas results from the main effects model have been presented for all 5 models. To study the effect of the left or right rein, additional models were developed on all data, but where the random effect was changed to horse within rider, rider, horse, and trial within horse. In this model the a priori fixed effects were rider position combined with gait, rein, and their interaction. Pairwise comparisons were done where interactions were involved, where P-values <0.0001 were deemed significant, and $0.0001 < P < 0.05$ was deemed as borderline (either P-values are provided or the distinction is made). Within interactions only selected comparisons, deemed as useful from an equestrian perspective, were evaluated, for example, if gait was included in an interaction all comparisons were made within gait (but in this case including comparisons between left and right lead canter) and changing one of the other variables at a time. PROC MIXED (SAS Institute Inc., NC) was used for modeling. Relevant pair-wise comparisons were defined within gait, and with only one other variable changing, with the exception of comparisons of categories within the combination of gait and rider position in the main models.

Results

Descriptive results

The descriptive statistics demonstrate substantial variation between gaits, rider position within gait, and between riders and horses (Table 1, Supplementary information 1 and 2). Magnitude differences between turns and lateral movements within gait were more difficult to confirm descriptively (Supplementary information 1). Note that not all horses performed all lateral movements, and rather few performed lengthening ($n = 9$) and collection ($n = 6$). From supplementary information 2 we note that data were missing from 2 categories because of limited problems with the left rein tension meters.

Main effect results from all models

There were 1,188 observations in the dataset (316 from walk, 505 from trot, 180 from left lead canter, and 187 from right lead canter ([descriptive statistics see supplementary information 3]). "Low" and "auc" rein tension were modeled as logarithm-transformed while the others as square-root transformed. The main effects (Figure 2, Table 2) show that the major determinants found for amount of rein tension, deemed both from statistical significances and differences judged as substantial descriptively were gait; walk < trot < canter. The rider's position in the saddle had a large influence both at trot (posting < sitting) and at canter (light seat < sitting). There was no significant difference in magnitude of rein tension between left or right lead canter within light seat or sitting position. However, comparing between

Table 1
Descriptive statistics for rein tension (N) in all gaits for the left and right rein separating sitting from posting and light seat in trot and canter. The statistics are derived from horse-based means from raw (calibrated) data (means, STDs et cetera are produced as means of means, STDs et cetera)

Rein tension (N)									
Gait	n	Rein	Mean	STD	Min	2 perc	Median	98 perc	Max
All gaits	24	Left	19	15	0	1	16	60	130
		Right	21	17	0	1	17	67	144
Walk long reins	24	Left	4	5	0	0	2	21	51
		Right	4	5	0	0	2	20	56
Walk short reins	24	Left	14	11	0	1	12	46	112
		Right	15	13	0	1	12	52	123
Trot sitting	21	Left	20	14	0	2	17	58	102
		Right	23	17	0	2	19	68	120
Trot posting	24	Left	16	11	0	1	14	46	107
		Right	17	13	0	1	14	51	130
Left lead canter sitting	18	Left	25	18	0	2	21	72	139
		Right	28	21	0	2	23	83	160
Left lead canter light seat	13	Left	19	14	0	2	16	55	95
		Right	19	16	1	2	15	62	94
Right lead canter sitting	18	Left	25	20	0	2	20	80	158
		Right	28	21	0	2	24	82	166
Right lead canter light seat	12	Left	17	14	0	1	13	57	99
		Right	20	16	0	1	17	65	108

Perc, percentile; STD, standard deviation.

positions and gaits, light seat right lead canter had a slightly higher rein tension, compared to sitting trot, which is reflected by light seat right lead canter and sitting trot being insignificant in all but the "auc" comparison, whereas the light seat left lead canter was significantly lower than sitting trot in the "median" (P = 0.0002) and "low" model (P < 0.0001). The magnitude of rein tension for walk and posting trot was close and low for all outcomes; however, posting trot was significantly associated with a slightly higher rein tension in all but the "range" model.

Horse level

Horse level was significant in all 5 models (P < 0.007) (Figure 2). Advanced horses (n = 4 horses at 2 riders) had the highest rein tension value in all, but the "low" model, in the same models followed by the young horses (n = 3 horses at 3 riders). In the "low" model the medium horses had the highest estimate while the statistical differences were actually found between groups with similar point estimates, demonstrating the diverse within-category variation for this variable.

Variation from horses and riders

Riders and horses contributed the following proportion of the variance in the respective models; in the "median" model (24/13%), the "low" model (33/2%), the "high" model (0/35%), the "range" model (0/28%), and the "auc" model (0/5%). The horse-side effect (the rein effect) was ≤12% in all but the "low" model where it was 23% (suggesting a larger variation by rein in the "low" tension).

Ridden exercises

There were no significant main effects in the median model for the ridden exercises corners and turns. However, significantly more rein tension was used when riding corners to the left compared to corners to the right across all other models except the "low" and "auc" models, reflecting a similar lowest left rein tension value. In contrast, turning was borderline associated with a lower rein tension than not turning in the "low", "high," and "range" models. The "auc" model (Figure 2), where the outcome reflects the time the rider used for each exercise as well the tension applied demonstrated a number of similarities with the other models and all included effects, but rein, were significant ($P \le 0.0009$).

Lateral movements

In the median model, half-pass to the right was associated with higher rein tension than half-pass to the left and the baseline (i.e., no lateral movement, P = 0.002). Half-pass to the right was also associated with higher rein tension in the "low" model (P = 0.04), whereas in the "high" the conclusion changes somewhat to that

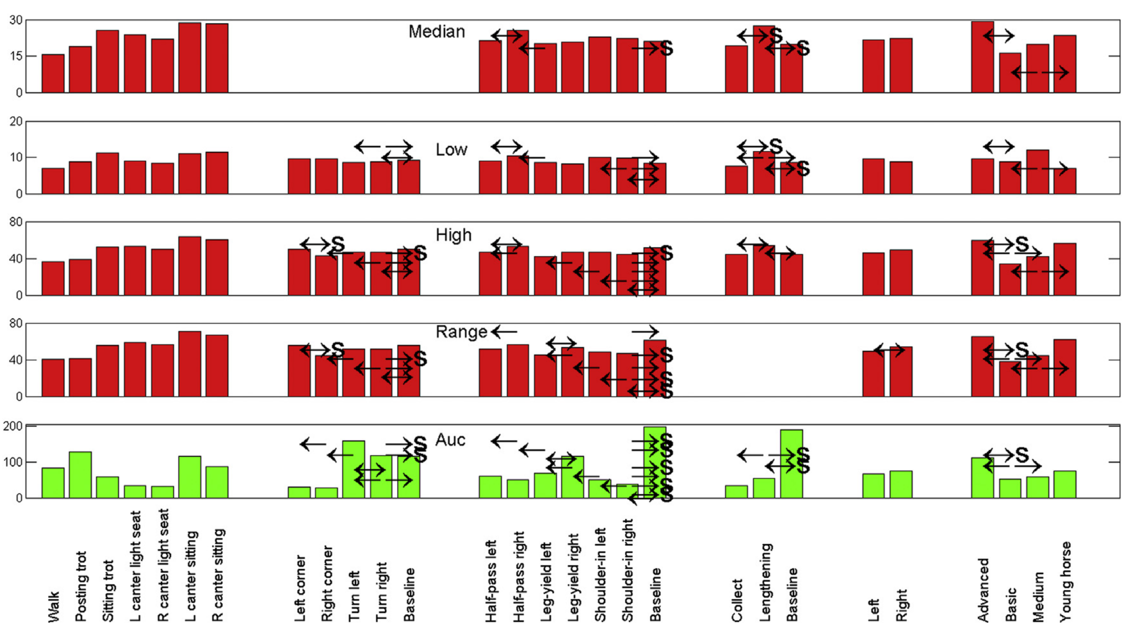

Figure 2. Rein tension (N) evaluated from main effects models. The unit on the y-axes of the red bar graphs s is N, whereas on the graph with green bars (area under curve (AUC)) is Ns. Arrows indicate statistical differences, if denoted by "s" $P < 0.0001$ otherwise the comparisons are at $0.0001 < P < 0.05$. Significances of comparisons relative to gait are shown in Table 2. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article).

Table 2
Showing the statistical significances of the comparisons for rider position within gait for the 5 main effects models (effect magnitude see Figure 2), S denotes $P < 0.0001$, borderline (BL) $0.0001 < P < 0.05$ and ns $P \geq 0.05$

Model	Walk	Posting trot	Sitting trot	L canter light seat	R Canter light seat	L canter sitting	R Canter sitting
Median							
Walk							
Posting trot	S						
Sitting trot	S	S					
L canter light seat	S	BL	BL				
R canter light seat	S	S	ns	ns			
L canter sitting	S	S	BL	S	S		
R canter sitting	S	S	S	S	S	ns	
Low							
Walk							
Posting trot	S						
Sitting trot	S	S					
L canter light seat	BL	ns	S				
R canter light seat	S	ns	S	ns			
L canter sitting	S	S	ns	S	S		
R canter sitting	S	S	ns	S	BL	ns	
High							
Walk							
Posting trot	BL						
Sitting trot	S	S					
L canter light seat	S	S	ns				
R canter light seat	S	S	ns	ns			
L canter sitting	S	S	S	S	BL		
R canter sitting	S	S	S	S	S	ns	
Range							
Walk							
Posting trot	ns						
Sitting trot	S	S					
L canter light seat	S	S	ns				
R canter light seat	S	S	ns	ns			
L canter sitting	S	S	S	BL	BL		
R canter sitting	S	S	S	S	S	ns	
AUC							
Walk							
Posting trot	S						
Sitting trot	S	S					
L canter light seat	S	S	S				
R canter light seat	S	S	BL	ns			
L canter sitting	ns	BL	BL	S	S		
R canter sitting	BL	ns	S	S	S	BL	

L, left; R, right; AUC, area under curve.

half-pass to the left is lower than the both the baseline ($P = 0.006$) and half-pass to the right ($P = 0.01$).

Collection or lengthening

For the "median", "low," and "high" outcomes the finding was that all measures of rein tension were higher at lengthening, whereas collection did not differ from any collection or lengthening. (In the "range" model collection/lengthening the group P-value was >0.05.) In the "auc" model the results reflected that collection and lengthening was more seldom performed, that is, the resulting impulse was highest when none of these were performed.

Interaction models

The conclusions from the median interaction model were similar to those in the main effects model (Supplementary information 4-6). Another interaction results were that (sitting) right lead canter in half-pass to the right (least square mean, 32.9 N) differed from (sitting) right lead canter without lateral movements (least square mean, 27.8 N, $P = 0.004$). From supplementary information 6 it is seen that the inner rein had a significantly higher tension than the outer rein in sitting or light seat right lead canter and light seat left lead canter. The "high" and "range" models had no interactions, whereas the "low" and "auc" model had 2 and one interaction (data not shown).

Rein

In the models dedicated to look at if the left and right rein differed, the interaction term between rider's position within gait and rein was significant in 3 models; "median" ($P < 0.0001$), "low" ($P = 0.0008$), and "range" ($P = 0.04$). In the "median" model there were 4 relevant comparisons with $P < 0.05$. In sitting trot the right rein had a slightly higher tension [left/right rein 20/21 N, $P = 0.03$]. In canter if we change nomenclature to inside or outside rein we find the inside rein associated with the highest tension (one horse was ridden in counter-canter, Supplementary information 1). In light seat left lead canter the inside rein was higher [left/right 20/15 N, $P < 0.0001$], and in both sitting [left/right 22/27 N, $P < 0.0001$] and light seat [left/right 17/21 N, $P = 0.005$] right lead canter the right inner rein was higher.

In the "low" model there were 3 relevant comparisons with $P < 0.05$. In walk the right rein had a lower tension [left/right rein 5.9/5.4 N, $P = 0.02$], in light seat left lead canter the inside rein was higher [left/right 7.6/5.7 N, $P = 0.002$], and in sitting right lead canter the inside rein was higher [left/right 8.4/9.8 N, $P = 0.01$]. In the "range" model 4 relevant comparisons had $P < 0.05$ and in all these the right rein was associated with the highest tension;

walk [left/right rein 40/43 N, $P = 0.03$], sitting trot [left/right rein 54/61 N, $P = 0.001$], posting trot [left/right rein 40/46 N, $P = 0.0008$], and sitting left lead canter [left/right rein 65/79 N, $P < 0.0001$], where in the latter comparison the outside rein was higher.

In the “high” and “auc” models the 2 main effects, rider position within gait and rein, were significant, but not their interaction. The right rein was in both these models higher than the left (“high” [left/right rein 41/45 N, $P < 0.0001$], “auc” [left/right rein 499/550 Ns, $P = 0.03$]).

Discussion

This study is the first to our knowledge with the aim to document the distribution of rein tension during entire riding sessions. Earlier studies have mainly recorded shorter sequences of rein tension during predetermined riding exercises. By letting our participating riders structure their riding sessions themselves during data collection we received rein tension data that likely reflect the normal situation for each horse-rider combination in terms of magnitude and in relation to exercises performed.

When studying the descriptive statistics of rein tension applied by our study participants we found substantial variation in magnitude (Supplementary information 1) and from the models riders contributed a larger part of the variation than the horses in the “median” and “low” models, but interestingly rather low to very low proportions in the other 3 models. This suggest that horses, compared to riders, contribute rather much to the found high or peak tension, but less to the maintained lower tension or the total tension or impulse (“auc”) during the session. Although the participants in our study were of diverse background and educational level we found certain reoccurring patterns and strong determinants with regards to amount and distribution of rein tension for the variables gait, rider position in the saddle, ridden exercise performed, and educational level. We thus suggest that rein tension data benefit from being categorized according to similar variables in studies of rein tension in relation to other variables.

Our most pronounced results were the strong connection between magnitude of rein tension and gait (walk < trot < canter) as well as rider position in the saddle (posting/light seat < sitting). Similar results for association with gait have been found by Clayton et al. (2003) and Kuhnke et al. (2010). Conversely, the fact that rider position played a large part in the amount of rein tension used was more of a surprise. It seems that this is a factor that merits consideration during rein tension studies. Perhaps this result is connected to the large vertical and horizontal accelerations and decelerations of the horse’s trunk at the trot and canter, and the rider’s ability to adjust and adapt to these movements (Byström et al., 2009). Perhaps some riders support their seat through use of the reins while sitting? Or the higher values of rein tension at sitting trot and canter, compared to posting or light seat, may also reflect posting and light seat being used during warm-up and suppling work, with less demands on the horse, although sitting to the gait might be used in exercises striving to collect and “work” the horse. However, it is not fully in principle with riding theory that a horse that is more worked should do so with higher rein tension. Though targeting the variation between and during diverse ridden exercises; we selected measures associated with the most common rein tension values, instead of the extreme values minimum and maximum. The maximum rein tension values were not analyzed as these maximum peaks are rare and may yield an inaccurate picture of the rein tension the horse has been subjected to. In addition, these peaks likely don’t reflect the amount of rein tension normally used by the rider or horse. The maximum rein tension peaks may also often occur as the horse stumbles, shies, coughs, or pulls the reins out of the rider’s hands. Although these events can be interesting to study they are not within the scope of this study. The differences between the minimum value and the 2 percentile as well as the 98 percentile and the maximum rein tension values per gait can be seen in Table 1. We suggest that the 98 percentile should be reported along with the maximum value in rein tension studies. The “low” variable was quite similar for all categories of data ranging from 6.9 N-12.1 N, median 9.0 N, (Figure 2) and may perhaps be interpreted as the contact on the reins (Anonymous, 1997). This “low” category also resembles the mean rein tension values found in other rein tension studies where data were collected from shorter and more predetermined ridden exercises (Warren-Smith et al., 2007). The “high” variable on the other hand had a larger point estimate range of 34-63 N, median 47 N, indicating that certain variables were connected to a higher variability of rein tension than others, as also seen from the “range” variable (Figure 2). For example, sitting trot and sitting canter (left/right) had an equal magnitude of rein tension in the “low” category, but differed approximately 10 N in the “high” category, suggesting that rein tension vary with higher magnitudes in the canter compared to the trot.

Interestingly, an equal amount of rein tension was used for turning to the left and right respectively (left/right rein combined), whereas significantly less rein tension was used when riding corners to the right compared to corners to the left (Table 2, except for in the “auc” model see discussion further down). This raises the question of laterality in horses and riders, and how it affects certain ridden exercises. In the current study, a significant effect of perceived laterality was not found (data not shown). Yet, ridden exercises on straight and bent lines, including lateral movements, studying the rein tension used on the inside and outside rein merits further investigation. Many left or right rein comparisons were significant using the model that was dedicated to this. In the other models, except in the “range” model, we found that the rein effect was absorbed by the random effect. The right rein most often had higher rein tension than the left rein, with the exception of 3 comparisons, of which 2 were from the “low” model (the right rein had a lower tension in walk and the inside rein was higher in left lead canter), suggesting that the right hand in general is associated with higher tension but perhaps also somewhat associated with more release (the third one was the left rein in left lead canter). This might reflect the principle that “every asking rein aid must be followed by a yielding aid” (Anonymous, 1997). At canter more rein tension was placed on the inside rein compared to the outside rein, with the exception that range was higher on the outside rein in sitting left lead canter in the rein-dedicated analysis (Figure 2, Supplementary information 6). These general results are partly opposite to those of Kuhnke et al. (2010) and handbooks on riding suggest that the outside rein should keep a more continuous contact with the horse’s mouth and the inside rein should act and release according to need (Anonymous, 1997). These conflicting results demonstrate the complexity of rein tension measurements.

Our results with regards to the horse’s educational level are interesting and merits consideration in future rein tension studies. In the light of the small number of young horses included going through young horse basic training, it is still noteworthy that they were ridden with almost as much rein tension as the advanced horses and more rein tension than the basic level horses. This may be explained by the fact that young horses may not yet have learned to respond correctly to the rider’s pressure signals and are perhaps going against the rein tension instead of yielding and alter speed, direction, or head position. This doesn’t have to be a problem, as long as the rider notoriously release the rein tension as the correct response is given by the horse, that is, using the principles of negative reinforcement appropriately. However, the median rein tension of 24 N and the "high" value of 57 N is far more rein tension than the naive horses in Christensen et al. (2011) were willing to take on to receive a food reward, comparing to mean 10 N and max 38 N, suggesting that the young horses in our study had already habituated to rein tension signals to some extent.

It is more contradictory to riding handbooks that basic < medium < advanced level horses in terms of magnitude of rein tension, because lightness to the rider's signals should be further and further developed as the training progresses (Decarpentry, 1949). Given that lightness is one of the cornerstones of dressage riding, repeatedly emphasized both by the FEI and riding handbooks (Fédération Equestre Internationale, 2014), a light contact between the rider's hand and the horse's mouth should be one of the key features in all ridden exercises regardless of level or difficulty. Nevertheless, the magnitude of rein tension between the horse's mouth and the rider's hand likely also depend on the rider's purpose and intention with the ride as well as the horse's response to the rider's requests.

Horses are generally trained to seek contact with the bit as this is one of the objectives for competitive dressage and what is sought for is the horse "accepting the bridle with a light and consistent soft submissive contact" (Fédération Equestre Internationale, 2014). The reins are required to be taut during dressage competition and not demonstrate any slack during the ride as looseness of the rein would indicate an inconsistent contact with the horse's mouth. Although the FEI advocates a continuous contact between the rider's hand and the horse's mouth, and it is described by Clayton et al. (2011) that this is done by the horse pushing against the bit to some extent, it is, however, evident that rein tension always demonstrate an uneven contact as the "range" values (the difference between the 2-98 percentile) range from 40 N at the walk to 70 N at sitting right lead canter (Table 2), and this feature is further demonstrated by studies on rein tension in relation to the horse's stride cycle (Clayton et al., 2003; 2011; Eisersiö et al., 2013; Egenvall et al., 2015).

Correspondingly, a low rein tension and a small rein tension variance were important features in von Borstel and Glißman (2014) for receiving high rideability scores (i.e., the measure of how comfortable it feels to ride a certain horse). They found that the lower and more steady the rein tension the higher the rideability score given by the judges. In addition, variation of rein tension is of great interest as pressure signals are used to communicate requests to the horse, and it is not yet elucidated from rein tension data what the rein tension peaks represent in reality. We suggest that the resulting rein tension data seen in the dataset are derived from a combination of the oscillating movement of the horse's gait, the rider's ability to follow the horse's movement, the signaling actions of the rider's hand and the horse's interaction with the bit. None of these factors have hitherto been well elucidated relative to rein tension in riding.

The "auc" statistic produced measures that are related to how long a horse was ridden in a specific exercise multiplied by the magnitude of rein tension. Because of this posting trot was a determinant of high importance, because posting trot was simply very commonly performed (Eisersiö et al., 2015). In lateral movements and collection or lengthening the baselines all yielded high values because of the same reason. The high "auc" in the advanced horses reflected that they were ridden for a slightly longer time, and at gaits of higher speed, compared to the other horses. Turning left had a higher value than turning right, while other statistics for left or right turn showed miniscule differences, a finding that may need more fine-tuned methods for elucidation. The "auc" reflects the pressure from the whole riding session, and if the horse, for example, has a bar ulcer, a large "auc" may imply a sustained discomfort for the horse. Pressure sores arise from a combination of the intensity and duration of the pressure applied (Chang and Seireg 1999), though specific related to the mouth of the horse has not been investigated.

The rein tension meter used in our study relied on strain gauge technique for generating rein tension data (Eisersiö, 2013). Previous studies have also used strain gauge transducers for rein tension measurements with reliable results (Clayton et al., 2003, 2005; Heleski et al., 2009; Clayton et al., 2011). An advantage with this rein tension meter was its broad measuring range of 0-500 N and resolution of 0.11 N, making sure that no peaks of tension were cut of as has been a problem in previous studies with other rein tension meters (Egenvall et al., 2012; Christensen et al., 2014) while still catching the small variations of rein tension that occur.

Currently, the field of research on equine welfare with focus on horse training and rein tension advocate a rigorous use of the principles of learning theory during horseback riding. Another important aspect worth investigating and discussing when carrying out research on rein tension is the horse's physical and perceptual experience of the pressures applied in its mouth. The rein tension meter fastened on the reins solely measure the tension applied on the leather. How this tension is distributed along the bit in the horse's mouth is unknown. The pressure from the bit the horse feels in its mouth is likely affected by the shape and size of the bit, how the bit and bridle is fitted on the horse, the head and neck position of the horse, and how the horse chooses to carry the bit in its mouth and, in particular, the anatomy of the horse's oral cavity. Besides the rein tension applied on the reins by the horse or rider, all of these variables contribute to how the pressure is applied in the horse's mouth.

To document and analyze rein tension further is important both from in terms of equine performance and welfare. It is highly likely that if novices can be instructed in how to use the reins more explicitly, they can faster develop a more aware and precise rein handling that will increase their riding abilities at a faster rate and lead to enhanced horse welfare. On prerequisite for optimal usage of the reins will be that the hand is as far as possible independent of the seat (Anonymous, 1997).

The detailed approach taken, including categorization of collection and lengthening, prohibited extensive and detailed data analysis of a much large sample. The limited number of riders and horses leads to some problems with extrapolation, though riders were from different stables without obvious problems with dependence or clustering. Our perception from the study is that they produce a reasonable subsection of the targeted population, however this cannot be verified. Ideally, we would have wanted more participants in our study and more days on each horse-rider combination as rein tension is likely affected by both the rider's and the horse's physical and emotional state of the day, that is, targeting also between-session variability. In the design, it included speed measurements using a GPS, but data collection from this unfortunately failed to a large degree (for several reasons). Although our study design had the advantage of capturing the ordinary situation for horse and rider in terms of duration and order of exercises performed, it also meant that we didn't receive data for all exercises in all horses. A potentially more severe problem is that one evaluator classified all the exercises (Eisersiö et al., 2015). For example, whether a horse is in collection or not can be debated. On the other hand, riding with a rein tension meter will likely always produce a psychological effect on the rider, especially when done in front of a video camera. Having "good hands" is an important feature in riding, and it is highly probable that riders modify their riding to some extent to not just have their horse perform well but to also "look good" during data collection. We hope this effect of "showing off" was limited by the data collection capturing the riders' normal training schedule. We have included descriptive statistics based on the raw data and on a series of statistics in the multivariable analysis. This has produced a somewhat different picture with regard to the descriptive statistics in some instances, especially when rein tension values were close such as for left or right corners, where it can be seen that the 98 percentiles of Supplementary information 1 and the results from Figure 2 are somewhat contradictory. As we demonstrate variation related to 2 levels of variation this could not be avoided.

Conclusion

The assessment and interpretation of the rein tension signal is complex and rein tension data thus need to be addressed and scrutinized in detail on several levels. Our results suggest that variables to consider in rein tension studies are the gait of travel, the rider's position in the saddle, the ridden exercise performed, the educational level of horse, the rider and horse per se, and to some extent the left or right rein. We also suggest that the range of rein tension within gait and exercise and reporting the 98 percentile of data are important features. Studying, for example, more of the within-stride variation and between-stride variation of the rein tension data are next steps in receiving a more complete picture of the events taking place during riding.

Acknowledgments

The study was funded by The Swedish Research Council Formas (2011-556). The funding body had no influence on the study design; in the collection, analysis, and interpretation of data; in the writing of the article; or in the decision to submit the article for publication. We thank the riders for their contributions. The idea for the article was conceived by Agneta Egenvall, Marie Eisersiö, Lars Roepstorff, and Marie Rhodin. The experiments were designed by Marie Rhodin and Marie Eisersiö. The experiments were performed by Marie Eisersiö. The data were analyzed by Agneta Egenvall and Marie Eisersiö. The article was written by Marie Eisersiö, Agneta Egenvall, Marie Rhodin, and Lars Roepstorff.

Ethical considerations

According to the Swedish legislation no specific ethical permit was necessary for this study.

Conflict of interest

None of the authors have any potential conflicts of interest, including any financial, personal, or other relationships with other people or organizations, within 3 years of beginning the submitted work that could inappropriately influence, or be perceived to influence, the work.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jveb.2015.05.004

References

Anonymous, 1997. The Principles of Riding: The Official Instruction Handbook of the German National Equestrian Federation. Kenilworth Press, Shrewsbury, UK pp 74, 85, 156–157.
von Borstel, U.K., Glißman, C., 2014. Alternatives to conventional evaluation of rideability in horse performance tests: suitability of rein tension and behavioural parameters. PLoS One 1, 1–9.
Byström, A., Rhodin, M., Von Peinen, K., Weishaupt, M.A., Roepstorff, L., 2009. Basic kinematics of the saddle and rider in high-level dressage horses trotting on a treadmill. Equine Vet. J. 41, 280–284.
Chang, W.L., Seireg, A.A., 1999. Prediction of ulcer formation on the skin. Med. Hypotheses. 53, 141–144.
Christensen, J.W., Zharkikh, T.L., Antoine, A., Malmkvist, J., 2011. Rein tension acceptance in young horses in a voluntary test situation. Equine Vet. J. 43, 223–228.
Christensen, J.W., Beekmans, M., van Dalum, M., Van Dierendonck, M., 2014. Effects of hyperflexion on acute stress responses in ridden dressage horses. Physiol. Behav. 128, 39–45.
Clayton, H.M., Singleton, W.H., Lanovaz, J.L., Cloud, G.L., 2003. Measurement of rein tension during horseback riding using strain gage transducers. Exp. Tech. 27, 34–36.
Clayton, H.M., Singleton, W.H., Lanovaz, J.L., Cloud, G.L., 2005. Strain gauge measurement of rein tension during riding: a pilot study. Eq. Comp. Ex. Phys. 2, 203–205.
Clayton, H.M., Larson, B., Kaiser, L.J., Lavagnino, M., 2011. Length and elasticity of side reins affect rein tension at trot. Vet. J. 188, 291–294.
Decarpentry, A., 1949. Academic Equitation. A System Based on the Methods of D'Aure, Baucher and L'Hotte (Équitation Academique, Translated by Nicole Bartle). Robert Hale Ltd, London, UK, p. 45.
Eisersiö, M. 2013. How to Build a Rein Tension Meter. Degree Project in Biology, Swedish University of Agricultural Science, http://stud.epsilon.slu.se
Eisersiö, M., Roepstorff, L., Weishaupt, M.A., Egenvall, A., 2013. Movements of the horse's mouth in relation to horse–rider kinematic variables. Vet. J. 198, e33–e38.
Eisersiö, M., Roepstorff, L., Rhodin, M., Egenvall, A., 2015. A snapshot of the training schedule for 8 professional riders riding dressage. Comp. Ex. Phys. 11, 35–46.
Egenvall, A., Eisersiö, M., Roepstorff, L., 2012. Pilot study of behavior responses in young riding horses using 2 methods of making transitions from trot to walk. J. Vet. Behav. 7, 157–168.
Egenvall, A., Eisersiö, M., Rhodin, M., van Weeren, R., Roepstorff, L., 2015. Rein tension during canter. Comp. Ex. Phys. 11, 107–117.
Fédération Equestre Internationale. 2014. Dressage Rules 25th Edition. http://www.fei.org/fei/regulations/dressage. Page visited 2014-09-16.
Heleski, C.R., McGreevy, P.D., Kaiser, L.J., Lavagnino, M., Tans, E., Bello, N., Clayton, H.M., 2009. Effects on behaviour and rein tension on horses ridden with or without martingales and rein inserts. Vet. J. 181, 56–62.
Kuhnke, S., Dumbell, L., Gauly, M., Johnson, J.L., McDonald, K., von Borstel, U.K., 2010. A comparison of rein tension of the rider's dominant and non-dominant hand and the influence of the horse's laterality. Comp. Ex. Phys. 7, 57–63.
Ludewig, A.K., Gauly, M., Von Borstel, U.K., 2013. Effect of shortened reins on rein tension, stress and discomfort behavior in dressage horses. J. Vet. Behav.: Clin. Appl. Res. 8, e15–e16.
Manfredi, J.M., Rosenstein, D., Lanovaz, J.L., Nauwelaerts, S., Clayton, H.M., 2010. Fluoroscopic study of oral behaviours in response to the presence of a bit and the effects of rein tension. Comp. Ex. Physiol. 6, 143–148.
Tell, A., Egenvall, A., Lundström, T., Wattle, O., 2008. The prevalence of oral ulceration in Swedish horses when ridden with bridle and bit. Vet. J. 178, 405–410.
Warren-Smith, A.K., Curtis, R.A., Greetham, L., McGreevy, P.D., 2007. Rein contact between horse and handler during specific equitation movements. Appl. Anim. Behav. Sci. 108, 157–169.