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Final report

***Project title:* Measuring rein tension in Standardbred trotters: are we driving with a faulty brake?**

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Main applicant:
Elke Hartmann, Swedish University of Agricultural Sciences, SLU
elke.hartmann@slu.se

Co-applicant(s):
Malin Connysson (SLU, Wången)
Magnus Karlsteen (Chalmers University, Sweden)
Kathrin Kienapfel-Henseleit (Agroscope Switzerland)

Other project group members: Prof Agneta Egenvall (SLU), Dr Anna Byström (SLU), Prof Paul McGreevy (University of New England, Australia), Mette Pökelmann (Wången)

Part 1: Detailed summary

Travsport är riskfyllt, eftersom hästarna springer nära varandra i hög hastighet under träning och tävling. En effektiv kommunikation mellan kusk och häst, via signaler från töm till bett, är därför avgörande ur säkerhetssynpunkt och med hänsyn för hästens välfärd. Trots detta saknas det vetenskapliga studier av hur hög kraften i tömmarna är hos travhästar.

Målet med projektet var därför att studera variationen i tömkraft hos varmblodiga travhästar vid träning på hemmabana (studie 1) samt under ett träningslopp på en tävlingsbana (studie 2). Dessutom ville vi undersöka hur kuskarna upplevde tömkraften och hästens svar på tömsignaler samt deras bedömning av hästens körbarhet under träning och lopp. Projektets övergripande mål var att tillhandahålla evidensbaserad data som kan stödja den svenska travsporten i att tillhandahålla evidensbaserat utbildningsmaterial för kuskar och tränare och fatta välgrundade beslut med hänsyn till hästvälfärd.

Projektet var uppdelat i två två studier. I *studie 1* mätte vi tömkraften hos 9 varmblodiga travhästar (skolhästar) som kördes av 11 kuskar på riksanläggning Wångens travbana där de utförde standardiserade körövningar (t.ex. tempoväxlingar och nedtagningar, höger/vänster körriktning). I *studie 2* studerade vi 8 av Wångens skolhästar och 4 privatägda travare körda på Österunds travbana under ett träningslopp (2 lopp med 6 hästar vardera). Tömkraft registrerades med sensorer placerade mellan höger och vänster töm och bettet. Data loggades via bluetooth till en mobiltelefon. Det visade sig i efterhand att samtliga datapunkter (80/s) inte alltid

registrerades. Därför kunde variation och maxvärde för enskilda steg inte studeras, istället uppskattades genomsnittlig (median) tömkraft. Hästarnas rörelsesymmetri i trav vid hand, hjärtfrekvens, hastighet och förekomst av munskador registrerades också. Kuskarna fick svara på enkätfrågor, t.ex. hur de uppfattade hästarnas körbarhet, temperament, om hästarna upplevdes som mjuka i munnen och de fick uppskatta tömkraftens storlek hos hästen de körde.

I *studie 1* låg kraften i tömmarna mellan 5.1-6.2 kg i vardera töm när hästarna travade i full hastighet, maximalt upp till 7.3-8.7 kg (uppskattat genomsnitt per steg). Högre hjärtfrekvens hade ett samband med högre tömkraft, vilket är förväntat eftersom både tömkraft och hjärtfrekvens var högre i snabbt tempo. Bakbensasymmetri var förknippat med högre tömkraft jämfört med symmetriska hästar. Kuskarnas bedömning av hästens känslighet i munnen avspeglades inte i tömkraften. Det fanns inte heller något samband mellan tömkraft och kuskens skattning av hästens körbarhet. Dock fanns det en korrelation mellan kuskarnas uppskattade tömkraft (genomsnitt för uppskattad kraft: 16 kg) och deras bedömning av körbarheten, dvs. körbarheten ökade vid högre upplevd tömkraft i snabbare tempo i trav.

I *studie 2* ingick både privatägda hästar och skolhästar från Wången, totalt 12 hästar. Hästarna kördes under tävlingsliknande förhållanden under ett provlopp på Östersunds travbana. Data analyseras för närvarande. Preliminära resultat tyder på att tömkraften i genomsnitt (median) var i nivå med studie 1, mellan 4.0-8.0 kg, men att de maximala värdena var betydligt högre, 15.8-19.8 kg. Kuskarna upplevde tömkraften som ännu högre, genomsnitt för uppskattad kraft var ca 30 kg. Kuskarna skattade hästarnas körbarhet till 7 i genomsnitt, på en skala från 1 (dåligt) till 10 (utmärkt), vilket är något lägre än i studie 1 (genomsnitt 8). Före loppet hade ingen av de 12 hästarna några munskador (blåmärken eller sår) i bettområdet men direkt efter provloppet hade 8 hästar någon typ av munskador.

Studierna, som är de första i sitt slag, visade tydligt att tömkraften hos travhäst vid träning i snabb trav och under lopp är högre än tygelkrafter som uppmätts hos de flesta ridhästar. Vad som är optimal tömkraft med tanke på körbarhet, hästens välfärd och kuskens säkerhet är en fråga som återstår att besvara och som nu studeras i ett uppföljande projekt: Travsporten ur ett vetenskapligt perspektiv - körbarhet som ett koncept för att förstå kopplingar mellan beteende, val av utrustning, optimal prestation och god hästvälfärd (Stiftelsen Hästforskning, 2022-2025).

I motsats till vad som ursprungligen angavs i projektansökan mätte vi inte tygelkraften hos ridna travare (så kallad ”Monté” dvs. travlopp med ryttare) på grund av brist på tillräckligt antal lämpliga ryttare-häst par på riksanläggningen Wången. Det kvarstår att undersöka i en framtida studie då det är mycket relevant med hänsyn till att vissa hävstångsbett idag endast är tillåtna i monté och det saknas objektiva argument för att tillåta dessa. Ryttarens position vid monté är också närmare bettet och hur detta kan påverka tygelkraften har inte undersökts.

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Part 2: Main report

Introduction

Undoubtedly, horse sport is in the spotlight of public debate and the sector itself is calling for significant horse welfare improvements across all equestrian disciplines and competition levels (Douglas et al., 2022). Scientific data present a troubling image of the various sports, as reflected, for example, in a high percentage (35-80%) of horses competing with mouth injuries (e.g., Björnsdóttir et al., 2014; Tuomola et al., 2019; Uldahl and Clayton, 2019; Tuomola et al., 2021a). Inappropriate equipment choices and ill-fitting tack, either alone or in combination with excessive rein tension (RT) leading to equally excessive bit pressures in the horse's mouth are among the probable causes.

To facilitate positive change, it is important to assess the variability and magnitude of RT that harness racing horses are exposed to during training and competition, together with horses' accompanying behavioural, physiological (heart rate), and locomotory responses. Moreover, to maintain a thriving and sustainable harness racing industry in which safeguarding horse welfare is a primary concern, we need to understand drivers' perceptions of RT and what parameters they use to characterise optimal driveability and horse welfare.

By measuring RT objectively, we can identify a starting point for informing and educating drivers about how communication via the driving reins can be enhanced so that the use of harsher equipment and associated potential horse welfare risks can be avoided. This can set benchmarks to optimise training and performance outcomes.

Thus, the current project aimed to measure RT during standardised tests (at home and on a public racetrack) to: 1) determine the variation and magnitude of RT; 2) determine how RT relates to the horses' behaviour, physiological responses (heart rate), perceived driveability and incidence of soft tissue injuries in the mouth; and 3) determine associations between RT and movement symmetry.

Overall, the project objective was to provide evidence-based data that can support the harness racing industry in tailoring education for drivers/trainers/handlers and in making informed decisions on animal welfare grounds.

Material and methods

The project was divided into two parts: *Study 1* aimed to measure RT in Standardbred horses driven on their home racetrack, whereas *Study 2* aimed to measure RT in trotters driven in a simulated competition at a nearby public racetrack. The studies were conducted in close collaboration with Wången, Sweden's national centre for the education and development of harness racing and Icelandic horse riding. The participating trotters were race-trained adult school horses (Standardbred mares and geldings) driven by experienced students and staff from Wången as well as privately owned horses driven by their drivers/trainers.

Prior to participation in these studies, all horses underwent an oral health check (protocol according to Tuomola et al. (2019) and gait examination (see Egenvall et al., 2022) to assure that they were free from mouth lesions and lameness.

Study 1 - Methods

Study 1 involved a total of nine Standardbreds (4 mares, 5 geldings) between 3 - 14 years (mean 7.8 ± SE 2.1 years), seven of which had competition experience. Eleven drivers were enrolled; of whom seven drivers were students from Wången's secondary school and four drivers were staff members, all of whom were experienced in the management, training and racing of Standardbreds. Participating drivers were asked to complete a questionnaire that included questions on their experience of training and racing Standardbreds, their handedness (e.g., preferred hand for writing, throwing, brushing teeth), and how they experienced the horse they drove in the current study (e.g., temperament, softness in the mouth, responses to rein signals, perceived RT).

The horses were driven on Wången's racetrack (1000 m long banked gravel oval track) in groups of three. Each group performed three tests in succession on the same day, and in each test, horses were driven by a different driver (who had been randomly allocated to the horses). Seven horses participated in three test drives each, and two horses participated in five. Thus, the total number of tests was 31. The exercise test on the racetrack consisted of driving in different gaits, speeds and directions, as outlined in Table 1. This was done to simulate race training and thereby to record corresponding variations and magnitudes of RT. Horses wore their regular training equipment, consisting of an open bridle (i.e. without blinders) with a loose noseband and a single-jointed snaffle-type metal driving bit. Horses were not driven with any auxiliary equipment for controlling head/neck movements.

Table 1. Exercise test containing the segments in order of occurrence and specification for direction [i.e. driving to the left (counterclockwise) or right (clockwise)], and average speed (in m/s; Mean ± SD)

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

All test horses were equipped with commercially available rein sensors (IPOS Technology B.V., Eindhoven, The Netherlands) for measuring the tension applied through both the left and the right rein. Additionally, horses wore equipment for measuring heart rate and speed (Polar Electro, Kempele, Finland).

Study 2 - Methods

In Study 2, five adult Standardbred mares and seven geldings between 3-12 years (6.3 ± 0.8) in competition condition were included. Of these, eight horses were school horses from Wången and four horses were privately owned. The 12 horses were driven by 12 different drivers. Students from Wången drove the school horses and the privately owned horses were driven by their respective drivers/trainers. Bit type used varied between horses and included single-jointed (10 horses), double-jointed (1 horse), and straight (1 horse) snaffle-type driving bits. Ten of the twelve horses wore an overcheck, but overcheck bits were only used in three horses. One horse was raced with a tongue tie. All drivers answered a questionnaire, as in Study 1.

The horses were driven in a simulated competition race that covered a distance of 2140 m on Östersund's public racetrack. Six horses participated in the first race, and another six in the second. Horses wore the same measuring equipment for RT and heart rate as outlined for Study 1. Motion pattern symmetry was assessed in horses trotted in-hand before the test race. The horses' mouths (i.e., inner and outer lip commissures, mandible bars, buccal area near the upper teeth, hard palate, tongue) were examined before and directly after the race. The races were video-recorded to allow synchronisation of RT with heart rate and race sections (see Table 2), and to record other events, e.g., if a horse started to gallop. For subsequent analysis, the race was divided into seven segments, as shown in Table 2. Racing direction was counter-clockwise in accordance with Swedish racing standards.

Table 2. Overview of race segments and median speed (m/s) per segment for race 1 and 2.

Segment	Description	Speed race 1	Speed race 2
Parade Ring	Horses jog on a left circle in starting order beside the racetrack	6.6	6.3
Parade	Horses trot over a distance of 200 m on the racetrack pass the audience and judge/finish line in starting order	2.2	2.1
Volte	Circle-start i.e. horses trot on a volte in starting order and face up in the direction of travel (counter-clockwise) at the start command	9.8	7.6
Race 0-140 m	Horses race over a distance of 140 m from circle-start to finish line	12.2	12.4
Race 140-1140 m	Horses race over a distance of 1000 m from 140m and to finish line	11.3	11.9
Race 1140-1940 m	Horses race from finish line over a distance of 800 m to 200 m pole corresponding to area of the circle-start	12.8	13.8
Race 1940-2140 m	Horses race from 200 m pole over a distance of 200 m to finish line	3.4	3.7

Data analysis and statistics

Data were handled in the same way for Studies 1 and 2. RT and heart rate data were processed in Matlab. Due to RT data loss (e.g., malfunctioning of some sensors and incomplete raw data-logging), median-filtered rein tension data (see example in Fig. 1) were used for most RT analyses, calculated 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.

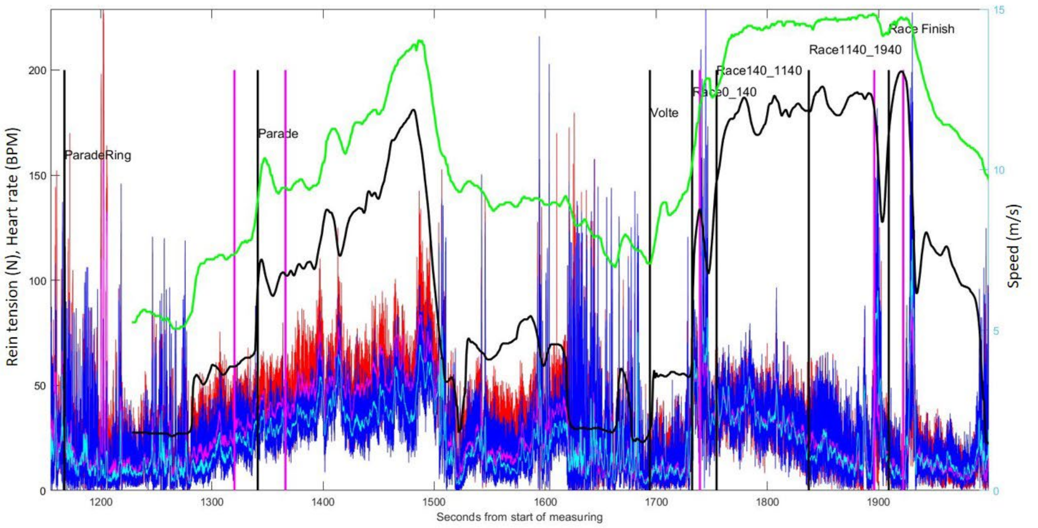

Figure 1. Rein tension (Newton, N), heart rate (beats per minute, BPM) and speed (seconds, m/s) recorded for one horse in study 2 (for examples from Study 1, see Egenvall et al., 2022). Red (left rein) and blue (right rein) traces represent raw data, and magenta (left) and cyan (right) represent median-filtered rein tension. The black trace shows speed, and the green trace heart rate. The vertical lines with acronym labels indicate the start of each race segment (see Table 2) based on manual time protocols from video recordings.

Statistical analyses were based on mixed models (SAS-procedure MIXED) with the outcome variable RT. Horse and driver were included as random effects, and parameters such as segments, fore- or hindlimb asymmetry, heart rate, mouth lesions, experience of driver and horse, horse sex, horse age or position in the field were included as fixed effects (for description of statistical methods used in Study 1, see Egenvall et al., 2022). Questionnaire response variables were analysed separately in mixed models with measured RT (median-filtered) and driveability scores as outcome variables and further summarised descriptively (see Hartmann et al., 2022). Analyses for Study 2 are ongoing and presented results are preliminary.

Results and discussion

Study 1 - Results

None of the nine school horses participating in Study 1 showed any mouth lesions prior to testing. Based on the gait analysis conducted prior to the exercise tests, and according to the lameness locator thresholds, one horse showed forelimb asymmetry, two horses had hindlimb asymmetry, and one horse both fore- and hindlimb asymmetry (see Egenvall et al., 2022).

Figure 2 gives an overview of the measured median RT during racing trot, trotting in a circle and walking while horses were driven in their home environment, performing a standardised exercise test on the racetrack. Median RT peaked during trot at racing speed and was at its lowest during walk ($P < 0.001$). Median RT in fast trot tended to be higher in racing direction (counter-clockwise) than when horses were driven in clockwise direction ($P = 0.058$). RT increased with increasing heart rate ($P < 0.0001$), e.g., if heart rate increased from 100 to 200 BPM, median RT increased from 16 to 28 N.

Horses with hindlimb asymmetry had almost twice the magnitude of RT than those with hindlimb symmetry (least square means 48 N vs. 28 N, $P < 0.01$). None of the drivers showed a significant difference between left and right median RT but three horses showed higher RT in the left rein and one horse in the right rein. Of these four horses, two horses were labeled as asymmetric according to the lameness locator threshold values.

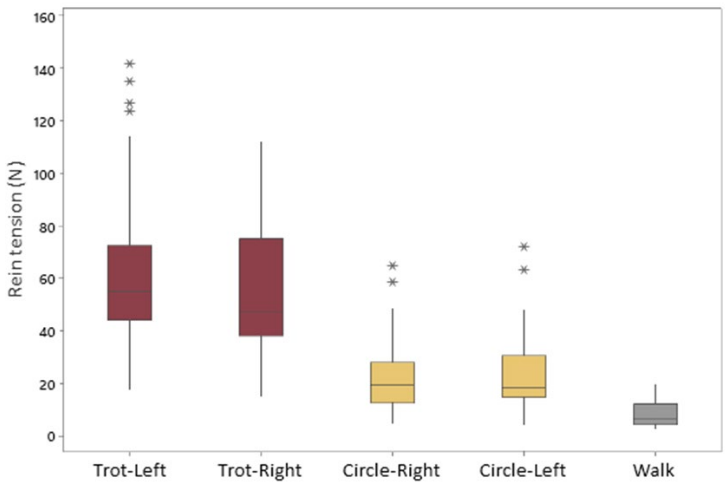

Figure 2. Box plot showing the median RT (Newton, N) for the 31 driver-horse pairs in the segments fast trot (left/right), trot on a circle in each direction and during walking. The box plots show the first quartile (25%), median, second quartile (75%) and range of RT (minimum, maximum). Outlier (*).

Drivers who perceived their horse as leaning on the left rein (33%, 10/30 test drives) had a higher median RT (62.7 N) than horses scored as not leaning on the left rein (36.9 N, P < 0.001). Most horses were labeled as soft in the mouth (79%, 23/29), while some were described as leaning on the bit or pulling the reins (21%, 6/29 tests). Horses described by the driver as relaxed (scale from 1 - do not agree to 5 - completely agree) by the driver tended to have lower RT (26.4 N) than those horses not perceived as relaxed (30.4 N, P = 0.063).

On an ordinal scale from 1 (poor) to 10 (excellent), the median driveability score assigned to the horses was 8. Driveability scores had no significant association with RT considering measurements from the segments racing trot, trotting on a circle and walking (P = 0.986). Drivers' estimated RT for racing trot was predictive of measured RT (P < 0.001), i.e., higher perceived RT was associated with higher measured RT (see Fig. 3). Furthermore, drivers' estimated RT for fast trot was significantly associated with driveability (P = 0.030), i.e. scores increased with increasing estimated RT (see Fig. 4).

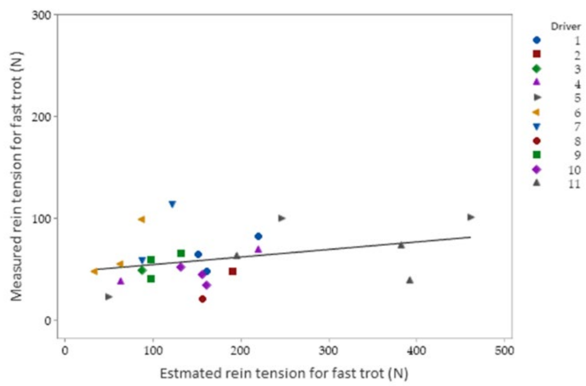

Figure 3. Scatterplot with regression line showing the relation between measured RT (Newton, N) and estimated RT (N) by 11 drivers for fast trot (left/right).

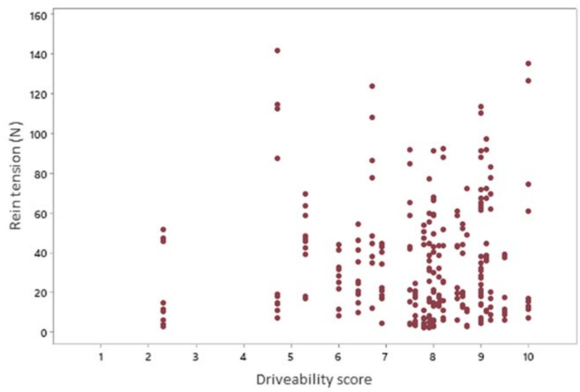

Figure 4. Scatterplot showing the relationship between driveability scores (1- poor to 10- excellent) assigned by 11 drivers and measured RT (Newton, N).

Study 1 - Discussion

In summary, faster gait was associated with higher RT, which aligns with empirical data from ridden horses (Dumbell et al., 2019). Moreover, average RT seems to be higher in driven harness race horses than in ridden horses (Eisersiö et al., 2015; Egenvall et al., 2016; Dumbell et al., 2019). RT tended to be higher in counter-clockwise direction, i.e. the direction in which horses race during competitions in Sweden. This difference may be connected to asymmetrical muscle power from inadvertently asymmetrical training and/or horses' habitual responses of running faster to the left than to the right which may coincide with higher arousal levels.

Most drivers perceived an even left/right rein contact, i.e. horses were perceived to lean equally on both reins. This may be desirable as any lateral flexion of the neck and associated changes in RT could potentially interfere with performance (Byström et al., 2021) or compromise safety during racing. Interestingly, perceived softness in the mouth was not associated with low RT and neither was driveability. This implies that drivers may have scored with other traits in mind and that an even, heavier contact via the reins may be desirable as part of optimal driveability.

The concept of 'contact' and what constitutes optimal rein contact are discussed widely across equestrian disciplines and possibly also within racing. Based on learning theory, rein contact without any intentional increase in RT is typically regarded as a neutral stimulus (McLean and Christensen, 2017). Thus, horses could potentially habituate to a heavier baseline contact which implies that the pressure threshold for eliciting deceleration or changes in direction may need to increase. The fluctuations of these pressure gradients may be a source of confusion for the horse according to McLean and Christensen (2017), specifically if RT is not partially or fully released to reinforce the desired response (as is required in negative reinforcement learning). In harness racing, increased bit pressure may be primarily used to restrain horses from running too fast at the beginning of the race whereby the release of RT then signals horses to increase speed. The same practice of RT for restraint and its release as a cue for acceleration (primarily horses are cued to make their run) is observed in galloping races. This may be a source of confusion because the same cue may be applied to actively slow horses down, e.g. after a parade or during a circle start. This undesirable prospect underlines the potential benefit of combining rein signals with cues of other modalities (e.g., whip signals or voice commands if horses are raced without earplugs) 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 RT may reflect an inherent difference between training horses for riding and racing and warrants further investigation in terms of rein contact.

Horses that were identified as being hindlimb asymmetric had substantially increased median RT. The underlying reason for this relationship is unclear. It may be that horses with such a gait gain some stability by hanging more on one or both reins. Further studies are warranted that measure horses' movements continuously during exercise in combination with RT. The possible relationship between locomotory asymmetry and oral lesions that may result from increased RT also merits scrutiny.

Study 2 - Results

Data from Study 2 are currently being analysed and, therefore, results remain preliminary until publication. All 12 horses were free of oral lesions in the bit area prior to racing whereas seven horses showed lesions when examined a second time directly after the race (see Table 3). Four horses exhibited tongue lesions either at the tip, sides, or ventrum of the tongue, and two horses had small amounts of blood outside their mouths (see Table 3).

Table 3. Oral health data (bit area/tongue region) recorded after the race (protocol by Tuomola et al., 2019). Bruises (points 1-4) and wounds (points 2-8; if deep +2) were given points depending on lesion size (< 5mm, ≤1cm, < 3cm, ≥3 cm) [as per Tuomola et al. (2019)]. Tongue lesions were not included in the total lesion score. Lesion severity status (L-Status) of each horse was determined as follows: none 0 points; mild 1-2 points; moderate 3-11 points and < 8 points for any single lesion; severe >11 points or 8 or more points from a single lesion.

Horse	Description bit-area/tongue	Lesion location	Blood	Total score	L-Statuts
1	-		-	0	none
2	> 1 cm bruise (3p)	left inner lip commissure	-	3	moderate
	0.5-1 cm superficial wound	tongue side			
3	> 1 cm bruise (3p)	right inner lip commissure	-	3	moderate
	0.5-1 cm superficial wound	tongue side			
4	-	-	-	0	none
5	0.5-1 cm superficial wound (2p)	left inner lip commissure	-	2	mild
6	-		-	0	none
7	-		-	0	none
8	0.5-1 cm superficial wound	tongue tip	-	0	none
9	0.5-1 cm superficial wound (4p)	right inner lip commissure	yes	16	severe
	0.5-1 cm superficial wound (4p)	left bar			
	> 1 cm superficial wound (6p)	left buccal area			
	0.5-1 cm bruise (2p)	right bar			
10	0.5-1 cm bruise (2p)	left bar	yes	4	moderate
	0.5-1 cm bruise (2p)	right bar			
	3 cm or larger bruise	under the tongue			
11	0.5-1 cm deep wound (6p) #	right bar	-	6	moderate
12	3 cm or larger bruise (4p)	left inner lip commissure	-	4	moderate

Horse with incidental finding of wolf tooth in the bar of the right mandible.

Based on data obtained from the objective gait evaluation before the race, three horses had forelimb asymmetry, seven horses had hindlimb asymmetry, and two horses had asymmetry in both fore- and hindlimbs.

Questionnaire data revealed that all drivers perceived their horse as leaning on the bit/hanging on the reins. Five horses were perceived to be hanging on the left rein, three horses on the right rein, and four horses were perceived as hanging on both reins. Despite this, the majority of drivers (67%, 8/12) reported that horses were soft in the mouth and scored driveability between a minimum of 2.5 to maximum 9.6 (median 7).

Comparing the two races, the second race was driven a little faster (see Table 2), with horses in a closer group. Rein tension was higher in the second race than the first race, as shown in Table 4. Drivers' estimations of left/right RT during the parade and race are illustrated in Figure 5. The RT was perceived higher during racing (left/right rein 30.8/30.0 kg, respectively) than during the parade (left/right rein 25.0/25.5 kg).

Table 4. Minimum, median and maximum rein tension (analysis based on median filtered RT in Newton, N) recorded during race 1 (R1) and race 2 (R2) and number (No) of observations. Rein tension data were available from 8 horses and from 2 other horses, processed data were used for analysis.

Race	Rein	No observations	Minimum	Median	Maximum
R1	left	36	10	40	155
R1	right	35	9	42	162
R2	left	35	10	76	178
R2	right	36	12	72	194

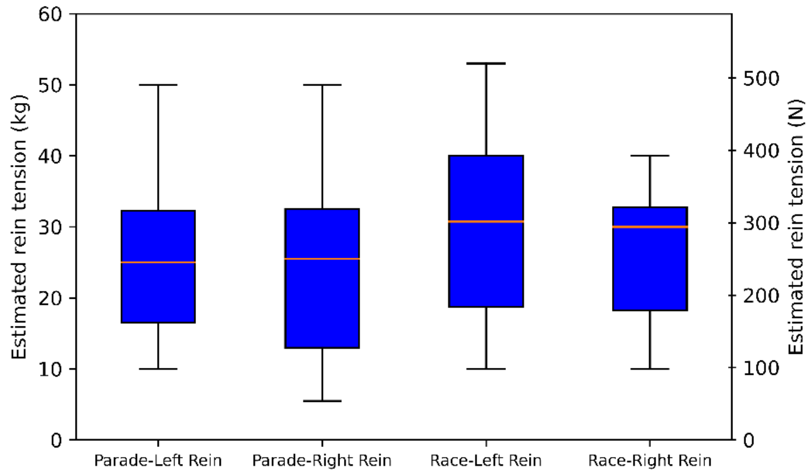

Figure 6. Box plot of drivers' reported perceived rein tension for left and right reins in kilogram (kg) and Newton (N). Drivers could score on a numeric scale from 0-60 kg. Kilogram was chosen as it may be easier for drivers to relate to this measuring unit than to Newton.

Study 2 - Discussion

Since analyses of data from Study 2 are still ongoing, we remain cautious about drawing conclusions. Nevertheless, the data clearly show that measured RT was higher during competitive racing on a public racetrack than when horses were driven in their home environment in Study 1. This corresponds to the generally held belief that the competition environment may be experienced as more arousing for many horses (Munk et al., 2017; Bohák et al., 2018). Higher arousal levels and/or stress in horses may be reflected in diminished responses to human signals and/or horses being more difficult to drive. This may lead to higher RT and corresponds to the finding that horses described as more relaxed tended to have lower RT than horses not perceived as relaxed.

None of the included horses in Study 2 had any mouth lesions in the bit area prior to racing. In contrast, 7 out of 12 horses had mouth lesions recorded directly after competitive racing; a finding that resembles those from other published studies in trotters (e.g. Tuomola et al., 2019). The frequency of oral lesions in trotters seems to be generally higher than those in event horses examined after a cross-country competition (Tuomola et al., 2021a) even though horses in both disciplines perform at high speed. This suggests that additional factors, other than speed and associated higher RT, such as type of bit (Tuomola et al., 2021b) or other equipment (Bennett-Wimbush et al., 2020), including drivers' skill levels, may increase the relative risk of mouth lesions.

Conclusions

To the authors' knowledge, this project has provided the first objective data on RT during training and competition of harness race horses, i.e. Standardbreds. Together with drivers' subjective rating of horses' driveability and perceived levels of RT, it sets the base for informed discussions about horse welfare and driver and horse safety.

Harness racing differs from most other equestrian sports in that the main communication between horse and human is through the driving reins. So, it is paramount that RT is applied optimally and strategically. Drivers need to be aware of both the RT they apply as part of restraint and horses' responses to discrete rein signals. This awareness would also help to avoid the use of harsher equipment in response to diminished responses to rein signals. The current study has confirmed that RT data may have a place in providing an evidence-base for objectively defining 'contact' and horses' responses to rein signals which may be perceived differently by multiple drivers.

Further studies are needed to compare the current results with those that apply to professional drivers and high-level competition horses. Moreover, the relatively small number of drivers and horses in the current studies represents a limitation. This calls for further inquiries that are based on a larger sample size so that e.g., the effects of different types of bits and other equipment, horses' motion patterns and training/competition level can be considered when evaluating the effect of RT on horse welfare. Some of these aspects will be studied in our follow-up project, e.g., motion patterns will be recorded continuously during racing and synchronised with RT, and the effects of certain types of bits on RT and occurrence of mouth lesions will be assessed.

Relevance for the practical horse sector incl. recommendations

The current results provide a base for informed animal welfare discussions within the racing industry, and can support drivers and trainers in making evidence-based decisions about training approaches and equipment choices to ultimately improve the communication between driver and horse. By recognising the forces applied to the horse's mouth through the reins and monitoring horses' oral health throughout training and competition, we can set the base for positive change.

Furthermore, our results emphasise the importance of monitoring horses' responses to rein signals and the need for an open discussion with drivers and trainers about when, how and why rein tension is applied and released in various situations. For example, our results indicate that gait asymmetries (and potentially lameness) are associated with higher measured RT, which suggests that the reins are not only used to control speed and direction but may also be used to balance the horse and keep it from breaking into canter. Interestingly, higher perceived RT was related to higher driveability scores. In contrast, rideability (equivalent industry term for riding horses, i.e. ease and comfort with which a horse can be ridden) scores in riding horses dropped inversely with increased mean, maximum and variability in RT (König von Borstel and Glißman, 2014). Thus, we need to engage in dialogue with drivers and trainers to disentangle attitudes and opinions about driveability as it relates to performance and horse welfare.

Clearly, RT has the potential to provide a more objective evaluation of drivers' sense of contact and control when driving a specific horse, in addition to being a predictor of potentially compromised horse welfare. By combining RT measurements with behavioural parameters, optimal driveability could be characterised in a manner that would allow its objective evaluation. This, in turn, can support informed training and performance decisions e.g., when matching driver-horse pairs or evaluating training progress.

The follow-up study financed by Stiftelsen Hästforskning will focus on:

- Drivers' perspectives on driveability for optimal performance and horse welfare
- What equipment and horse behaviour can reveal about driveability and performance
- How rein tension and equipment use are associated with various gait characteristics, for example locomotor asymmetry
- How trotters are reported through E-BARQ (Equine Behaviour Assessment and Research Questionnaire), a validated online survey tool to gather repeatable behavioural data on horses

Result implementation will be achieved by informing racing industry stakeholders about our findings and by raising awareness about the potential of monitoring RT to help assure horse welfare, performance and driver/horse safety. Increased knowledge of how horses learn to respond to drivers' cues and the importance of regular monitoring of horses' oral health, both before and after competition, are vital for safeguarding horse welfare and thereby contributing to a sustainable sport.

Communication of results to the industry will be achieved in close collaboration with the Swedish Trotting Association to disseminate results via their channels such as their website and social media and via contacting the (inter)national media. The table in Part 3 gives an overview of how we have already communicated project results to the industry and scientific audience. This autumn we plan to have a workshop for teachers at trotting schools and we will present our results at the World Trotting Conference in August 2023. Furthermore, we will inform about our project in newsletters and during a conference presentation at the International Society for Equitation Science (ISES). We will also distribute results via SLU's research program "Future Animals, Nature and Health" and HästSverige, a Swedish online platform translating equine science findings into lay language.

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Part 3: Result dissemination

Scientific publications, *published*	*Author(s), year, title, journal, Vol, No, pp., doi-link*
	Egenvall, A., Byström, A., Pökelmann, M., Connysson, M., Kienapfel-Henseleit, K., Karlsteen, M., Hartmann, E. 2022. Rein tension in harness trotters during on-track exercise. Frontiers in Vet Sci, 9. https://doi.org/10.3389/fvets.2022.987852
	Hartmann, E., Byström, A., Pökelmann, M., Connysson, M., Kienapfel-Henseleit, K., Karlsteen, M., Egenvall, A. 2022. Associations between driving rein tensions and drivers' reports of the behaviour and driveability of Standardbred trotters. Appl Anim Behav Sci, 254, 105726. https://doi.org/10.1016/j.applanim.2022.105726
Scientific publications, *submitted*	*Author(s), title*
Scientific publications, *manuscript*	Egenvall, A., Byström, A., Pökelmann, M., Connysson, M., Karlsteen, M., McGreevy, P., Tuomola, K., Hartmann, E.: Rein tension in test-raced warmblood harness trotters (data analysis ongoing, incl. manuscript writing, order of authors preliminary)
Conference publications/ presentations	*Author(s), year, title, conference name, location and date, (link if applicable)*
	Plenary talk by E Hartmann: Harness racing through the lens of science: rein tension, training methods and horse welfare at the World Trotting Conference in Berlin, August 14-18, 2023
Other publications, *media etc.*	*Title, year/date, place of publication (link if applicable)*
	Så viktigt är rätt tömtryck. Travhästen 4, 2022. Text A Adre-Isaksson
	Så hårt spänns tömmarna under ett travlopp. SLU-Nyhet (press release) 5, 2022 https://www.slu.se/ew-nyheter/2022/9/sa-hart-spanns-tommarna-under-ett-travlopp/
	Elke Hartmann om sin forskning kring tömtryck under travlopp. Travronden 7, 2022. https://www.travronden.se/travsport/djurskotsel/travtraning/traningsstudie/a/elke-hartmann-om-sin-forskning-kring-tomtryck-under-travlopp
	Så hårt spänns tömmarna under ett travlopp. HästSverige 7, 2022 https://hastsverige.se/news/sa-hart-spanns-tommarna-under-ett-travlopp/
Oral communication, *to horse sector, students etc.*	*Title, year/date, group presented to (link if applicable)*
	Oral presentation at the Nordic Animal Welfare committee meeting (Nordisk Djurvälfärdskommitté), 14 June 2023 by Mette Pökelmann with representatives from Nordic harness racing associations
Student theses	*Author/Student, co-authors/supervisors, year, title, type of thesis*
Other	