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Associations between driving rein tensions and drivers' reports of the behaviour and driveability of Standardbred trotters

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ABSTRACT

Effective communication between driver and horse through the reins is essential in harness racing to promote safety and optimise performance. Yet, the magnitudes of rein tension applied to driven horses, particularly Standardbred trotters (ST) are currently poorly understood. This is surprising given the number of reports that speak of mouth lesions after competition and equipment use that give raise to horse welfare concerns. Combining rein tension measurements with behavioural parameters has the potential to characterize "driveability" (as compared to "rideability", the equivalent industry term for riding horses). Thus, the aims of the current study were: (i) identify how drivers perceive ST's behavioural reactions in response to rein signals when driven on a racetrack, (ii) investigate whether drivers' subjective appraisals of horses' behavioural responses align with measured rein tensions (RT), (iii) relate these appraisals to the horses' perceived driveability (score 1 = poor, 10 = excellent), and (iv) assess whether drivers differ in their scoring of horses' driveability. Nine ST (5 geldings, 7.8 mean ± 2.1 SE years; 4 mares, 6.8 ± 0.5) were driven by 11 drivers (7 females; 4 males) all of whom were experienced in driving ST. Nine drivers tested three different horses each, and two drivers drove two of the horses. This resulted in 31 test drives involving several segments, each comprising a series of changes of gait and direction of travel. Rein tension meters were used throughout. After each test, drivers were asked to report on their experience of each horse they had just driven and to estimate RT (continuous rating scale from 0 to 50 kg) while driving that horse. Overall, segment had a significant effect on median RT ($P < 0.001$), with RT rising significantly in racing trot (average 59 N; Trot Left/Trot Right) than trotting on a circle (23 N; Circle Left/Circle Right) and walking (8 N), and was higher in counter-clockwise than in clockwise direction in racing trot ($P = 0.058$). Furthermore, there was an alignment between recorded RT and drivers' estimates of perceived RT ($P < 0.001$), and driveability scores increased when estimated RT increased. The current study has confirmed that rein tensiometry may have a place in providing an evidence-base for consistent rein use, especially when horses are driven by multiple drivers. Whether or not soft tissue damage after competitive racing is correlated to higher peak RT, caused by the use of harsher equipment, or a combination of both, merits further investigation.

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1. Introduction

Effective communication between rider/driver and horse through the reins is essential to promote human safety and optimise performance. However, the magnitudes of rein tension applied to ridden horses are currently better understood than those applied to driven horses, particularly Standardbreds. This is surprising given that the magnitude of rein tensions applied has implications for horse welfare, irrespective of discipline.

Standardbreds are bred for the purpose of running fast. Maintaining control over the racing horse in a tight field of other horses and being able to regulate speed and direction via rein signals are of critical importance. There is some evidence that winning Thoroughbred racehorses tend to be those individuals that are more relaxed and calmer in the parade-ring prior to racing than highly aroused horses (Hutson and Haskell, 1997; Pinchbeck et al., 2004; Wells et al., 2022). Equally, horses that are excited before racing may be more difficult to control (Pinchbeck et al., 2004). This may even be undesirable in trotters, especially during harness races over prolonged distances where drivers often report that they “hold on” to the horse in the beginning of the race to moderate its speed and thus conserve energy. By contrast, the subsequent release of rein tension signals the trotter to accelerate. Consequently, many horses race at high speed while being restrained through bit-induced pressure, which is contraindicated because it reliably habituates the horse to bit signals (McLean and Christensen, 2017). Beside habituation, some horses may even learn to seize the bit between the premolars or pull the reins through the hands to avoid bit pressure (Manfredi et al., 2009). Clearly, horses with suboptimal responses to rein signals can become dangerous to drive and to ride. In an attempt to regain control over such horses, a variety of harsh bits and other restrictive head equipment are used in harness racing similar to various other disciplines (Condon et al., 2022). In turn, such devices may become a source of acute or chronic pain. This is reflected in the increased prevalence of mouth injuries recorded in show-jumping, dressage and eventing horses when examined before and after competition (Tuomola et al., 2021a; Uldahl et al., 2022), but also in trotters and other horse breeds used for harness racing, particularly after a race (Odelros and Wattle, 2018; Tuomola et al., 2019, 2021b). Unfortunately, and perhaps especially in trotters, in the absence of objective data there is almost entire reliance on visual appraisal of rein tensions and subjective terms that describe horses’ reactions to rein signals, such as “hard-mouthed” or “leaning on the bit”.

Three recent studies have measured the rein tension (and concomitant bit pressure) that horses are willing to tolerate while moving freely with side reins attached to the bit (Christensen et al., 2011; Piccolo and Kienapfel, 2019; Vogt et al., 2019). In all of these studies, the tensions voluntarily imposed via the reins did not exceed 10 N. In ridden horses, peak rein tensions can occasionally reach 284 N, specifically during canter (for overview, see Dumbell et al., 2019). That said, on average for all gaits, reported mean rein tensions during ridden work vary between approximately 7 N (Warren-Smith et al., 2007) and 20 N (Eisersiö et al., 2015). Presumably, higher tensions are expected when horses are long-reined from the ground (using long lines connected to the bit) than when being ridden, perhaps because of the relative length of the reins (and consequent greater weight) in long-reining (Warren-Smith et al., 2007). The distance from the trainer’s hand to the horse’s mouth can also result in a delayed and only-partial release of tension (Warren-Smith et al., 2007). During carriage-driving under competition conditions, notably when driving through obstacles and transitions from fast trot or gallop to walk or halt, peak rein tensions can reach 245 N (Preuschoft et al., 1999). The first reports from drivers competing with Standardbreds in trotting indicate estimated peak tensions of up to around 392 N (given a perception of 40 kg; Preuschoft et al., 1999), which would be far higher than has been measured during competitive carriage-driving (Preuschoft et al., 1999) and riding (Clayton et al., 2003; Eisersiö et al., 2015; Egenvall et al., 2019).

In most equitation, riders/drivers rely chiefly on negative reinforcement, e.g., change of direction or reduction in speed is signaled via the application of pressure, often via the reins to the bit (or via shifting weight, applying leg pressure) which, upon the horse’s correct response, should be removed immediately (McLean and Christensen, 2017). Failure to remove pressure in this way leads to the horse habituating to the signal, which can result in unresponsiveness. An escalation in baseline tension then proceeds, as the horse’s sensitivity spirals downwards. Hence, it is paramount to maintain the horse’s sensitivity particularly to rein signals to avoid accidents due to horses becoming less responsive and also to reduce the risk of mouth injuries as a consequence of excessive bit pressure. Clearly, rein tension can reveal the horse’s level and quality of prior training and can also provide a more objective evaluation of riders’/drivers’ sense of control when riding/driving a specific horse (König von Borstel and Glißman, 2014). The ease and comfort with which a horse can be ridden are summarized under the umbrella term ”rideability”. Rideability is considered by riders and breeders to be one of the most important traits in riding horses, usually scored during young horse performance tests. Surprisingly, the analogous trait “driveability” in driving horses has been largely neither discussed nor scrutinized. Finland may be the only country that has introduced a driveability test; specifically for evaluation of breeding Finnhorse stallions (trotters). In this test, horse cooperation and disposition are assessed in walk and trot by two different drivers. Combining rein tension measurements with behavioural parameters and quantitative as well as qualitative assessment of temperament traits has the potential to characterize optimal driveability and allow its objective evaluation. This, in turn, can support informed decisions when selecting horses for breeding, for matching driver-horse pairs and for evaluating training progress.

The aims of the current study were (i) to identify how drivers perceive Standardbreds’ behavioural reactions in response to rein signals when driven on a racetrack, (ii) to investigate whether drivers’ subjective appraisals of horses’ behavioural responses are reflected in measured rein tensions, (iii) to relate these appraisals to the horses’ perceived driveability, and (iv) to assess whether drivers differ in their scoring of horses’ driveability.

2. Methods

The study was conducted over four consecutive days in October 2021 at Wången, the National Center for the education and development of harness racing and Icelandic horse riding. The experimental procedures were approved by the local Animal Ethics Committee (Umeå, Sweden) under the protocol A 18–2021.

2.1. Horses and management

Nine Standardbreds that all had been kept as school horses at Wången (eight horses for at least 6 months, one horse for 1 month) were selected. They were between 3 and 14 years (5 geldings, 7.8 mean $\pm$ 2.1 SE years; 4 mares, 6.8 $\pm$ 0.5) with a bodyweight between 413 and 597 kg (497.2 $\pm$ 19.6). They were all in training and regularly driven by different students under the supervision of staff members and licensed trainers with the Swedish Trotting Association. Seven of the horses had participated in official races (number of races 24.8 $\pm$ 8.5) with average lifetime earnings of 116,096 SEK ($\pm$ 35,088).

Seven of the horses were stabled in individual boxes (3 $\times$ 3 m) with wood shavings and were turned-out in pairs during the daytime for 4 – 6 h. The remaining two horses were kept in a 24-h outdoor group housing system with automatic feeding stations and free access to straw. All horses were fed between 11 and 13 kg of haylage and a concentrated ration based on pelleted feed containing, e.g., oats, wheat, alfalfa, beet pulp, molasses (1.4 kg $\pm$ 0.3, Krafft Groov Original, Lantmännen Krafft AB, Sweden) daily. Water was available ad libitum.

All horses were checked for oral soft tissue health by Wången’s equine veterinarian the day before testing started. This mouth check was performed without sedation or using a mouth gag. The examination started by palpating the external and buccal commissure of the upper and lower lips and continued by a visual examination of the mandibular diastema, the buccal area and tongue. All horses passed the oral examination as there were no obvious signs of lesions. Notably, oral health of the school horses is monitored at regular 12-month intervals as part of their routine health checks.

Directly after the veterinary oral assessment for the current project, movement asymmetry was recorded with the Equinosis Lameness Locator (Columbia, MO, USA) as described by Keegan et al. (2011). Horses were trotted in-hand repeatedly up to four times along a straight line on the hard surface of a 20-m long stable aisle. Data recordings were processed by the software package in the Equinosis gait analysis system. The Equinosis Lameness Locator system detected movement asymmetries that were over the symmetry threshold for lameness in three of the nine horses. However, the school's highly experienced equine veterinarian considered all horses healthy after visual appraisal. Movement asymmetry is not unusual among trotters and riding horses of all ages (Ringmark et al., 2016; Kallerud et al., 2021a).

2.2. Drivers

A total of 11 drivers were enrolled of whom five were female and two were male students aged between 17 and 18 years from Wången's upper secondary school. All students were experienced with the management and driving of Standardbreds. They had on average 8.6 ± 1.9 years of driving experience and five students had previously competed in official harness races (number of races 34.2 ± 14.2). Moreover, two female and two male members of Wångens̀ staff, aged between 29 and 65 years (46.5 ± 7.4) all whom had experience as licensed drivers or trainers, drove some of the horses in this study. The staff members' driving experience comprised on average 31.3 ± 10.1 years. Two of them had competed in 4 and up to 50 races, and one staff member in over 10.000 races. This background information was obtained from drivers via a hard copy questionnaire administered prior to the start of the exercise tests. This questionnaire also included questions on the respondents' preferred hand for writing, throwing, brushing teeth, cutting and eating with a spoon. Based on the answers, ten of the eleven drivers were considered right-handed.

2.3. Exercise test and equipment

The exercise tests were conducted at Wången's racetrack (1000 m long banked gravel oval track). A protocol was designed to measure rein tension while driving at different gaits and during changes in tempo within the same gait in both directions (see Table 1). The horses were driven in groups of three; each group performed three tests in succession on the same day but, within each test, horses were driven by different drivers (random allocation of drivers to horses). Two of the nine horses underwent two additional tests on a different day, with two different drivers. The remaining seven horses participated during only one day. The total number of tests was 31 (i.e., three tests for each of the nine horses and two additional tests for two of these horses). During each test, the first horse was always driven in the leading position, the second horse was driven on the outside, and the third horse was positioned behind the first horse on the inside of the racetrack. The drivers retained these positions during each of their three tests, thus only horses changed their position between each test round.

All horses were prepared in the aisle of their home stable yard. They wore their regular training equipment, consisting of an open bridle with a loose noseband and a single-jointed metal driving bit. None of the horses were driven with an overcheck bit or any other equipment restricting head/neck movements. Horses were driven in a Grafström Speedcart Sport Classic training cart (Grafströms Sulkytillverkning AB, Sundsvall, Sweden) except for one horse (driven in a Finntack T4 Speedcart; Oy Finntack Ltd, Hollola, Finland). Synthetic or leather driving reins, reinforced with solid stainless steel end-pieces for safety (weight 1.1 – 1.2 kg, length 4–5 m), were attached to the rein sensor device with a leather strap as a connector (as the sensor's connection bar for the rein was too narrow to fit the driving reins).

Table 1
Overview of the segments that comprised the exercise test and the relevant direction of driving [i.e. left (counterclockwise) and right (clockwise)] for each segment, including distance driven on the racetrack (m) and average speed during each segment (Mean ± SD). Rein tension data for the walk segments were combined for statistical analysis and the median calculated. The jogging segment was not analyzed due to missing time points (start/end) during live recording of clock-times.

Segment	Description	Direction	Distance (m)	Speed (m/s)
Walk 1	Walking from stable to entrance racetrack		50–100	1.4 ± 0.5
Jog	Warming-up in slow trot	Right	1000	
Walk 2	Walking from finish line to circle	Right	120	
Circle Right	4 circles in trot (Ø 20 m)	Right		3.1 ± 0.6
Trot Left	Racing (fast) trot	Left	200	9.3 ± 2.5
Walk 3	Transition to walk and walking to finish line	Left	120	
Circle Left	4 circles in trot (Ø 20 m)	Left		2.9 ± 0.8
Trot Right	Racing (fast) trot	Right	200	10.0 ± 2.2
Walk 4	Transition to walk, walking to finish line and back to stable		120	

2.4. Rein tensiometry

We used the commercially available IPOS rein sensors (IPOS Technology B.V., 5656 AE Eindhoven, The Netherlands) for measuring the tension applied through both the left and right side driving reins to the horse's bit. The measuring range of the load cell was 0–500 N and the sensor weight was 68 g. Data were sampled at a rate of 80 Hz with a 16-bit resolution. Sensor data were received wirelessly via Bluetooth (minimum required version 4.3) by the IPOS training application on a smartphone carried by the drivers. Before each test, the rein sensors were calibrated (zero offset adjusted) using the IPOS training application (placing the device on a horizontal surface with no applied load). The IPOS sensors are shipped calibrated by the manufacturer, but this calibration was verified before the exercise tests, using five known reference weights ranging from 1.25 to 15 kg.

2.5. Driver questionnaire about horses

After each test, all drivers were asked to respond to nine questions to report on their experience of each horse they drove in the current study (Questions 1–6) and to estimate rein tension while driving that horse (Questions 7–9). Under Swedish regulations, since no sensitive personal information was collected and answers were handled anonymously for statistical analysis, no ethical approval had to be obtained.

For the first four questions (Questions 1–4), the option to respond with '*Don't know/No opinion*' was offered as one alternative. The drivers were asked if they perceived that the horse was leaning on one rein more than the other (Q1). The options available were: *Yes, left rein*; *Yes, right rein*; and *No, same on both reins*. Respondents were further asked if the horse was soft in the mouth (Q2). The options available were: *Yes; No, horse leans on the left of the bit; No, horse leans on the right of the bit; No, horse is sensitive to the bit and does not take contact; No, horse is insensitive to the bit and tries to pull the reins;* and *No, horse leans on the bit and is heavy*. Respondents were then asked if the horse was more difficult to drive in one direction compared to the other (Q3), with the options being: *Yes, more difficult to drive in left direction; Yes, more difficult to drive in right direction* and *No*. The respondents were also asked if the horse was more difficult to turn on a circle in one direction than in the other (Q4), with the options being: *Yes, to the left; Yes, to the right* and *No*. Moreover, respondents were requested to select characteristics they would use to describe the horse's temperament while driven (Q5), using terms from the following list: *relaxed, tense, slow, alert, strong-willed*. For each of these attributes, responses were made using a 5-point Likert scale: *strongly disagree/disagree/neutral/agree/strongly agree*. Next, the respondents were asked to estimate the horse's driveability (Q6) on a linear numeric scale from 1 (poor) to 10 (excellent). Finally, the drivers were asked to estimate, on a scale from 0 to 50 kg, the amount of rein tension (on average) they perceived to have used with the horse while driving in walk (Q7), in slow trot/jogging (Q8), and in fast trot (Q9). Participants were asked to estimate rein tension in kg, rather than in N, because drivers were expected to relate to kg more easily. The 0–50 kg range was chosen as it corresponded to the IPOS sensor's measuring range (0–500 N/51 kg). We did not ask the drivers to differentiate between left/right rein when estimating rein tension for Q7–9, nor to consider the summed combined left/right rein tension. Thus, we focussed on the total experienced tension primarily because drivers hold both reins in their hands and may rarely ever drive without any tension.

2.6. Data management

The IPOS app automatically uploads the recorded rein tension data to a cloud database from which data were retrieved in CSV format via the IPOS web-interface. The data were further handled in MATLAB (version R2020a). Due to considerable data loss in some measurements, stride median rein tension data were approximated by applying a moving median filter with a fixed window width of 1.4 s, corresponding to at least one stride at walk and two strides at fast trot (see Fig. 1). This filter was applied to the raw data for the left and the right rein separately. Data for each test were split into sections, using rein tension data time-stamps and clock times recorded during the test. The current study used data from five segments (see Table 1): walk in a straight line, trot at racing speed in both directions and trot on a circle in both directions. For each segment, medians of the filtered rein tension data from the left and right reins were calculated prior to statistical analysis. This did not apply to rein tension data from 'jog' because we could not synchronize time-stamps of rein tension recordings with real time intervals for jogging. Thus, data from question Q8 were excluded from further analysis.

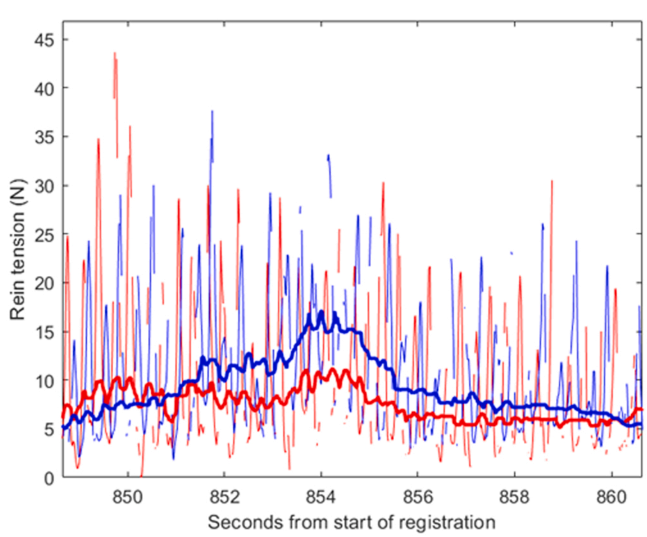

Fig. 1. Showing an example (test day 8, horse 2) of the raw data for left (red) and right (blue) median rein tension (in N). Lines represent data after application of the moving median filter (left rein: red; right rein: blue) for a horse while circling in trot to the right.

The following data were extracted from the driver questionnaires about horses: the three response alternatives for Q1 (horse leaning on left/right/both reins) were combined into two binary variables, i.e., leaning on the left rein (yes/no), and leaning on the right rein (yes/no). For Q2, exploring whether or not the horse was perceived as soft in the mouth, answers were simplified to yes/no (all negative responses were combined). For questions Q3 and Q4, exploring whether the horse was more difficult to drive or turn in one direction than the other, answers were coded as difficult to the left yes/no and difficult to the right yes/no, similar to Q1. For Q5 (scoring of temperament), the average score across all horses was determined for each temperament characteristic and these averages were used as a cut-off to create dichotomous variables, i.e., relaxed (yes if scored ≥ 3), tense (if ≥ 2), slow (if ≥ 2), alert (if ≥ 3), and strong-willed (if ≥ 1). If drivers responded '*Don't know/No opinion*' to any question, this was recorded as a missing value. Answers to Q7 and Q9 were recorded as numerical values.

2.7. Data analysis

SAS (version 9.4, SAS Institute Inc., Cary, NC, US) and Minitab Statistical Software (version 19.2020.1, United Kingdom) were used for statistical analysis.

To investigate whether drivers' subjective appraisal of horses' behavioural responses was related to actual rein tension (see Aim ii) and perceived driveability (see Aim iii), data were analysed with mixed models that accounted for repeated measures per driver and horse (SAS Proc MIXED procedure). Models were formulated with the following two outcome variables: (A) segment median rein tension (for both left and right reins), and (B) driveability. In model A, the variables segment (Walk, Circle Left/Circle Right, Trot Left/Trot Right,) and rein (left/right) were forced as fixed effects to control for these factors. The following explanatory variables of horse and driver attributes were added to both models, i.e., horse sex (mare, gelding), driver sex (male, female), driver experience ($\geq$ 10 years, or less), driver competition experience (yes/no), horse's position on the track (first/second/third) and test number (first/second/third of the day) were modelled as categorical effects. The horses' age was modelled as a linear effect. Non-significant driver/horse characteristics were then sequentially removed according to the type III p-value < 0.05. To these reduced models (A and B), questionnaire response variables describing the driver's perception of the horse were added (except that driveability scoring, Q6, was not tested in model B because it was the outcome variable in that model). For Q1, Q3, and Q4, both response options derived from the respective question were added in a single model. Other than that, all questionnaire variables were evaluated separately, one at a time. All questionnaire response variables were modelled as categorical effects, except Q6 (driveability), Q7 (perceived rein tension in walk) and Q9 (perceived rein tension in trot) that were analysed as linear effects. Horse and driver were included as random factors in all models. Since drivers were not asked to evaluate the horses separately for each segment, data for the segments judged as most relevant for each question were selected. The segments analysed were Trot Left/Trot Right for questions Q1–3, Circle Left/Circle Right for Q4, all segments (Trot Left/Trot Right, Circle Left/Circle Right, Walk) for Q5–6, Walk for Q7, and Trot Left/Trot Right for Q9.

Model B was also used to investigate the effect of driver and horse, respectively, on driveability (see Aim iv). Thus, the model included either of these as fixed effects, while removing the same factor from the random portion.

Outcome variables were modelled after normality evaluation by Box-Cox transformation (SAS-procedure PROC TRANSREG). Median rein tension data were modelled in fourth-root format, and driveability data were modelled in square-root format. Least-square means were calculated and back-transformed for easier interpretation (presented in both

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formats). The SAS-option PDIFF was used for pair-wise comparisons of categories when the type III p-value was significant. Adjustments for multiple comparisons were not made and interactions were not tested. The p-value limit was set to 0.05.

3. Results

Eleven drivers were assigned to a pool of nine horses such that nine drivers tested three different horses each and two drivers drove only two of the horses. This resulted in a total of 31 test drives.

Overall, segment had a significant effect on rein tension ($F_{4,\ 234} = 195.3$, $P < 0.001$; Fig. 2). Rein tension was significantly higher in racing trot (Trot Left/Trot Right) than trotting on a circle (Circle Left/Circle Right) and walking ($P < 0.001$) and tended to be higher in the counter-clockwise direction than in clockwise direction when trotting fast ($t = 1.90$, $P = 0.058$). There was no effect of side of rein, i.e., left or right rein on median rein tension ($F_{1,\ 234} = 0.57$, $P = 0.452$).

The explanatory variables of horse and driver attributes that were initially evaluated in Models A and B had no significant associations with measured rein tension or driveability scores. Therefore, none of these variables were included in the models. Apart from rein (left/right) and segment (which were forced), there were significant effects of questionnaire variables Q1, Q5, and Q9 for rein tension (Model A) and variables Q1 and Q9 for driveability scores (Model B, see Table 2). Driver had a significant association with driveability score ($F_{10,\ 14} = 4.19$, $P = 0.008$; see Fig. 3a) but not horse (see Fig. 3b).

3.1. *Leaning on the left or the right rein (Q1)*

After just over half of the test drives (57%, 17/30), horses were described by drivers as leaning on both reins while in 33% (10/30), horses were reported to lean more on the left rein, and in only 7% (2/30) horses were reported to lean more on the right rein. One driver used the answer alternative '*Don't know/No opinion*'. The questionnaire response variable '*lean left*' affected rein tension significantly ($F_{1,\ 77} = 21.0$, $P < 0.001$). For racing trot in both directions, drivers who scored horses as leaning more to the left had higher rein tension (62.7 N) than the horses described as not leaning on the left rein (36.9 N; $t = -4.6$, $P < 0.001$).

When drivers reported horses as leaning more to the left, driveability scores tended to increase from score 6.5 (not leaning on the left rein) to 7.9 (leaning on the left rein; $F_{1,\ 11} = 4.13$, $P = 0.067$, Table 2).

3.2. *Softness in the mouth (Q2)*

After most test drives (79%, 23/29), the horses in the current study were reported to be soft in the mouth whereas in 21% (6/29) horses received the opposite score, i.e., were described as leaning on the bit or pulling the reins. However, reported softness in the mouth was not significantly associated with rein tension in fast trot ($F_{2,\ 81} = 2.1$, $P = 0.129$).

3.3. *Directional preference (Q3, Q4)*

After 61% (19/31) of the test drives, the horses were described as easy to drive in both directions. After 26% (8/31) of the tests, horses were described as more difficult to drive in clockwise direction while after only 10% (3/31) of test drives, horses were described as more difficult in counter-clockwise direction. One driver chose the answer alternative '*Don't know/No opinion*'. The drivers' scoring of horses as either difficult to drive to the left (yes/no; $F_{1,\ 81} = 0.85$, $P = 0.358$) or to the right (yes/no; $F_{1,\ 81} = 0.05$, $P = 0.826$) had no association with rein tension recorded in fast trot.

When drivers were asked to score easiness of trotting on a left versus a right circle, most reported horses as being more difficult to the left (77%, 24/31 of drives) than to the right (3%, 1/31 of drives). After 19% (6/31) of drives, no difference in easiness of trotting on a circle in either direction was reported. There was no significant association between measured rein tension and drivers' scores for easiness of trotting on a circle ($P > 0.05$).

Driveability scores were affected by neither how the driver experienced the horse when trotting in counter-clockwise or clockwise direction nor when trotting on a circle in either direction ($P > 0.05$).

3.4. *Temperament (Q5)*

On a scale from 1 (do not agree) to 5 (completely agree), most horses were described as alert (median score 4 [3; 4]) and relaxed (3 [2; 4]).

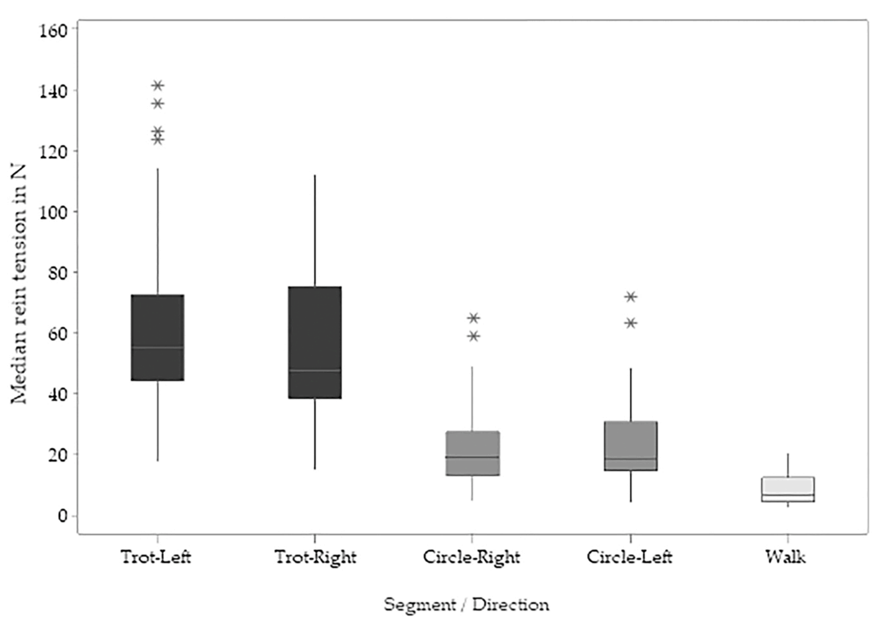


Fig. 2. Boxplot of the distribution of filtered rein tension (median in N) for the 31 driver-horse pairs in the segments fast trot (Trot Left, Trot Right), trot on a circle in each direction (Circle Left, Circle Right) and during walk. The grey boxplots show the first quartile (25%), the median, the second quartile (75%) and the range of rein tensions (minimum, maximum) including outliers (*).

Table 2
Overview of summary statistics including the variables analysed in Model A (Rein tension) and Model B (Driveability). Model results are presented as least square means in untransformed (estimate) and back-transformed format.

Dependent variable	Explanatory variable		Least-square means: Estimate	Standard error	Estimate back-transformed	p-value
(A) Rein tension	Segment	(Intercept)	1.71	0.08		< 0.001
		Circle Left	2.16	0.08	21.81	
		Circle Right	2.16	0.08	21.81	
		Trot Left	2.81	0.08	62.62	
		Trot Right	2.72	0.08	55.07	
		Walk	1.70	0.08	8.31	
	Q1	Leaning left - yes	2.81	0.08	62.70	< 0.0001
		Leaning left - no	2.46	0.11	36.88	
	Q4	Circle left - yes	2.07	0.12	18.30	0.531
		Circle left - no	2.02	0.12	16.79	
	Q5	Relaxed - yes	2.27	0.08	26.42	0.063
		Relaxed - no	2.35	0.07	30.40	
(B) Driveability	Q1	Leaning left - yes	62.87	6.10	7.93	0.067
		Leaning left - no	42.35	10.84	6.51	

Fewer horses were described as tense (2 [1; 3]), slow (2 [1; 2]) and strong-willed (1 [1; 1]; see Fig. 4). When considered across all segments, those horses described as relaxed had lower rein tensions ($F_{1, 233} = 3.5$, $P = 0.063$) than those described as not relaxed (relaxed: 26.4 N; not relaxed: 30.4 N).

3.5. Driveability scoring and rein tensions (Q6)

On a linear scale from 1 (bad) to 10 (excellent), the median driveability score assigned to horses was 8 [Q1 6.7; Q3 8.7] (see Fig. 3b). There was no significant effect of driveability scores on rein tension including measurements from the segments for fast trotting, trotting on a circle and walking ($F_{1, 233} = 0.00$, $P = 0.986$; see Fig. 5).

3.6. Estimated versus measured rein tensions (Q7, Q9)

Drivers' estimated rein tension for fast trot was significantly predictive of measured rein tension ($F_{1, 82} = 11.89$, $P < 0.001$), i.e., in that higher estimated rein tension was associated with higher actual rein tension (analysed as median filtered rein tension, see Fig. 6).

Furthermore, drivers' estimated rein tension for fast trot was associated significantly with driveability scores ($F_{1, 13} = 5.90$, $P = 0.030$) in that driveability scores increased with increasing estimated rein tension. In walk, there was no significant association between drivers' reported rein tension and measured rein tension in walk ($F_{1, 33} = 0.09$, $P = 0.765$).

4. Discussion

The current study has, for the first time, provided objective quantitative measures of rein tension as they arise in training for harness racing as well as qualitative data on horses' reactions and perceived driveability.

4.1. Rein tensions during racetrack training

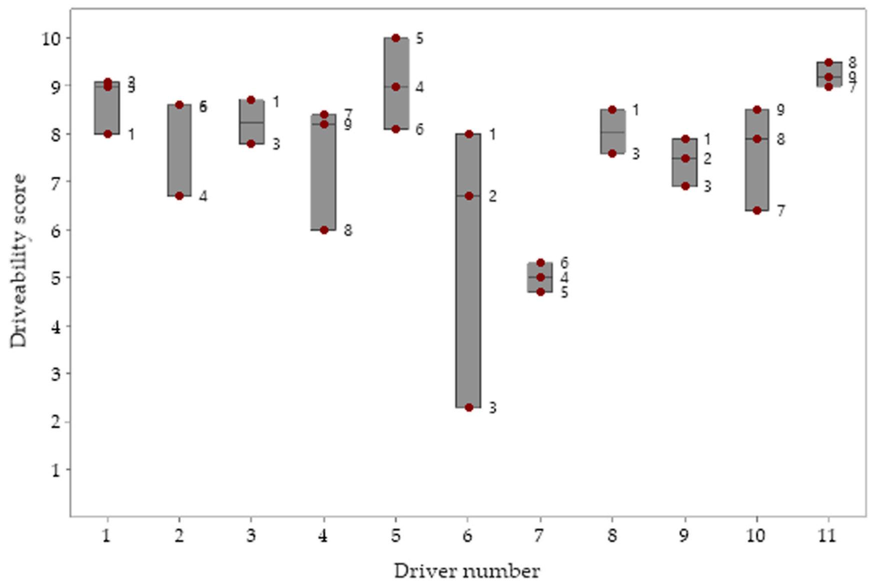
Overall, when Standardbreds were driven by Wången's students and staff on the school's racetrack, faster gaits were reliably associated with higher rein tension. This aligns with the general consensus among drivers and empirical data (Dumbell et al., 2019) that the magnitude of rein tension increases with the gait. In the current study, rein tensions reached on average 8 N when walking, 23 N during slow trot on a circle and 59 N during racing trot. By comparison, in riding horses, average rein tensions measured during walking were, e.g., 4 N and 15 N with short versus long reins, respectively (Eisersiö et al., 2015), 22 N during sitting trot and 17 N in posting trot (Eisersiö et al., 2015; Dumbell et al., 2019). During canter, rein tensions can reach on average 23 N (Eisersiö et al., 2015) or up to 56 N (Egenvall et al., 2016). Thus, average rein tensions (not accounting for peak-rein tension) in Standardbreds seem to be higher than in ridden horses specifically during fast trot where they resemble values for horses ridden in canter. Notably, there are currently no published data available that reveal peak rein tensions when Standardbreds compete, as distinct from when they are trained at their familiar home racetrack (as was the case in the current study). It is well established that the competition environment can elicit stress responses in the horse (Munk et al., 2017) which, in case of racing Standardbreds, may prompt an escalation of rein tensions as drivers work to maintain control. This may be reflected in significantly higher incidences of soft tissue damage in the mouth after competition than have been recorded in Standardbreds in training (Odelros and Wattle, 2018; Tuomola et al., 2019). Whether or not soft tissue damage after competitive racing is correlated to higher peak rein tensions or whether it is caused by the use of harsher equipment, or a combination of both, remains open for investigation.

Measured rein tension based on the direction of trotting (i.e., to the left or the right hand) tended to be higher when racing counter-clockwise which is also the direction horses compete at official races in Sweden. The reason for this difference can only be speculated upon. For example, perhaps horses have simply learned, based on the driver's cues, that fastest locomotion is connected to trotting in counter-clockwise direction. Moreover, during race training, trotting slower for warm-up purposes is often conducted in a clockwise direction, which would support this hypothesis.

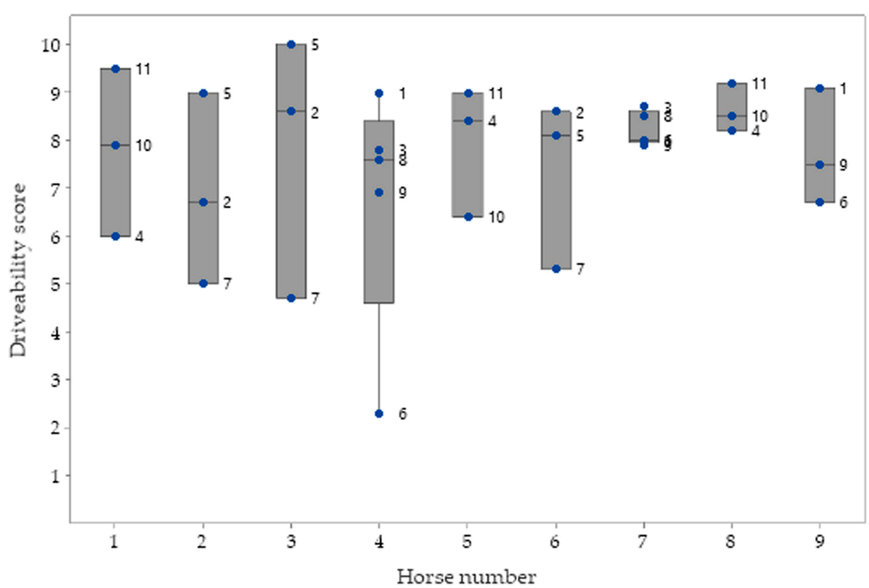
The side of rein (i.e., left or right) had no effect on recorded rein tensions. Thus, on an oval racetrack, horses seem to be driven with equal left/right rein tension throughout which may be supported by the track features such as radius and banking of the curves (Thomason and Peterson, 2008; Kallerud et al., 2021b). This provides evidence that an 'even contact' can be maintained not only in a straight line (Warren-Smith et al., 2007) but around the curves of an oval, depending on track features. Lateral flexion of the neck, which is usually associated with differences in left/right rein tension (Kuhnke et al., 2010) would be undesirable on the racetrack as it can interfere with performance (e.g., deviation from a straight line would lead to a biomechanical disadvantage). This would cause vertical movement asymmetries and changes in stride characteristics including speed (Clayton, 1994; Vilar et al., 2008; Pfau et al., 2012; Byström et al., 2021) and comprised safety (e.g., bended neck can obscure the driver's view and disturb neighbouring horses when racing in a tight field of other horses).

4.2. Drivers' perceptions of horses' behavioural reactions that accompany rein tensions

After 57% of drives, horses were reported to be leaning on both reins,



(a)



(b)

Fig. 3. Boxplot of driveability scores (1 = poor, 10 = excellent) assigned by 11 drivers (numbers 1-11) to each of their three and two horses (total nine horses, numbers 1-9). Figure (a) shows the driveability score distribution among drivers, and figure (b) according to horses. Grey boxplots showing the first quartile (25 %), the median, the second quartile (75 %) of assigned driveability scores and the range of values (minimum, maximum).

which highlights that side of rein was not associated with actual rein tensions. Nevertheless, 33% of horses were described as leaning more on the left rein. This aligns with the finding that such horses also had higher rein tensions than horses not described as leaning to the left. Thus, drivers seem to be able to assess accurately horses' reactions to rein signals.

Softness in the mouth may be regarded as one important indicator of a horse's responsiveness or sensitivity to rein signals. After most test drives (79%), drivers described the Standardbreds in the current study as being soft in the mouth. Yet, the test horses were not characterised by having especially low measured rein tensions. Hence, there is no evidence that a 'soft mouth' may be linked to lower average rein tension. Thus, softness in the mouth remains a subjective evaluation and raises the question of what constitutes optimal contact to safeguard horse welfare. As an example, the driving rules of the Fédération Equestre Internationale (FEI, 2022, Article 954, 18.3) define contact as "the connection through the reins between the Athlete's hands and the horse's mouth and [it is noted that it] should be soft and steady at all times." Clearly, this calls for more studies investigating of what drivers think they are doing and what they are actually doing to improve our understanding of common equitation concepts (Randle and Abbey, 2013) and how they relate to harness racing horses.

The reported ease with which the current horses could be driven in both directions may, at least in part, reflect the drivers' overall perception that most horses were neither leaning more on one side of the rein than the other and that they were experienced as soft in the mouth. Even though competitive racing is performed in counter-clockwise direction, training of Standardbreds is usually conducted in both directions. Thus, not only the school horses but also the drivers in the current study were familiar with driving to the right, which may help to

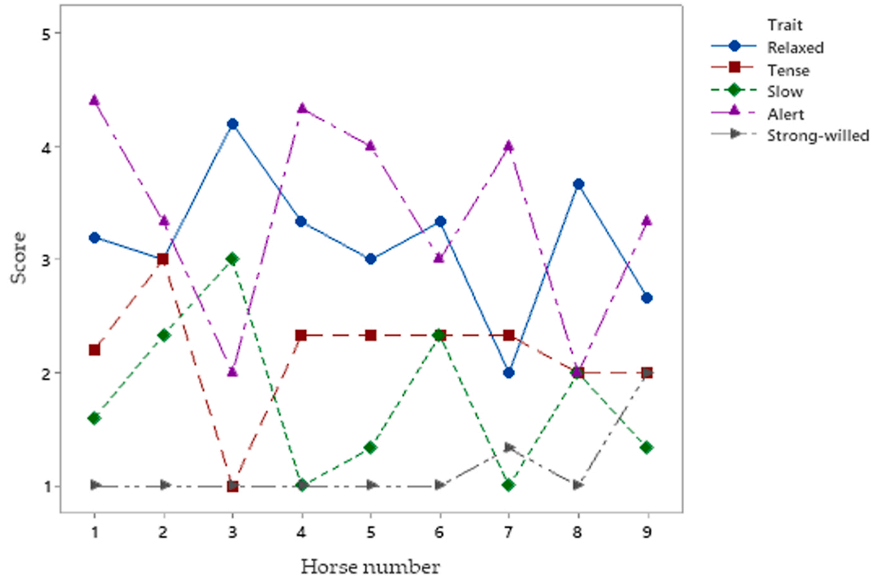


Fig. 4. The mean distribution of behavioural traits of the nine horses (numbers 1 – 9) as scored by 11 drivers. Each trait was scored on a scale from 1 (do not agree) to 5 (completely agree).

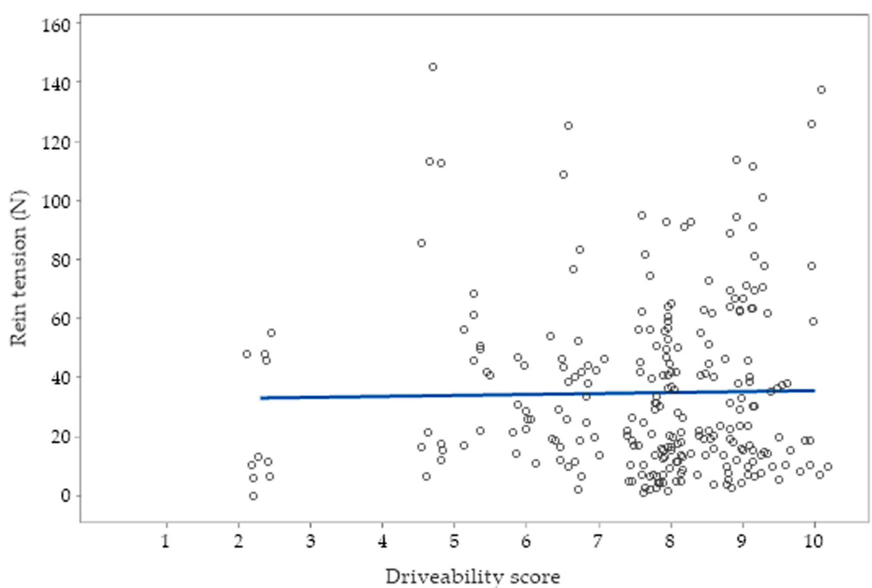


Fig. 5. Scatterplot with regression line (blue) showing the relationship between driveability scores (linear numeric scale from 1 - poor to 10 - excellent) and measured rein tension.

explain this finding. Conversely, trotting in a circle is not part of regular race training but is requested during certain competitions for the purpose of aligning the field at the start of a race (as in a so-called circle start, from a 20 m diameter circle). During competitions, horses that prove difficult to control during circling may be disqualified immediately according to the Swedish competition rules for harness racing (Swedish Trotting Association, 2022, Article § 49). In the current study, after 77% of the drives, horses were described as being difficult to circle in counter-clockwise direction although this was not statistically associated with changes in measured rein tension. As a result of conditioned race-related arousal and consequent habit formation, horses may learn to anticipate that circling to the left hand is followed by fast trotting. This chain of associative learning may explain what the drivers perceive and report. This is in addition to established knowledge that any circular movement can cause systematic changes in movement symmetry in horses (Robartes et al., 2013; Byström et al., 2020) thus potentially compromising driveability. That said, driveability scores were not associated with how the drivers described their horses responsivity on a circle. This may reflect the large variation of the drivers' driveability scoring. Similar results have been found in ridden horses (Christensen et al., 2021) emphasising that individual riders/drivers differ in their interpretation of rideability/driveability possibly as an interaction with their personality traits (Visser et al., 2008), laterality and handedness (Kuhnke et al., 2010; Byström et al., 2020) or with riding style (Persson-Sjodin et al., 2018).

Clearly, the current driveability scores were not associated with actual rein tensions supporting the idea that drivers may have scored with traits other than rein tension in mind. This is in contrast to a study of ridden horses in which rideability scores dropped inversely with mean, maximum and variability in rein tension (König von Borstel and Glißman, 2014). Notably, assessment of driveability and its possible attributes (e.g., straightness, softness in the mouth, response to signals

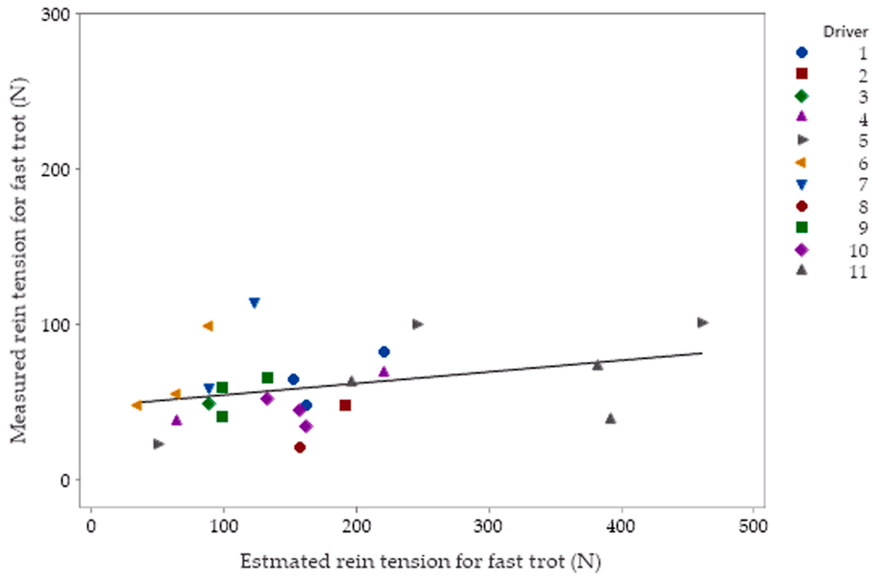


Fig. 6. Scatterplot with regression line (grey) showing the relation between measured rein tension and estimated rein tension (N) by 11 drivers (numbers 1–11) for fast trot in both directions.

from the driver) were not explained to drivers before they were asked to score the current horse and this omission may have affected current results. On the other hand, driveability scores in the current study increased with increasing estimated rein tension (in racing trot) whereas actual rein tensions tended to decrease when horses were described as 'relaxed'. In contrast with previous studies that evaluated pre-race behaviours as predictors of performance in Thoroughbreds (Hutson and Haskell, 1997; Pinchbeck et al., 2004), and indicated that relaxed horses may be easier to control, it may be that, in the case of the Standardbred, an even, heavier contact via the reins may be desired for optimal driveability. This is counter-intuitive but implies that, in harness racing, escalated rein tension is not applied as a form of negative reinforcement, but instead that the release of tension prompts horses to run faster as reports from race trainers have confirmed. So, in this instance, increased rein tension is used primarily to restrain the horses rather than to signal to them. The principles of learning theory suggest that this would lead to habituation to bit pressure, in that the more fast trotting horses undertake with elevated rein tensions, the worse their slowing or stopping response may become. This undesirable prospect underlines the potential benefit of combining rein signals with cues of other modalities (e.g., voice commands) to help horses to distinguish between the release of bit pressure and adoption of a certain speed. Notably, this variation in how horses acquire responses to changes in rein tensions may reflect an inherent difference between training horses for riding and harness racing. That said, anecdotal observations of rein use in galloping races suggest that rein tension for restraint and release as a cue for acceleration is also common in racing Thoroughbreds.

The study had several limitations. There are potential artefacts when investigating rein tensions applied to school horses driven by amateur students as compared to those that apply to professional drivers and high-level competition horses. Moreover, the relatively small number of drivers and horses in the current study represents a limitation, even though we counterbalanced variability on both drivers and horses by having a cross-over study design. Also, it was not explicitly explained to participating drivers how to estimate rein tension. Thus, there may be variation in how they judged how 1 kg of rein tension, for example, might feel. Due to considerable data loss during sampling and a lower sampling frequency than the 100 Hz recommended by Clayton et al. (2021), the rein tension meter could not provide accurate and reliable peak rein tension readings for all measurements. This would have been important to include in the data analysis to objectively evaluate potential risks to horse welfare. Nevertheless, we see this project as a first important step toward quantifying rein tensions as they apply to Standardbreds in training. Moreover, the current data provide a strong base from which to develop follow-up studies that can address questions such as the effect on rein tension of driver's experience, horse's training level and equipment used.

5. Conclusions

Harness racing differs from most other equestrian sports in that the main communication between horse and human is through the driving reins. Thus, it is paramount that drivers are aware of the rein tensions they apply so that training deficits reflected in habituation to rein signals and consequent loss of effective control can be avoided. Moreover, this would also help to avoid the use of harsher bits as a default response to decreased controllability and thereby low driveability. Clearly, measuring rein tension objectively and monitoring can optimise training and performance outcomes while simultaneously making driving horses safer for humans. The current study has confirmed that rein tensiometry may have a place in providing an evidence base for consistent rein use when horses are driven by multiple drivers. It opens up further scientific enquiry to establish a reliable assessment of driveability in harness racing trotters, i.e., Standardbreds and Coldblooded trotters and ultimately in other horse breeds used for harness racing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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