Applied Animal Behaviour Science 277 (2024) 106356

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Is rein tension associated with horse behaviour and mouth injuries in harness racing trotters? – Pilot study

Kati Tuomola [a,*], Nina Mäki-Kihniä [b], Riikka Sirviö [a], Anna Valros [a]

[a] *Research Centre for Animal Welfare, Department of Production Animal Medicine, University of Helsinki, Helsinki, Finland*
[b] *Independent researcher, Pori, Finland*

ARTICLE INFO

Keywords:
Horse behaviour
Harness racing
Horse racing
Rein tension
Mouth injuries

ABSTRACT

Numerous mouth injuries have been reported in relation to bit use in horses. Rein tension is a potential risk factor, as it exerts pressure on the rostral parts of the mouth via the bit. The aim of this pilot study was to investigate rein tension during driving and its association with horse behaviour and mouth injuries. Eight horses were driven clockwise on a 1000 m oval racetrack for 3–4 km at walk and trot. Rein tension was measured with two IPOS rein sensors. Researchers filmed the horse's behaviour from a vehicle moving alongside the horse on the outer track. The bit area of the mouth was examined before and after the session. One observer, blinded to the rein tension and mouth injury results, coded behaviours from videos according to a predefined ethogram. Median rein tensions in one rein ranged from 5 N to 36 N. Maximum rein tensions ranged from 106 N to 236 N. Five 30-second data subsets, representing samples of Low, Medium1, Medium2, High and Peak tension, were visually selected from the rein tension graphs to investigate behaviour differences during different rein tension levels. The durations of unrushed walk ($P < 0.001$) and mouth closed ($P = 0.003$) were longer in the Low rein tension subset. The durations of *slow* ($P = 0.01$) and *fast trot* ($P = 0.003$), *mouth widely* ($P = 0.02$) or *repeatedly open* ($P = 0.03$) were longer in the higher rein tension subsets. None of the horses had any prior mouth injuries in the bit area. After driving, three horses experienced moderate bruising. Their median rein tension was numerically higher (left 35 N; right 34 N) than that in horses without injuries (22 N; 18 N), and they showed longer periods of *rushed walk* ($P = 0.04$). Rein tensions were quite high, as previous studies suggest that horses find tensions above 6–10 N aversive. Horse trainers should monitor the horse's mouth behaviour, arousal state and ability to walk calmly and modify training accordingly, as mouth *widely or repeatedly open* at higher rein tensions may indicate aversion (mouth discomfort/pain) and *rushed walk* may indicate high arousal, which in turn may increase the risk for mouth injury.

1. Introduction

The use of bits in horses is mostly automatic and unquestioned routine (Luke et al., 2024). However, numerous mouth injuries have been reported in relation to bit use (Annan et al., 2023; Björnsdóttir et al., 2014; Mata et al., 2015; Odelros and Wattle, 2018; Swoboda, 2021; Tell et al., 2008; Tuomola et al., 2021a, 2019; Uldahl et al., 2022; Uldahl and Clayton, 2019). The problem is not new (Dwyer, 1868; Hinebauch, 1889; Mayhew, 1862; Merillat, 1917; Russell, 1893; Youtt, 1831), but injuries go readily unnoticed because they are located inside the mouth (Tuomola et al., 2019). In trotters, the use of Crescendo bit, unjointed mullen mouth regulator bit and unjointed Happy Mouth bit has been associated with higher risk for moderate or severe mouth injuries (Tuomola et al., 2021b). However, the drivers may select these bit types if they have encountered difficulties using light rein cues (Tuomola et al., 2021b).

Rein tension is a potential risk factor for injuries, as it exerts pressure on rostral parts of the mouth via the bit. Rein tension refers to the force applied through the rein by the rider/driver, and it can be measured with a sensor attached between the bit and the rein (Clayton et al., 2021; Dumbell et al., 2019). Rein tension is primarily human-derived, given that higher tensions have been recorded when horses have been exercised with the rider (max 24 N) than without the rider (max 7.5 N) (Piccolo and Kienapfel, 2019).

There are several indicators to evaluate horses' welfare or emotional state; physical (e.g. injuries, lameness, cough, body condition score);

* Corresponding author.
E-mail address: kati.tuomola@helsinki.fi (K. Tuomola).

https://doi.org/10.1016/j.applanim.2024.106356
Received 2 February 2024; Received in revised form 4 July 2024; Accepted 15 July 2024
Available online 17 July 2024

physiological (e.g. cortisol, oxytocin, white cell counts, heart rate, heart rate variability, eye temperature); or behavioural (e.g. abnormal/stereotypic behaviour, time-budget, reaction to humans, cognitive bias) see Annan et al., (2023); Hall et al., 2018; Lesimple, (2020); Maurício et al., (2023) for further references. To be able to apply the various indicators in everyday situations, it is important to develop methods, which are not too invasive.

Behaviour is a visible sign of how a horse perceives a particular situation (Hall et al., 2018, 2013). Conflict behaviours in horses are a normal response to stress and can indicate distress caused by various factors such as negative reinforcement errors, frustration, anxiety, fear, discomfort, or pain (Fenner et al., 2019; Hall and Heleski, 2017; McLean and Christensen, 2017; Pearson et al., 2022; Piccolo and Kienapfel, 2019). In equestrianism, conflict behaviour often refers to behaviour that occurs when the horse's motivation conflicts with the rider/driver's wishes (Hall and Heleski, 2017; König von Borstel et al., 2017; Løkken, 2020). Conflict behaviours are characterized by avoidance/aversion/evasion and hyper-reactivity (McGreevy et al., 2005; McLean and Christensen, 2017) which may be unconditioned (not learned, instinctive) or conditioned (learned) (Mills and Marchant-Forde, 2010). Conflict behaviours are particularly evident when a horse is unable to escape or avoid human requests (König von Borstel et al., 2017; Mills and Marchant-Forde, 2010), and therefore, has difficulty coping physically or mentally (Górecka-Bruzda et al., 2015). Horses may show changes in head, tail, mouth, tongue and ear movements (Cook and Kibler, 2019; Górecka-Bruzda et al., 2015; Kienapfel et al., 2014) or increased visible eye white, unwanted gait changes (Dyson et al., 2018; von Borstel et al., 2009) or more overt signs of distress such as rearing, bucking, or shying (de Cartier et al., 2005; McGreevy, 2004; Mills and Marchant-Forde, 2010).

Rein tension measurement has been suggested as a tool to improve horse welfare (Clayton et al., 2021; König von Borstel and Glißman, 2014; McGreevy, 2007). Studies of rein tension in trotters are scarce (Egenvall et al., 2022; Hartmann et al., 2022; Preuschoft et al., 1999). Maximum rein tensions in trotters on record are 392 N (Preuschoft et al., 1999) and 250 N (Egenvall et al., 2022).

To our knowledge, conflict/distress behaviours in trotters during driving have not been studied. Furthermore, there is no information regarding the amount and duration of rein tension that can lead to mouth injuries in horses. The objective of this pilot study was to investigate rein tension in trotters during driving on track and its association with horse behaviour and mouth injuries. During rein tension measurement, we filmed the horse's behaviour from a vehicle driving alongside the horse. Our more detailed aims were to gain insight into i) whether higher rein tension is associated with horses' conflict (distress) behaviours during driving, ii) whether higher rein tension is associated with mouth injuries and iii) whether horse behaviour during driving can be used as a predictor of mouth injuries.

2. Materials and methods

2.1. Ethics and consent

The study was reviewed and approved by the Research Ethics Committee on Animal Research, University of Helsinki (Statement 9/2022). The study was voluntary for horse trainers, who received information concerning the study via email before the study. Written informed consent prior to participation was obtained.

2.2. Horses and drivers

The study was conducted during summer and autumn 2022 on three sandy 1000 m oval racetracks in Western Finland; there was no rain and temperature was 16–22°C. A convenience sample of volunteer trainers and their horses were recruited for the study. Horses should meet the following requirements: 1) Breed: Cold-blooded Finnhorse or Standardbred trotter, 2) Age: 3–15 years, 3) Sex: mare or gelding, 4) Previously driven on the particular racetrack, 6) Without a known fear of vehicles, 7) Currently in training, without known health problems and 8) Driveable with a snaffle trotting bit and without eye blinds. On short notice, one horse was substituted by a horse running with eye blinds. The day before the test, the trainers were advised to verify with a preliminary inspection that the bit area is free from injuries before arrival to the track (method Tuomola, 2022; Tuomola et al., 2019).

Ten privately owned horses were recruited for the study. Data from two horses were excluded due to rein sensor fault, leaving eight horses for the analysis (4 Finnhorses and 4 Standardbred trotters; 4 mares and 4 geldings; age 3–10 years, Md = 7). Weight was estimated with a weight tape. Finnhorses ranged from 458 to 596 kg (Md = 518 kg) and Standardbreds from 408 to 470 kg (Md = 461 kg). The researchers judged all other horses to be of normal weight, while one Finnhorse was overweight. The horses were familiar with their drivers (6 drivers). All drivers were experienced horse handlers and had racing experience. The study was performed on a familiar track; the horses were either stabled nearby (n = 3) or regularly trained on the track (n = 5). Information on horse statistics was obtained from Hippos, the Finnish Trotting and Breeding Agency's public Heppa platform. The number of starts for the horses ranged from 0 to 110 (Md = 21 ± IQR 69), and the prize money earned ranged from 0 to 75 000 € (Md = 5080 € ± 26 900 €).

2.3. Horse equipment

Private tack was used, except for the bit and the reins. The provided bit was a basic single-jointed snaffle trotting bit [three choices according to horse mouth width: bit length 12.5 cm (thickness 14 mm), 13.5 cm (thickness 14 mm) or 14.5 cm (thickness 16 mm)]. This bit type and thickness has earlier been shown to be least associated with mouth injuries (Tuomola et al., 2021a, 2021b). Bit thickness of 14 mm has been found on average to be suitable for horses (Anttila et al., 2022). Walsh synthetic beta driving reins with hand holds (Walsh Company, Inc., Waukesha, WI, USA) were chosen for the last six horses after noting that this rein model lacked the typical metal J-loop at the front, allowing the reins to be attached directly to the rein sensors.

An additional delta rein (Pelhamdelta, Fairfield, Hööks Hästsport AB, Borås, Sweden) was attached from the bit ring to the rein for safety in case the sensor disintegrated. The safety delta was visually assessed not to interfere with the rein sensors when the rein was in use.

Training sulkies were used for six horses and competition sulkies for two horses. Two horses wore a tongue tie made from elastic leg bandage, two horses wore earhoods, one horse had ear plugs, one horse wore a plastic no choke plate under the chin, two horses wore a kicking strap, one horse had a rear windsucker pad, one horse had the tail tied with a thin leather strap, eye blinds and an overcheck with a jaw strap.

2.4. Mouth examination

Oral examination of the bit area of the horse was carried out before and after the performance by a veterinarian (KT), and observations were verified by an assistant. The inner and outer lip commissures, bars of the mandible and the buccal area around the first upper cheek teeth, tongue and hard palate were examined using a headlamp but without sedation. The examination procedure is described in detail in our earlier studies (Tuomola, 2022; Tuomola et al., 2019). Noseband tightness was measured at the nasal planum using the ISES Taper Gauge and graded as 0 fingers, 1 finger or 2 fingers or more (Doherty et al., 2017).

2.5. Rein sensors; calibration and preparation

Two rein sensors were used (IPOS Technology, Eindhoven, The Netherlands). The sensors were attached between the bit ring and the rein. Each sensor weighed 95 g. According to the manufacturer, the sensor operating range is 0–500 N, damage threshold 1000 N, measurement sensitivity 0.2 N and sampling rate 80 Hz. The sensors were labelled LEFT and RIGHT to ensure consistent use. The IPOS Rein Sensor smartphone application v.1.5.58 installed on the iPhone 12 mini (Phone 1) was used for data collection. According to the IPOS manufacturer, the phone must be within 40 m of the sensor for the Bluetooth connection to work. The phone was therefore placed in the driver's pocket for the duration of the driving session.

Our preliminary calibration tests showed that the sensors measured weights (tensions) reliably only up to 21 kg (206 N, left) and 24 kg (235 N, right). The day before each field day, the function of the rein sensors was controlled with measured weights (1 kg, 2 kg, 3 kg, 5 kg, 8 kg, 10 kg and 21 kg). The maximum error observed was in the left sensor with the 10 kg weight (error +4 %). As the sensors are sensitive to ambient temperature and humidity, we calibrated them before each drive session in the field according to the manufacturer's instructions.

After the drive session, the rein sensor raw data file for each horse was downloaded from the IPOS cloud service in cvs (comma separated values) format and opened in Microsoft Excel. In the Excel spreadsheet, the Universal Time Stamp was converted to a readable format using the formula (=(A2/86400000)+DATE(1970;1;1).

2.6. Heart rate and speed measurement

Horses' heart rate, speed and location were measured with the Polar H10 heart rate monitor (Polar Equine, Polar Electro Oy, Kempele, Finland) using an app installed on the Samsung Galaxy S21 phone (Phone 2). The first two horses were recorded with the Polar Equine app and the rest with the Polar Beat app. The heart rate band was attached to the horse right before harnessing and monitoring started. The phone was placed in the driver's pocket for the duration of the drive.

2.7. Track drive session

The horses were driven clockwise on track for 3–4 km at walk, slow trot and fast trot. Clockwise is a common warm-up direction and the opposite of the competition direction. Horses were driven alone. The track was closed to others for the duration of the session. The speed was decided by the driver, and we filmed the horses from the left side from a vehicle (a van with automatic transmission) driving alongside the horse. To maximize safety and distance, the van was on the outermost track close to the railing and the horse was filmed through an open side window. After adequate data collection (about 8–16 minutes), the session was ended and everyone returned to the harnessing booth/stable.

2.8. Video recording and editing

The track performance was recorded with a digital camera (Panasonic GX7 with Lumix 14–140 HD Panasonic H-FS14140, video recording programme, MP4 or AVCHD for longer continuous recording time, frame rate 50 fps for all but the first horse). The camera was panned on a tripod from side to side and zoomed to follow the horse as the van moved ahead or lagged behind.

The video files were edited in Adobe Premiere Pro 2022. Audio track was unlinked and two time codes were added to the video: video playback time from zero and local time based on Time.is service recorded at the beginning of the video. To anonymize the driver and hide unnecessary visual information from the behaviour coder, the entire right side of the image was cropped (via the Effects controls panel, Crop function, Animation ON), resulting in a black block moving as needed to cover the driver.

2.9. Data synchronization

Rein tension measurement was started from the Phone 1 IPOS app at the turn of a minute. On the video, we recorded Phones 1 and 2 side by side at the start and end of each session, thus documenting how to match local time and running time of the IPOS app. When applicable, a second local time checkpoint from a digital wristwatch was video-recorded later on the track.

To verify synchronization of rein sensor data and video image, the left rein was pulled three times while the bit was held not to damage the horse to create isolated, recognizable spikes in the data. The IPOS app on the phone showed the spike with a delay of less than one second. However, the time stamp in the IPOS data file for these pressure events, which were readily identifiable in the data plot, did not correspond with the IPOS app time shown on Phone 1 or with local time. The difference was sometimes several seconds. In subsequent off-track manual pulling tests, we consistently found such temporal discrepancies, but no obvious fixed temporal discrepancy pattern. Therefore, we could not use these manual tension events for data synchronization. To determine whether this phenomenon might affect actual, continuous rein tension data, we identified distinct rein tension events from both the video and respective tension graphs, and the IPOS timestamps for these events corresponded satisfactorily with the video time codes and the events taking place on the video.

2.10. Description of the final study protocol

The practical study protocol is outlined below in chronological order. The total time for the study protocol was approximately one hour (see also supplementary material).

1. An oral examination of the horse was performed.
2. The driver harnessed the horse as usual in the harnessing booth or in their own stable on the racecourse premises. The equipment used was recorded on the examination form.
3. A suitable bit for the horse was selected.
4. The tightness of the noseband was measured with ISES taper gauge.
5. Horse's weight was estimated with weight tape.
6. Rein sensors were calibrated to zero.
7. Heart rate sensor was fitted.
8. Reins and rein sensors were attached.
9. Video recording and rein tension measurement were started.
10. Phone 1 (showing IPOS app running time) and Phone 2 (showing local time from Time.is) were recorded on the video.
11. Left rein was pulled three times for data synchronization.
12. The delta reins for safety were attached.
13. The driver placed both phones in a suitable jacket pocket.
14. The horse left the booth/stable towards the track and researchers followed in the van.
15. The wristwatch local time was recorded on video.
16. The horse was driven clockwise on a 1000 m oval racetrack for 3–4 km at walk and trot, and its behaviour was filmed from the van.
17. The driver was asked to drive the horse to the harnessing area. The video recording continued until the final manual three-pull test had been recorded in the harnessing booth/stable.
18. The rein and heart rate sensors were disconnected and removed.
19. The driver unharnessed the horse, the oral examination was repeated and any findings were recorded on the examination form.

2.11. Ethogram and behaviour coding

During ethogram (Table 1) compilation, the videos were viewed to determine which behaviour types were observable and expressed by the horses. Due to practical challenges with driving alongside the horse and this affecting the video protocol, not all behaviours could be analysed. These unidentifiable behaviours, such as facial expressions, nostrils, eye and right ear, were thus excluded from the ethogram.

The observer, who was unaware of the rein tension and mouth injury

Table 1
Ethogram of coded behaviours and duration of behaviours during the 8–16-minute total track drive session expressed as seconds per 60-second period. The behaviour duration has been adjusted for the time when the behaviour was visible from the video (n = 8). The ethogram is based on previous reports (Draaisma, 2020; Dyson et al., 2018; McGreevy, 2004; Piccolo and Kienapfel, 2019; Pierard et al., 2019; Seck et al., 2022; Torcivia and McDonnell, 2021).

Category	Behaviour	Duration of behaviour (s) /60 s median (min-max)	Description
Head	Head 0–69°	59.8 (53.7–60)	Nasal plane is in front of vertical (between 0 and 69°)
	Head behind vertical	0.04 (0–6.3)	Nasal plane is behind vertical (less than 0°)
	Head up ≥70°	0 (0–3.1)	Nasal plane is in front of the vertical. (70° or higher). This behaviour includes sudden upward movements head tossing, nose flipping) or rotational head movement starting below the withers and swinging upwards (head swing)
	Head not visible		Head position is not visible in the video
Poll	Poll high	59.3 (50.3–60)	Poll is higher that withers level
	Poll low	0.7 (0–10)	Poll is at withers level or below
	Poll not visible		Poll position is not visible in the video
Ear	Ear forward	19.1 (5.6–39.9)	Left ear is pointing forward
	Ear side	30 (13.5–52.4)	Left ear is pointing sideways
	Ear back	0 (0–40)	Left ear is pointing backwards
	Ear bouncing	0 (0–10.2)	Left ear is moving freely back and forth in the rhythm of the gait
	Ear not visible		Left ear is not visible in the video
Mouth	Mouth closed	29.4 (3.8–52.3)	Lips are closed
	Mouth slightly open	6.6 (0.6–19.7)	Mouth is open, lips or teeth are separated
	Mouth widely open	1.6 (0.4–6.2)	Mouth is open, large visible gap between upper and lower incisors
	Mouth repeatedly open	19.7 (2.5–44.8)	Mouth is opening and shutting repeatedly two times or more and the mouth is open or closed for less than one second at a time.
	Mouth not visible		Mouth is not visible in the video
			Note: mouth open does not include openings during licking
Tongue	Tongue inside	60 (57.4–60)	Tongue is inside the mouth. Tongue can be visible if the mouth is open or invisible if the mouth is closed
	Tongue outside	0 (0–0)	Tongue is protruding or hanging outside the mouth
	Licking	0 (0–6.1)	Horse is extending tongue outside the mouth and licking
	Mouth area not visible		Mouth area is not visible in the video
Gait	Unrushed walk	7.8 (3.4–20.8)	Four-beat unrushed gait. May include few trot steps. Neck is moving relaxed with the movement
	Rushed walk	0.3 (0–14.9)	Rushed/hurried walk. May include few trot steps. Tension in the neck
	Slow trot	22.4 (1.4–50.7)	Two-beat gait where diagonal pairs of limbs moving forward simultaneously. Slower trotting tempo for a particular horse.
	Fast trot	20.5 (5.9–36.5)	Faster trotting tempo for particular horse
	Canter	0 (0–0.9)	Three-beat gait
	Transition down	0.4 (0–1.2)	Transition from trot to walk or from canter to trot. Transition starts when rein is tightened and horse's speed starts to decrease. Transition ends when lower speed gait has been achieved
	Gait not visible		Horse's gait type is not visible in the video
		Number of behaviours / 60 s	
Tail	Tail swish	0 (0–0.1)	Includes vertical lash, lateral swish or circular tail movements
	Tail not visible		Tail is not visible in the video
Other	Head shake	0 (0–0.1)	Horse is shaking its head from side to side
	Head tilt	0.4 (0–0.8)	Head is tilted on one side on vertical axis
	Pulling reins	0.8 (0–8.7)	Horse is extending its head forward and pulling the reins

results, coded the horses' behaviour and gait using *CowLog 3* software (Pastell, 2016). Videos were viewed five times at different playing speeds, focusing on different body parts each time: i) head and poll (video speed 0.25–0.4 x, meaning 25–40 % of the original video speed), ii) left ear (0.25–0.4 x), iii) mouth and tongue (0.25–0.4 x), iv) gait, horse pulling at reins, tail swish (0.8–1 x) and v) head tilt, head shake (1 x). Different playing speeds were used when analysing the head and neck, e.g. one horse with an overcheck (one subject) expressed fewer head and neck movements, allowing for a faster video playing speed.

2.12. Data handling and missing data

Track drive sessions ranged from 8 min 38 s to 16 min 28 s (mean 11 min 50 s). Raw rein tension data were displayed in grams, which were converted to Newtons for analysis. The data sporadically contained negative values. According to the manufacturer, the left and right sensors are constantly synchronized, and a specific large negative value (-327680) marks a missing data point. Specific smaller negative values (-10 or -20) may indicate some form of calibration error due to residual tension in the sensor during calibration. The data also included other negative values, but their meaning remained unclear. All negative values were removed from the data before analysis. We also found that the sensors at times failed to achieve the full target sampling rate of 80 Hz (80 times per second). The final rein tension data comprised data points ranging from 47 158–75 353 (mean 54 687 ± SD 10 714) for the left rein and 28 586–51 464 (39 029 ± 8167) for the right rein per horse. The right sensor missed an average of 30 % of the measurements. Missing values, including removed negative values, are presented as a percentage in the results section.

Five 30-second data subsets, Low (L), Medium1 (M1), Medium2 (M2), High (H) and Peak (P) rein tension, were visually selected from the individual rein tension graphs to investigate whether there was a difference in the horse's behaviour during different rein tensions. Subset L was the lowest and H the highest rein tension area of a particular horse. M1 was higher than L and M2 was lower than H but higher than M1 subset. The P subset contained a recognizable peak in the rein tension data, i.e. rein tension increased to a high level and then decreased (Fig. 1

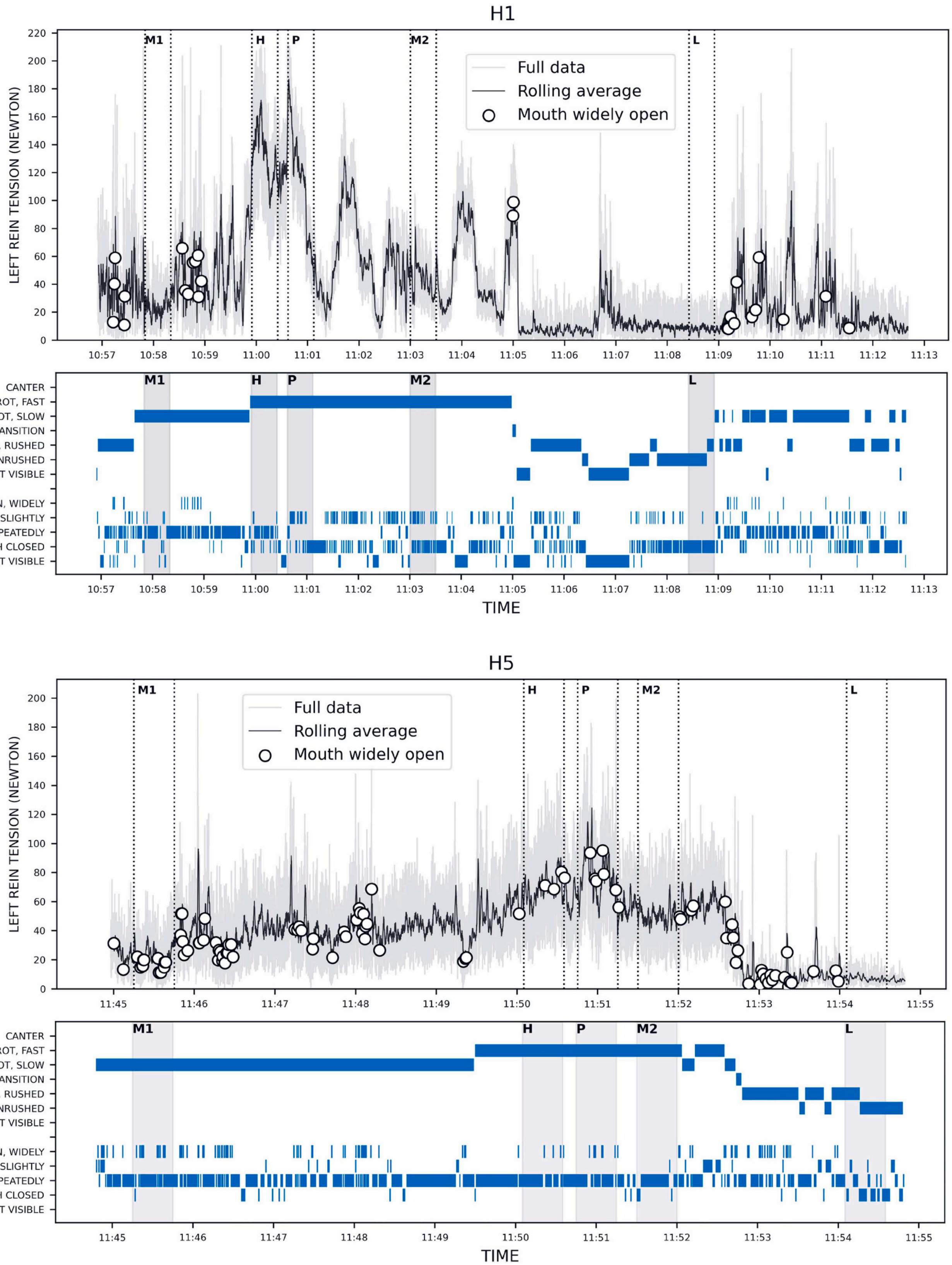

Fig. 1. Rein tension for horses H1, H5, H6 and H8 are presented to show individual variation between horses. Full data plot is of raw data (80 Hz), rolling average shows the means of 80 last data points. Number and duration of mouth behaviours and gait are presented as bars. Different rein tension subsets used in analysis: Low (L), Medium 1 (M1), Medium 2 (M2), High (H), Peak (P).

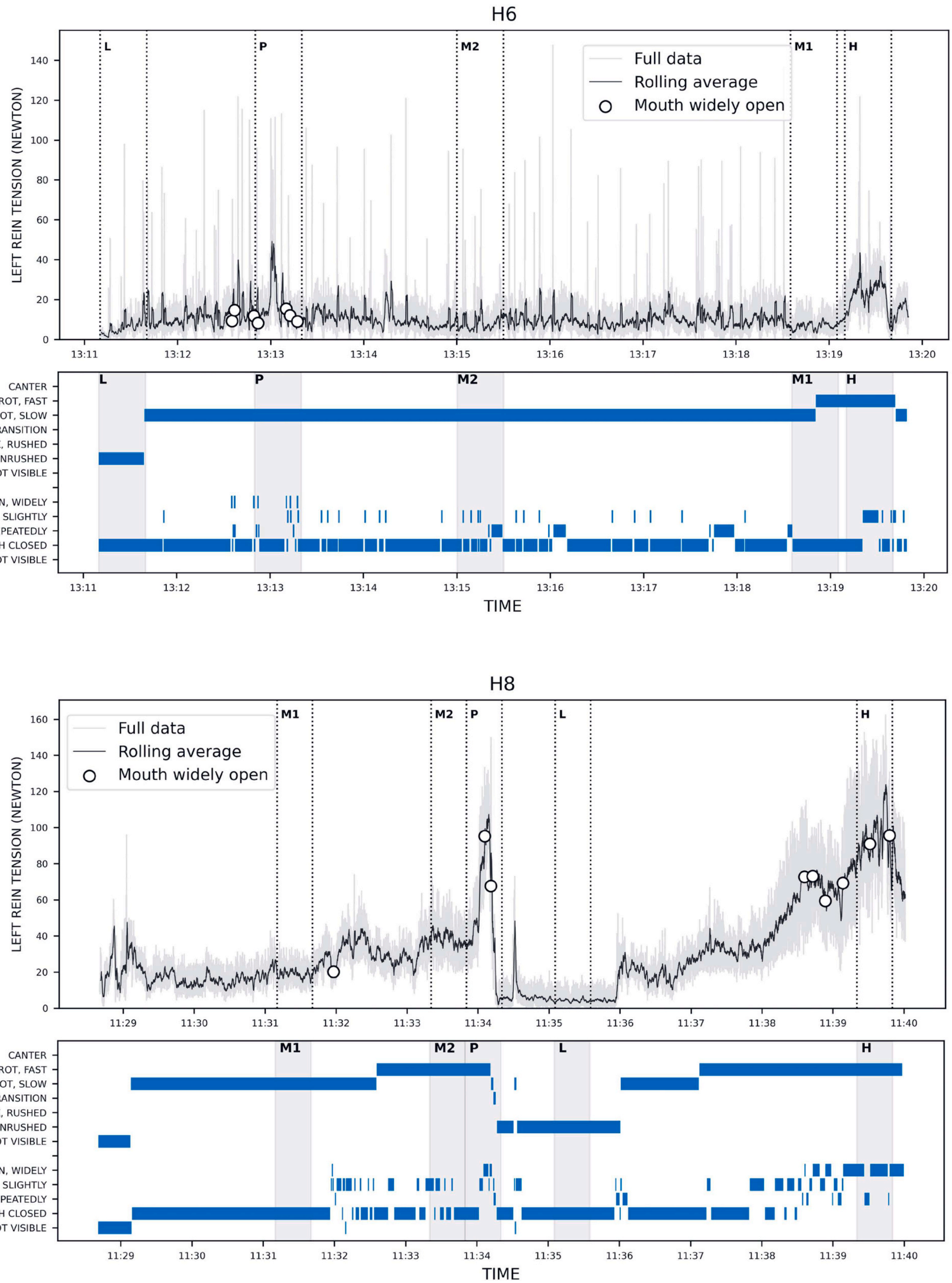

Fig. 1. (*continued*).

and Supplementary material). Occasionally, a particular part of the horse (mouth, ear, head, tail, etc.) was not visible in the video and was coded as NV = not visible. In the total track drive session analysis, the behaviour analysis time is the total track drive session time minus the NV time. In the subset analysis, the NV time was included in the analysis.

2.13. *Statistical analysis*

RStudio (1.3.1056) and JupyterLab (3.4.4) (Python) were used to visualize the rein tension data. IBM SPSS 28.0 was used for statistical analysis. Most of the data was not normally distributed, therefore non-

Table 2
Results of horses' rein tension measurements, heart rate and speed during the total track drive session (n = 8). Horses with bruising in the bit area after the session are in boldface. Bpm = beats per minute.

Horse	Rein tension left (N) Median (Q1–Q3)	Max	Rein tension right (N) Median (Q1–Q3)	Max	Heart rate (bpm) Median (min–max)	Speed (km/h) Median (min–max)
1	**24 (9–55)**	**212**	**26 (10–57)**	**234**	**121 (103–209)**	**23 (6–38)**
2	33 (8–63)	209	35 (9–72)	206	-	-
5	**36 (16–56)**	**203**	**34 (14–51)**	**212**	**157 (96–209)**	**29 (2–42)**
6	8 (5–14)	148	5 (3–9)	120	136 (67–193)	20 (4–46)
7	15 (9–26)	128	14 (8–23)	106	-	-
8	25 (14–39)	163	18 (10–31)	170	131 (53–183)	23 (1–36)
9	22 (6–38)	211	18 (5–36)	236	119 (81–204)	18 (6–27)
10	**35 (16–56)**	**211**	**35 (16–56)**	**236**	**123 (56–201)**	**23 (6–36)**
All	24 (10–44)	206	22 (9–47)	209	127 (74–201)	**23 (5–36)**

- Missing value

parametric tests were used for statistical analysis: i) *Spearman's rank correlation* coefficient was used to examine the association between horses' behaviour duration/60 s and rein tension (median, mean, IQR) during total track drive session; ii) The *Mann-Whitney U test* was used to analyse the association between the horses' behaviour duration/60 s and mouth injuries (any injuries vs. no injuries) during total track drive session and; iii) The *Friedman test* was used to compare horse behaviour duration, median heart rate and median speed between different rein tension subsets (L, M1, M2, H, P). P-value ≤ 0.05 was considered statistically significant in all analyses.

3. Results

3.1. Rein tension and behaviour; total track drive session

Median rein tensions ranged from 8 N to 36 N (Md = 24 N, left) and from 5 N to 35 N (Md = 22 N, right). Maximum rein tensions ranged from 128 N to 212 N (Md = 206 N, left, n = 8) and from 106 N to 236 N (Md = 209 N, right, n = 8) (Table 2 **and** Supplementary material).

In total track drive session analysis, duration of *mouth slightly open* correlated positively with IQR (greater variation in rein tension). Numbers of *mouth widely open* correlated positively with median rein tension (Table 3).

Head position of all horses most of the time was in front of the vertical plane, and tail swishing was shown only once by one horse. The tongue was inside the mouth all the time in five horses. Three horses showed licking: 1, 3 and 60 times. Horses opened their mouth wide from 9 to 102 times (Md = 13) and pulled the reins from 0 to 75 times (Md = 8). Descriptive results of horse's behaviour during the total track drive session in relation to the track time are presented in Table 1. As some behaviours (head shaking, head tilting, tail swishing, licking) occurred infrequently, they were not analysed further.

Two of the horses were not wearing a noseband and five of the horses had a basic cavesson noseband fitted such that two fingers could fit under the noseband in the nasal plane when measured with the ISES taper gauge. Only one horse had a noseband fitted such that one finger fitted under the noseband.

3.2. Rein tension and behaviour; subsets

The durations of *unrushed walk* and *mouth closed* were longer in the Low rein tension subset (Friedman test, $\chi2 = 30.05$, $P < 0.001$ and $\chi2 = 15.69$, $P = 0.003$, respectively). The durations of *slow* ($\chi2 = 13.22$, $P = 0.01$) and *fast trot* ($\chi2 = 15.76$, $P = 0.003$), *mouth widely open* ($\chi2 = 12.28$, $P = 0.02$) and *mouth repeatedly open* ($\chi2 = 10.71$, $P = 0.03$) were longer in the higher rein tension subsets (Table 4**,** Figs. 2 and 3**)**.

3.3. Mouth injuries

None of the horses had mouth injuries before but three had moderate bruises in the bit area after the driving session. Horse 1 had two bruises larger than 1 cm (right buccal area and left inner lip commissure), Horse 5 had one bruise larger than 1 cm in right inner lip commissure, and Horse 10 had two 0.5–1 cm bruises (left bar and left inner lip commissure). Median rein tension was numerically higher in horses with mouth injuries (left; Md_{md} = 35 N, 24–36 N, Md_{min}–Md_{max}) (right; Md_{md} = 34 N, 26–35 N) (n = 3) than in horses without injuries (left; Md_{md} = 22 N, 8–33 N) (right; Md_{md} = 18 N, 5–35 N) (n = 5) (Mann-Whitney U test, left; U = 2.0, P = 0.1, right; U = 2.5, P = 0.1). Horses with mouth injuries tended to hold their head behind the vertical for longer periods (Md = 6.0 s, 0.07–6.3, min–max) than horses without such injuries (Md = 0 s, 0–2.4, min–max) (Mann-Whitney U test, U = 14.0, P = 0.07). Horses with mouth injuries showed longer periods of rushed walk (Md = 13.3 s, 7.8–14.9/60 s, min–max) than horses without injuries (Md = 0.0 s, 0.0–0.5/60 s, min–max) (Mann-Whitney U test, U = 15.0, P = 0.04).

Table 3
Correlations between horse behaviour (duration of behaviours/60 seconds) and rein tension during the 8–16-minute total track drive session. Only correlation coefficients above 0.5 are presented. L= left rein, R = right rein. Statistically significant results are in boldface.

Behaviour	Rein tension	Correlation coefficient	P-value
Ear side	mean L	−0.584	0.1
	mean R	−0.508	0.2
Ear back	mean L	0.517	0.2
	mean R	0.537	0.2
Mouth closed	mean L	−0.524	0.2
	mean R	−0.524	0.2
	median L	−0.574	0.1
	IQR L	−0.619	0.1
	IQR R	−0.548	0.2
Mouth slightly open	mean L	0.667	0.07
	mean R	0.714	**0.05**
	median L	0.524	0.2
	median R	0.707	**0.05**
	IQR L	0.738	**0.04**
	IQR R	0.762	**0.03**
Mouth widely open	mean L	0.643	0.09
	median L	0.833	**0.01**
	median R	0.635	0.09
Horse pulling reins, number	mean L	−0.635	0.09
	mean R	−0.539	0.2
	median L	−0.539	0.2
	median R	−0.639	0.09

Table 4
Horses' median rein tension, speed and heart rate (HR) information during 30-second "sampling" at different rein tension levels: Low (L), Medium 1 (M1), Medium 2 (M2), High (H), Peak (P) (n = 8). Missing rein tension values are presented as % of all measurements. Speed and heart rate information available for only six horses. Bpm = beats per minute.

	Rein tension left (N)			Rein tension right (N)			Speed (km/h)	HR (bpm)
Subset	Median$_{md}$ (Q1$_{md}$–Q3$_{md}$)	Max$_{md}$	Missing %	Median$_{md}$ (Q1$_{md}$–Q3$_{md}$)	Max$_{md}$	Missing %	Median$_{md}$ (Md$_{min}$–Md$_{max}$)	Median$_{md}$ (Md$_{min}$–Md$_{max}$)
L	4 (2–8)	30	1.1	3 (2–7)	30	19.2	7 (6–10)	104 (68–117)
M1	19 (13–24)	44	0.3	17 (11–23)	50	32.8	25 (9–32)	126 (73–151)
M2	42 (33–54)	100	0.1	43 (34–54)	94	32.9	26 (19–33)	174 (131–187)
H	70 (51–90)	173	0.1	68 (52–87)	178	33.5	27 (21–39)	181 (155–181)
P	46 (31–89)	204	0.6	41 (25–95)	207	32.4	26 (20–37)	173 (129–206)

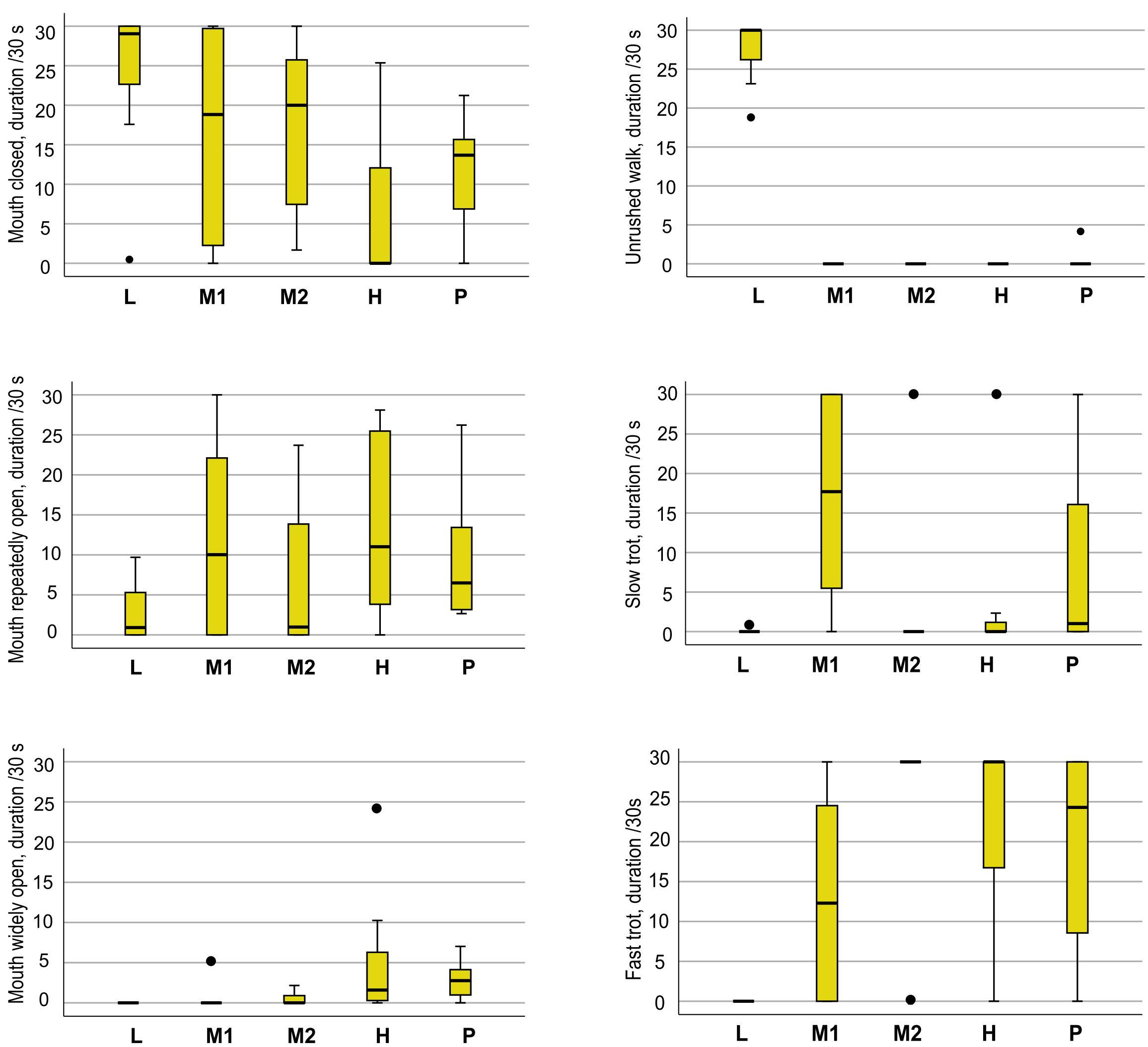

Fig. 2. Horse mouth behaviour and gait during 30-second samples at different rein tension subsets: Low (L), Medium 1 (M1), Medium 2 (M2), High (H), Peak (P) (n = 8).

3.4. Speed and heart rate

Heart rate and speed data were available reliably for only six horses. Median heart rate (beats per minute) was lowest during the Low rein tension subset and highest during the High and Peak subsets (Friedman test $\chi 2 = 16.4$, $P = 0.002$). Horse median speed was lowest during the Low rein tension subset and highest during the High subset (Friedman test $\chi 2 = 12.1$, $P = 0.02$) (Table 4).

4. Discussion

Median rein tensions in one rein ranged from 5 N to 36 N. Maximum rein tensions ranged from 106 N to 236 N. After relatively short driving session, three horses experienced moderate bruising. Their median rein tension was numerically higher than that in horses without injuries, and they showed longer periods of *rushed walk*. In the subset analysis, where the horses acted as their own controls, the durations of *slow* and *fast trot*, *mouth widely* or *repeatedly open* were longer in the higher rein tension subsets.

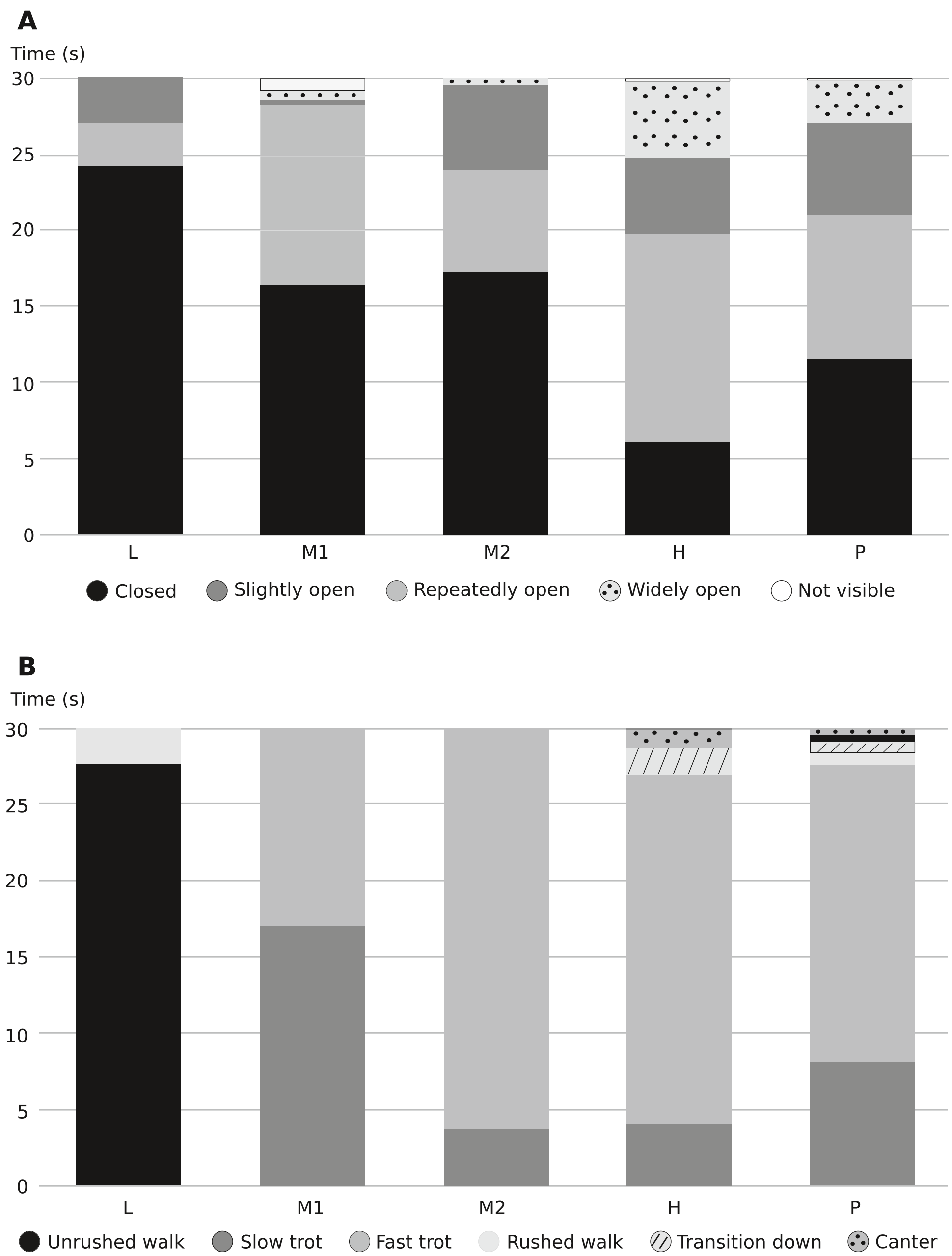

Fig. 3. Horses' median time budget divided by A) mouth behaviours and B) gait at different rein tension subsets: Low (L), Medium 1 (M1), Medium 2 (M2), High (H), Peak (P) (n = 8).

As an obligate nose-breather, the horse normally keeps its mouth closed during exercise (Cook, 1999). In previous studies, mouth opening in bitted horses has been associated with short reins (Christensen et al., 2024, 2011), rein tension during riding (Piccolo and Kienapfel, 2019) lameness (Dyson et al., 2018), (Christensen et al., 2024, 2011), pace and tölt gaits (Christensen et al., 2024), suspension phase in trot (Eisersiö et al., 2013) or the horse's attempts to relieve bit pressure (Eisersiö et al., 2023).

In the current study, walk was typical for the Low rein tension subset and trot for the higher subsets. The results are in line with previous studies where rein tensions were lowest in walk and higher in trot (Clayton et al., 2005; Egenvall et al., 2022; Eisersiö et al., 2015; Hartmann et al., 2022; Kuhnke et al., 2010).

4.1. *Mouth injuries, rushed walk and rein tension*

Single high rein tension events did not seem to cause visible mouth injuries, with bruising likely arising from the combination of force and prolonged rein tension exposure (impulse) (Clayton et al., 2021). Three horses with mouth injuries showed longer periods of *rushed walk*. Possibly, a horse may walk in a rushed manner if the driver wants the horse to walk and restricts it from trotting in a situation where the horse has associated track work with high arousal and fast gait. The horse may be in a high arousal state due to previous experiences, fear or pain (McBride and Mills, 2012). In ridden horses, rushed gait has been associated with lameness (Dyson et al., 2018) and described as an evasive behaviour (de Cartier et al., 2005). Optimal arousal level would likely benefit trotter performance (Hebb, 1955; McBride and Mills, 2012; Mendl, 1999; Mendl et al., 2010; Teigen, 1994; Yerkes and Dodson, 1908) and could minimize injuries. Interestingly, the horse with the lowest rein tension in the study was the only one that showed unrushed walk at the beginning of the recording. The driver's personal preference was that horses should enter and exit the track in walk.

4.2. Rein tension during total track drive session

Rein tensions were notably high, considering that previous studies in voluntary test situations suggest that horses find tensions above 6–10 N aversive (Christensen et al., 2011; Piccolo and Kienapfel, 2019). Our tension results were higher than observed previously in ridden horses (Clayton et al., 2005, 2003; de Cartier et al., 2005; Eisersiö et al., 2015; König von Borstel and Glißman, 2014; Kuhnke et al., 2010; Warren-Smith et al., 2007), but are in line with two studies of trotter rein tension (Egenvall et al., 2022; Preuschoft et al., 1999). In driving, tension can easily increase as drivers can lean back while being supported by the footrests in the sulky and hold their hands in the hand holds, allowing for a stronger grip (Foster, 2013).

Bit use is ideally based on operant conditioning and negative reinforcement, where the important aspect is pressure release and its timing (Bennett, 2006, 2001; McGreevy, 2011; McGreevy et al., 2005; Mills, 1998). Additionally, incorporating positive reinforcement into bit training has been shown to be potentially beneficial (Warren-Smith and McGreevy, 2007). Through repetition in training, a horse learns which behaviour leads to pressure release (Bennett, 2001; Eisersiö et al., 2021; Lethbridge, 2009; McGreevy et al., 2018). Therefore, the bit should be a tool for communication, not a means of control or restraint (McGreevy, 2011). However, it appears that drivers often hold the reins tightly to prevent the horse from going 'too fast' and to 'keep the horse at the desired speed' (Foster, 2013), which is contradictory to the principles of negative reinforcement (Hartmann et al., 2022; McGreevy et al., 2018; Tuomola, 2022). Fluctuating pressure threshold may cause confusion (McLean and Christensen, 2017) and make it difficult for the horse to learn the rein tensions (mouth pressure) to which they should habituate or respond (Baragli et al., 2015; McLean and Christensen, 2017). Rein tensions of 3.9 N for riding and 5.0 N for long reining have been suggested as 'light rein contact' (Warren-Smith et al., 2007). Unrelenting mouth pressure and its anticipation can cause pain, fear and distress and have detrimental effects on the horse's mental security (McLean and Christensen, 2017; Mellor, 2020). These, in turn, may affect the horse's behaviour, thereby posing safety risks for the horse handler (Bell et al., 2019; Hawson et al., 2010; Luke et al., 2022; McLean, 2005; Starling et al., 2016; Waran and Randle, 2017).

4.3. Minimum head behind vertical and tail swishing

Head was in front of the vertical plane all the time in four horses and over 90 % of the time for the other four. Three of the latter four horses had mouth injuries after the session. Of the four that never moved their head behind the vertical, only one wore equipment (overcheck) that could in theory prevent this behaviour. The current findings are in contrast to studies in dressage horses showing that riders commonly compete with the horse's head behind the vertical (HBV) [hyperflexion, low deep round (LDR), or rollkur] (Górecka-Bruzda et al., 2015; Kienapfel et al., 2014; McLean and McGreevy, 2010) and are often awarded with higher scores (Hamilton et al., 2022).

The front part of the horse was prioritized during filming. However, the tails of all horses were filmed for 8–14 minutes, and tail swishing was shown only once by one horse. Tail swishing thus does not appear to be associated with driving and high rein tension. In contrast, tail swishing has been associated with riding with the head behind the vertical (Kienapfel et al., 2014; von Borstel et al., 2009), riding in dressage (Dyson and Pollard, 2021a, 2021b; Górecka-Bruzda et al., 2015) and riding in Icelandic horse competitions (Christensen et al., 2024) as well as strong leg, spur or whip actions (Christensen et al., 2011; Kienapfel et al., 2014).

4.4. Pulling the reins

Six horses pulled the reins, i.e. the horse made a slow or fast head movement either forwards and down, which was mainly seen at walk, or forwards and up (nose flipping/tossing), which was seen at slow trot. In the total drive session analysis, there was a tendency for an association between number of rein pulling and lower mean/median rein tension, Horse 6 pulled the reins 75 times, which might explain the unparalleled vertical peaks in the rein tension graph. In previous studies, rein pulling has been suggested to be a learned behaviour, where horses have learned to make the handler loosen and even release the rein contact (Eisersiö et al., 2023; Górecka-Bruzda et al., 2015). Nose/head flipping/tossing has been associated with frustration (Torcivia and McDonnell, 2021) or pain (Cook, 2003), and there is possible relationship with lower rein tension since higher rein tension might restrict tossing behaviour (König von Borstel and Glißman, 2014).

4.5. Ideas for future research

Behaviour observation during harnessing was not in our study protocol, but a cursory review of field data notes suggested that the three horses with mouth injuries after the driving session exhibited anticipatory behaviours (Dyson et al., 2022) and potentially learned helplessness (Fureix et al., 2012; McGreevy and McLean, 2009; Ödberg and Bouissou, 1999), whereas the uninjured horses did not. This observation warrants further behaviour studies done during harnessing. Future research on how the amount of rein tension used can be decreased via training is also warranted.

4.6. Study limitations

When making conclusions based on this study, it is important to remember that the rein sensors were unable to measure forces above 206 N (left) and 235 N (right) and that the sample size was limited. Also, due to the time drift of the sensors, the timing of the sensor and behavioural data may differ slightly, but by no more than 5 seconds. Due to the lighting conditions and the equipment used on the horses, assessment of minute facial expressions was not possible. The equipment (e.g. tonguetie and overcheck) may also have affected the horses' ability to alter their behaviour. Finally, the study situation itself may have influenced the behaviour of driver and horse.

5. Conclusions

Our results indicate that rein tensions were quite high. Horses with mouth injuries after driving had numerically higher median rein tensions. Horse trainers and drivers should monitor the horse's mouth behaviour, arousal state and ability to walk calmly and modify training accordingly, as mouth *widely or repeatedly open* at higher rein tensions may indicate aversion (mouth discomfort/pain), and *rushed walk* may indicate high arousal, which in turn may increase the risk for mouth injury.

Funding

This study was funded by the Finnish Veterinary Foundation (Mercedes Zachariassen Foundation) (KT), Huittisten Säästöpankkisäätiö (KT), the Finnish Foundation of Veterinary Research (KT), the Erkki Rajakoski Foundation (KT), SEY Animal Welfare Finland-the Heli Castrén grant (RS), and the University of Helsinki.

CRediT authorship contribution statement

Kati Tuomola: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Nina Mäki-**

Kihniä: Writing – review & editing, Visualization, Methodology, Investigation, Conceptualization. **Riikka Sirviö:** Writing – review & editing, Investigation. **Anna Valros:** Writing – review & editing, Supervision, Formal analysis, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used *DeepL write* in order to improve the language and readability of the manuscript. After using this tool, the authors reviewed and edited the content as necessary and take full responsibility for the content of the publication.

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.

Acknowledgements

We are grateful to all horses and their trainers who participated in this study. Noora Jaakkola contributed to preliminary rein tension tests. Johanna Virtanen, Sari Alisaari and Jarkko Vuorela contributed by assisting at the racetrack. Ypäjä, Pori and Teivo racetracks contributed by allowing us to use their facilities for research purposes. Anna Kilpeläinen is thanked for valuable comments on the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2024.106356.

References

Annan, R., Trigg, L.E., Hockenhull, J., Allen, K., Butler, D., Valenchon, M., Mullan, S., 2023. Racehorse welfare across a training season. Front. Vet. Sci. 10, 1208744 https://doi.org/10.3389/FVETS.2023.1208744.

Anttila, M., Raekallio, M., Valros, A., 2022. Oral dimensions related to bit size in adult horses and ponies. Front. Vet. Sci. 0, 576. https://doi.org/10.3389/FVETS.2022.879048.

Baragli, P., Padalino, B., Telatin, A., 2015. The role of associative and non-associative learning in the training of horses and implications for the welfare (a review). Ann. Ist. Super. Sanita 51, 40–51. https://doi.org/10.4415/ANN_15_01_08.

Bell, C., Rogers, S., Taylor, J., Busby, D., 2019. Improving the recognition of equine affective states. Animals 9, 1–13. https://doi.org/10.3390/ani9121124.

Bennett, D.G., 2001. Bits and Bitting: Form and Function, in: Proceedings of the Annual Convention of the AAEP. San Diego, Usa, pp. 1–8.

Bennett, D.G., 2006. An overview of Bits and Bitting, in: AAEP Focus Meeting (2006). Indianapolis,IN, USA, pp. 1–15.

Björnsdóttir, S., Frey, R., Kristjansson, T., Lundström, T., 2014. Bit-related lesions in Icelandic competition horses. Acta Vet. Scand. 56 (1), 7. https://doi.org/10.1186/s13028-014-0040-8.

Christensen, J.W., Jensen, D., König von Borstel, U.U., 2024. Conflict behaviour in Icelandic horses during elite competition. Appl. Anim. Behav. Sci. 271, 106166 https://doi.org/10.1016/J.APPLANIM.2024.106166.

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. https://doi.org/10.1111/j.2042-3306.2010.00151.x.

Clayton, H.M., Singleton, W.H., Lanovaz, J., Cloud, G.L., 2003. Measurement of rein tension during horseback riding using strain gage transducers. Exp. Tech. 27, 34–36. https://doi.org/10.1111/j.1747-1567.2003.tb00112.x.

Clayton, H.M., Singleton, W.H., Lanovaz, J.L., Cloud, G.L., 2005. Strain gauge measurement of rein tension during riding: a pilot study. Equine Comp. Exerc. Physiol. 2, 203–205. https://doi.org/10.1079/ecp200553.

Clayton, H., Mackechnie-Guire, R., Byström, A., Le Jeune, S., Egenvall, A., Jeune, L., Egenvall, S.;, Guidelines, A., Se, A.B., 2021. Guidelines for the Measurement of Rein Tension in Equestrian Sport. Anim. 2021, Vol. 11, Page 2875 11, 2875. https://doi.org/10.3390/ANI11102875.

Cook, W.R., 1999. Pathophysiology of bit control in the horse. J. Equine Vet. Sci. 19, 196–204. https://doi.org/10.1016/S0737-0806(99)80067-7.

Cook, W.R., 2003. Bit-induced pain: a cause of fear, flight, fight and facial neuralgia in the horse. Pferdeheilkunde 19, 75–82.

Cook, W.R., Kibler, M., 2019. Behavioural assessment of pain in 66 horses, with and without a bit. Equine Vet. Educ. 31, 551–560. https://doi.org/10.1111/eve.12916.

de Cartier, d'Yves A., Ödberg, F., 2005. A preliminary study on the relation between subjectively assessing dressage performances and objective welfare parameters, in: Proceedings of the 1st International Equitation Science Symposium. Melbourne, Australia, pp. 89–110.

Doherty, O., Casey, V., McGreevy, P.D., Arkins, S., 2017. Noseband use in equestrian sports – an international study. PLoS One 12 (1), 18. https://doi.org/10.1371/journal.pone.0169060.

Draaisma, R., 2020. Language Sings & Calming Signals of Horses. CRC Press Taylor & Francis Group, Boca Raton, Florida.

Dumbell, L., Lemon, C., Williams, J., 2019. A systematic literature review to evaluate the tools and methods used to measure rein tension. J. Vet. Behav. 29, 77–87. https://doi.org/10.1016/j.jveb.2018.04.003.

Dwyer, F., 1868. On seats and saddles: bits and bitting and the prevention and cure of restiveness. In: Horses (Ed.), Second. ed. William Blackwood and Sons, Edinburg and London. https://doi.org/10.5962/bhl.title.18346.

Dyson, S., Berger, J., Ellis, A.D., Mullard, J., 2018. Development of an ethogram for a pain scoring system in ridden horses and its application to determine the presence of musculoskeletal pain. J. Vet. Behav. 23, 47–57. https://doi.org/10.1016/j.jveb.2017.10.008.

Dyson, S., Bondi, A., Routh, J., Pollard, D., Preston, T., McConnell, C., Kydd, J.H., 2022. An investigation of behaviour during tacking-up and mounting in ridden sports and leisure horses. Equine Vet. Educ. 34, e245–e257. https://doi.org/10.1111/eve.13432.

Dyson, S., Pollard, D., 2021a. Application of the ridden horse pain ethogram to elite dressage horses competing in world cup grand prix competitions, 1187 11 Anim 2021 Vol. 11, 1187. https://doi.org/10.3390/ANI11051187.

Dyson, S., Pollard, D., 2021b. Application of the ridden horse pain ethogram to horses competing at the hickstead-rotterdam grand prix challenge and the British dressage grand prix national championship 2020 and comparison with world cup grand prix competitions. Vol. 11, 1820 11 Anim 2021 1820. https://doi.org/10.3390/ANI11061820.

Egenvall, A., Byström, A., Pökelmann, M., Connysson, M., Kienapfel-Henseleit, K., Karlsteen, M., McGreevy, P., Byström, E., 2022. Rein tension in harness trotters during on-track exercise. Front. Vet. Sci. 9, 1528. https://doi.org/10.3389/FVETS.2022.987852.

Eisersiö, M., Rhodin, M., Roepstorff, L., Egenvall, A., 2015. Rein tension in 8 professional riders during regular training sessions. J. Vet. Behav. Clin. Appl. Res 10, 419–426. https://doi.org/10.1016/j.jveb.2015.05.004.

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. https://doi.org/10.1016/J.TVJL.2013.09.030.

Eisersiö, M., Yngvesson, J., Byström, A., Baragli, P., Egenvall, A., 2021. A rein tension signal can be reduced by half in a single training session. Appl. Anim. Behav. Sci., 105452 https://doi.org/10.1016/J.APPLANIM.2021.105452.

Eisersiö, M., Yngvesson, J., Hartmann, E., Egenvall, A., 2023. Gaping for relief? Rein tension at onset and end of oral behaviors and head movements in unridden horses. J. Vet. Behav. 59, 8–14. https://doi.org/10.1016/J.JVEB.2022.11.009.

Fenner, K., McLean, A.N., McGreevy, P.D., 2019. Cutting to the chase: how round-pen, lunging, and high-speed liberty work may compromise horse welfare. J. Vet. Behav. 29, 88–94. https://doi.org/10.1016/j.jveb.2018.05.003.

Foster, D.L., 2013. The gold standard of dental care for the adult performance horse. Vet. Clin. North Am. Equine Pract. 29, 505–519. https://doi.org/10.1016/j.cveq.2013.04.012.

Fureix, C., Jego, P., Henry, S., Lansade, L., Hausberger, M., 2012. Towards an ethological animal model of depression? A study on horses. PLoS One 7, e39280. https://doi.org/10.1371/JOURNAL.PONE.0039280.

Górecka-Bruzda, A., Kosińska, I., Jaworski, Z., Jezierski, T., Murphy, J., 2015. Conflict behavior in elite show jumping and dressage horses. J. Vet. Behav. 10, 134–146. https://doi.org/10.1016/j.jveb.2014.10.004.

Hall, C., Heleski, C.R., 2017. The role of the ethogram in equitation science. Appl. Anim. Behav. Sci. 190, 102–110. https://doi.org/10.1016/j.applanim.2017.02.013.

Hall, C., Huws, N., White, C., Taylor, E., Owen, H., McGreevy, P.D., 2013. Assessment of ridden horse behavior. J. Vet. Behav. Clin. Appl. Res. https://doi.org/10.1016/j.jveb.2012.05.005.

Hall, C., Randle, H., Pearson, G., Preshaw, L., Waran, N., 2018. Assessing equine emotional state. Appl. Anim. Behav. Sci. 205, 183–193. https://doi.org/10.1016/j.applanim.2018.03.006.

Hamilton, K.L., Lancaster, B.E., Hall, C., 2022. Equine conflict behaviors in dressage and their relationship to performance evaluation. J. Vet. Behav. 55–56, 48–57. https://doi.org/10.1016/J.JVEB.2022.07.011.

Hartmann, E., Byström, A., Pökelmann, M., Connysson, M., Kienapfel-Henseleit, K., Karlsteen, M., McGreevy, P., Egenvall, A., 2022. Associations between driving rein tensions and drivers' reports of the behaviour and driveability of Standardbred trotters. Appl. Anim. Behav. Sci., 105726 https://doi.org/10.1016/J.APPLANIM.2022.105726.

Hawson, L.A., McLean, A.N., McGreevy, P.D., 2010. The roles of equine ethology and applied learning theory in horse-related human injuries. J. Vet. Behav. 5, 324–338. https://doi.org/10.1016/J.JVEB.2010.06.001.

Hebb, D.O., 1955. Drives and the C. N. S. (conceptual nervous system). Psychol. Rev. 62, 243–254. https://doi.org/10.1037/H0041823.

Hinebauch, T.D., 1889. Veterinary Dental Surgery: For the Use of Students, Practitioners and Stockmen. Hinebauch T.D. Purdue University, Lafayette Indiana. https://doi.org/10.5962/bhl.title.42517.

Kienapfel, K., Link, Y., König, V., Borstel, U., 2014. Prevalence of different head-neck positions in horses shown at dressage competitions and their relation to conflict behaviour and performance marks. PLoS One 9, e103140. https://doi.org/10.1371/journal.pone.0103140.

König von Borstel, U., Glißman, C., 2014. Alternatives to conventional evaluation of rideability in horse performance tests: suitability of rein tension and behavioural parameters. PLoS One 9. https://doi.org/10.1371/journal.pone.0087285.

König von Borstel, U., Visser, E.K., Hall, C., 2017. Indicators of stress in equitation. Appl. Anim. Behav. Sci. 190, 43–56. https://doi.org/10.1016/j.applanim.2017.02.018.

Kuhnke, S., Dumbell, L., Gauly, M., Johnson, J.L., McDonald, K., König von Borstel, U., 2010. A comparison of rein tension of the rider's dominant and non-dominant hand and the influence of the horse's laterality. Comp. Exerc. Physiol. 7, 57–63. https://doi.org/10.1017/S1755254010000243.

Lesimple, C., 2020. Indicators of horse welfare: state-of-the-art. Animals 10, 294. https://doi.org/10.3390/ani10020294.

Lethbridge, E., 2009. Knowing You Horse. A Guide to Equine Learning, Training and Behaviour. Wiley-Blackwell, Oxford - Iowa.

Løkken, C.B., 2020. Factors affecting the behaviour of horses when ridden, with emphasis on bridles and other equipment used to control behaviour. Master Thesis. Norwegian University of Life Sciences.

Luke, K.L., McAdie, T., Smith, B.P., Warren-Smith, A.K., 2022. New insights into ridden horse behaviour, horse welfare and horse-related safety. Appl. Anim. Behav. Sci. 246, 105539 https://doi.org/10.1016/J.APPLANIM.2021.105539.

Luke, K.L., Rawluk, A., Mcadie, T., Smith, B.P., Warren-Smith, A.K., 2024. Investigating the motivational priorities underlying equestrians' horse-keeping and training practices. Anthrozoös. https://doi.org/10.1080/08927936.2024.2303228.

Mata, F., Johnson, C., Bishop, C., 2015. A cross-sectional epidemiological study of prevalence and severity of bit-induced oral trauma in polo ponies and race horses. J. Appl. Anim. Welf. Sci. 18, 259–268. https://doi.org/10.1080/10888705.2015.1004407.

Maurício, L.S., Leme, D.P., Hötzel, M.J., 2023. How to understand them? A review of emotional indicators in horses. J. Equine Vet. Sci. 126, 104249 https://doi.org/10.1016/J.JEVS.2023.104249.

Mayhew, E., 1862. The illustrated horse doctor. J. B Lippincott & Co, Philadelphia. https://doi.org/10.5962/bhl.title.42702.

McBride, S.D., Mills, D.S., 2012. Psychological factors affecting equine performance. BMC Vet. Res 8 (1), 11. https://doi.org/10.1186/1746-6148-8-180.

McGreevy, P.D., 2007. The advent of equitation science. Vet. J. 174, 492–500. https://doi.org/10.1016/j.tvjl.2006.09.008.

McGreevy, P.D., 2011. The fine line between pressure and pain: ask the horse. Vet. J. 188, 250–251. https://doi.org/10.1016/J.TVJL.2010.10.011.

McGreevy, P.D., Christensen, J.W., König von Borstel, U., McLean, A.N., 2018. Equitation Science, 2nd ed. Wiley-Blackwell, Chichester, UK.

McGreevy, P.D., McLean, A.N., 2009. Punishment in horse-training and the concept of ethical equitation. J. Vet. Behav. Clin. Appl. Res 4, 193–197. https://doi.org/10.1016/j.jveb.2008.08.001.

McGreevy, P.D., McLean, A.N., Warren-Smith, A.K., Waran, N.K., Goodwin, D., 2005. Defining the terms and processes associated with equitation. Conf.: Proc. 1st Int. Équit. Sci. Symp. . Melb. 1–44.

McGreevy, P.D. 2004. Equine behavior: A guide for veterinarians and equine scientist. https://doi.org/10.1016/B978-0-7020-2634-8.X5001-1.

McLean, A.N., 2005. The positive aspects of correct negative reinforcement. Anthrozoos 18, 245–254. https://doi.org/10.2752/089279305785594072.

McLean, A.N., Christensen, J.W., 2017. The application of learning theory in horse training. Appl. Anim. Behav. Sci. 190, 18–27. https://doi.org/10.1016/j.applanim.2017.02.020.

McLean, A.N., McGreevy, P.D., 2010. Horse-training techniques that may defy the principles of learning theory and compromise welfare. J. Vet. Behav. Clin. Appl. Res 5, 187–195. https://doi.org/10.1016/j.jveb.2010.04.002.

Mellor, D.J., 2020. Mouth pain in horses: physiological foundations, behavioural indices, welfare implications, and a suggested solution. Animals 10, 572. https://doi.org/10.3390/ani10040572.

Mendl, M., 1999. Performing under pressure: stress and cognitive function. Appl. Anim. Behav.Sci. 65, 221–244. https://doi.org/10.1016/S0168-1591(99)00088-X.

Mendl, M., Burman, O.H.P., Paul, E.S., 2010. An integrative and functional framework for the study of animal emotion and mood. Proc. R. Soc. 277, 2895–2904. https://doi.org/10.1098/rspb.2010.0303.

Merillat, L.A., 1917. Animal dentistry and diseases of the mouth Volume I. : Vet. Surg. Alexander Eger, Chic. 214–215. https://doi.org/10.5962/bhl.title.56458.

Mills, D.S., 1998. Applying learning theory to the management of the horse: the difference between getting it right and getting it wrong. Equine Vet. J. 30, 44–48. https://doi.org/10.1111/j.2042-3306.1998.tb05145.x.

Mills, D.S., Marchant-Forde, J.N., 2010. The encyclopedia of applied animal behaviour and welfare. CABI, Oxfordshire, UK.

Ödberg, F.O., Bouissou, M.F., 1999. The development of equestrianism from the baroque period to the present day and its consequences for the welfare of horses. Equine Vet. J. Suppl. 26–30. https://doi.org/10.1111/j.2042-3306.1999.tb05152.x.

Odelros, E., Wattle, O., 2018. Influence of racing on oral health in Standardbred trotters. Abstract, in: Poster Presentation, Nordic Equine Veterinary Congress, (2018). Bergen, Norway.

Pastell, M., 2016. CowLog – cross-platform application for coding behaviours from video. J. Open Res. Softw. 4, 15. https://doi.org/10.5334/jors.113.

Pearson, G., Waran, N.K., Fraser, A.F., 2022. Undesirable Behaviour and Stress. Fraser'S. Behav. Welf. Horse 179–194. https://doi.org/10.1079/9781789242133.0013.

Piccolo, L., Kienapfel, K., 2019. Voluntary rein tension in horses when moving unridden in a dressage frame compared with ridden tests of the same horses—a pilot study. Animals 9, 1–10. https://doi.org/10.3390/ani9060321.

Pierard, M., McGreevy, P., Geers, R., 2019. Reliability of a descriptive reference ethogram for equitation science. J. Vet. Behav. 29, 118–127. https://doi.org/10.1016/J.JVEB.2018.10.001.

Preuschoft, H., Witte, H., Recknagel, S., Bär, H., Lesch, C., Wüthrich, M., 1999. Über die Wirkung gebräuchlicher Zäumungen auf das Pferd. Dtsch. Tieratzliche Wochenschr. 106, 167–175.

Russell, M., 1893. How "pullers" are made- a study of methods of bitting the colt. San. Fr. Call. 15, 75.

Seck, M., Jobling, R., Brown, A.F., 2022. Trialling locally made, low-cost bits to improve bit-related welfare problems in cart horses: findings from a study in senegal, 13, 2 Anim 2023 Vol. 13, 2. https://doi.org/10.3390/ANI13010002.

Starling, M.J., McLean, A.N., McGreevy, P.D., 2016. The contribution of equitation science to minimising horse-related risks to humans. Animals 6, 15. https://doi.org/10.3390/ani6030015.

Swoboda, M.S., 2021. Der Einfluss sportlicher Nutzung auf die Kopf- und Maulgesundheit bei Reitpferden:Bestandsaufnahme und Auswertung pathologischer Befunde des Kopfes und der Gebisslage sowie Entwicklung eines Prototyps eines Bewertungsbogens für den Turniertierarzt. Tierärztliche Hochschule Hannover.

Teigen, K.H., 1994. Yerkes-dodson: a law for all seasons. Theory Psychol. 4, 525–547. https://doi.org/10.1177/0959354394044004.

Tell, A., Egenvall, A., Lundström, T., Wattle, O., 2008. The prevalence of oral ulceration in Swedish horses when ridden with bit and bridle and when unridden. Vet. J. 178, 405–410. https://doi.org/10.1016/j.tvjl.2008.09.020.

Torcivia, C., McDonnell, S., 2021. Equine discomfort ethogram. Animals 11, 580. https://doi.org/10.3390/ani11020580.

Tuomola, K., 2022. Bit-related lesions and risk factors in competing trotters and event horses, thesis. University of Helsinki.

Tuomola, K., Mäki-Kihniä, N., Kujala-Wirth, M., Mykkänen, A., Valros, A., 2019. Oral lesions in the bit area in finnish trotters after a race: lesion evaluation, scoring and occurrence. Front. Vet. Sci. 6, 1–12. https://doi.org/10.3389/fvets.2019.00206.

Tuomola, K., Mäki-Kihniä, N., Valros, A., Mykkänen, A., Kujala-Wirth, M., 2021a. Bit-Related lesions in event horses after a cross-country test. Front. Vet. Sci. 8, 651160 https://doi.org/10.3389/fvets.2021.651160.

Tuomola, K., Mäki-Kihniä, N., Valros, A., Mykkänen, A., Kujala-Wirth, M., 2021b. Risk factors for bit-related lesions in Finnish trotting horses. Equine Vet. J. 53, 1132–1140. https://doi.org/10.1111/evj.13401.

Uldahl, M., Bundgaard, L., Dahl, J., Clayton, H.M., 2022. Pre-competition oral findings in danish sport horses and ponies competing at high level. Anim. Open Access J. MDPI 12. https://doi.org/10.3390/ANI12050616.

Uldahl, M., Clayton, H.M., 2019. Lesions associated with the use of bits, nosebands, spurs and whips in Danish competition horses. Equine Vet. J. 51, 154–162. https://doi.org/10.1111/evj.12827.

von Borstel, U.U., Duncan, I.J.H., Shoveller, A.K., Merkies, K., Keeling, L.J., Millman, S. T., 2009. Impact of riding in a coercively obtained Rollkur posture on welfare and fear of performance horses. Appl. Anim. Behav. Sci. 116, 228–236. https://doi.org/10.1016/j.applanim.2008.10.001.

Waran, N., Randle, H., 2017. What we can measure, we can manage: The importance of using robust welfare indicators in Equitation Science. Appl. Anim. Behav. Sci. 190, 74–81. https://doi.org/10.1016/j.applanim.2017.02.016.

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. https://doi.org/10.1016/j.applanim.2006.11.017.

Warren-Smith, A.K., McGreevy, P.D., 2007. The use of blended positive and negative reinforcement in shaping the halt response of horses (Equus caballus). Anim. Welf. 16, 481–488. https://doi.org/10.1017/S096272860002741X.

Yerkes, R.M., Dodson, J.D., 1908. The relation of strength of stimulus to rapidity of habit-formation. J. Comp. Neurol. Psychol. 18, 459–482. https://doi.org/10.1002/CNE.920180503.

Youtt, W. 1831. The Horse with a Treatise on Draught, First, London. https://doi.org/10.5962/bhl.title.28539.