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Original Research

# A Bridle Designed to Avoid Peak Pressure Locations Under the Headpiece and Noseband Is Associated With More Uniform Pressure and Increased Carpal and Tarsal Flexion, Compared With the Horse's Usual Bridle

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ABSTRACT

Bits are frequently blamed for veterinary and performance problems, but there is minimal other research into bridle and horse interaction. Study objectives were to (1) determine sites of maximum pressure under a double bridle headpiece, and under a crank cavesson noseband in trot using a pressure mat; (2) design a headpiece and crank cavesson noseband combination that avoids maximal pressure locations during movement; and (3) compare maximum pressure and gait characteristics of horses wearing the designed bridle (bridle F) with their usual bridle (bridle S). In part 1, peak pressure locations were determined using calibrated pressure mats under the headpiece ($n = 8$ horses) and noseband ($n = 10$). In part 2, 12 elite horses and riders with no lameness or performance problem were ridden in bridle F and bridle S in a double blind crossover design. Pressure mat data was acquired from under the headpiece and noseband. High speed motion capture in trot was used to determine forelimb and hind limb protraction, and maximal carpal and tarsal flexion during flight. Under the headpiece, bridle S peak pressure was 106.7% (mean) greater than that of bridle F, and bridle S maximum force was 59.7% greater than that of bridle F. Under the noseband, bridle S peak pressure was 47.8% greater than that of bridle F, and bridle S maximum force was 41.2% greater than that of Bridle F. On gait evaluation, bridle F had 4.1%, 3.5%, and 4.2% greater carpal flexion, tarsal flexion, and forelimb protraction than those of bridle S. These findings suggest an association between reduced peak pressures and improved gait, which may indicate improved comfort for the horse.



## 1. Introduction

Contact and performance problems in horses are frequently attributed to the type of bit used, and there has been a variety of research into horse interaction with the bit [1–3]. Interaction between the horse and other parts of the bridle appears to have been relatively neglected even though problems are often not resolved by alterations in bitting.

Traditional bridle design positions the parts of the bridle over various anatomic prominences and moving parts of the head, whereas the ridden horse is often asked to position the head in a particular way that may influence relative positioning of the bridle and head. It is therefore

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important to understand interactions between parts of the bridle and horse. Excessive noseband pressure in horses has been raised as an issue potentially affecting welfare, performance, and injury, particularly with respect to use of crank nosebands with double bridles [4–6], but there has been minimal scientific investigation performed. Various headpiece designs are available, marketed commercially, claiming to reduce pressure around the headpiece and to improve performance as a result. However, it seems difficult to locate scientific support for these claims.

To our knowledge, there has been no previous reported investigation into the pattern of pressure distribution under bridles and whether alterations in design could alter pressure patterns or to improve performance. The objectives of this study were to (1) determine the sites of maximum pressure under the headpiece of a double bridle, and under a standard crank cavesson noseband in trot using a pressure mat; (2) design a headpiece and crank cavesson noseband combination that avoids sites of maximal pressure during movement; and (3) compare the maximum pressure and gait characteristics of horses wearing the designed headpiece and crank cavesson noseband combination bridle with those in the same horses wearing their usual bridle. It was hypothesized that (1) there are repeatable locations of maximum pressure under different noseband and headpiece designs; (2) use of a bridle designed to avoid locations of maximum pressure and force does reduce maximum pressure and peak force compared to the horse's usual bridle; and (3) use of the designed bridle leads to alterations in gait characteristics compared with the horse's usual bridle.

**Fig. 1.** The headpiece pressure mat positioned under a horse's headpiece during the study.

## 2. Materials and Methods

### *2.1. Experiment 1: Assessment of Pressure Distribution Under Horses' Usual Headpiece and Noseband*

Elite (International Equestrian Federation [FEI] small or big tour level) dressage and show jumping (grade A) competition horses (height 162 to 170 cm) and riders were used to evaluate pressure and force magnitude and distribution under the nosebands and headpieces that they normally used for training and competition. All horses were on a regular program of veterinary management and physiotherapy and were deemed fit and without lameness. To reduce variability, the same bit and reins were used for all comparisons.

(1) Headpiece (eight warmblood dressage horses: five geldings, two mares and one stallion; age range 8 to 12 y, height range 160 to 170 cm)

A small format pressure mat (432-mm-long and 108-mm-wide, 32-sensors-long and 8-sensors-wide; Sensor Elastisens ES-256-108/432-135 S/N S2085_06, Pliance; Novel gmbh) was positioned centrally underneath the headpiece with the bridle fitted normally to the horse (Fig. 1). The mat was initialized to 0 before any pressure being applied to the reins, ensuring that the mat remained central. Headpiece types assessed were standard flat leather headpiece with separate noseband strap positioned underneath the headpiece (n = 1); noseband strap full width of headpiece with the headpiece positioned on top as one unit (n = 2); wide padded headpiece with noseband strap positioned on top of the headpiece (n = 2); rolled leather headpiece and noseband with buckles located to one side of midline (n = 2); and padded headpiece with noseband threaded through crew holes and over the top (n = 1).

(1) Noseband (10 warmblood horses; five dressage: four geldings and one mare, age range 8 to 12 y, height range 164 to 170 cm; and five jumping: two geldings and three mares; age range 10 to 12 y; height range 160 to 170 cm)

A small format pressure mat (226-mm-long and 28.25-mm-wide, 16-sensors-long and 2-sensors-wide; Sensor Elastisens ESES-256 226–14, S2073-mod, Serial No. S2073_6, Pliance; Novel gmbh) was positioned centrally over the horse's nasal bone underneath a cavesson crank noseband with the bridle fitted normally to the horse. The mat was initialized to 0 with the noseband loosely in place before any pressure being applied to the reins, ensuring that the mat remained central (Fig. 2). The noseband was then adjusted to the tightness usually used by the rider. The mat was taped in position, and the connector was taped to the cheek pieces of the bridle. The long cable (CX2022-ES) was then held in


**Fig. 2.** The noseband pressure mat positioned under a horse's noseband during the study.

place in the mane with three plaits. The cable was threaded through the channel of the saddle and connected to the data logger mounted on the saddle cloth.

*2.1.1. Data Collection*

Before testing, repeatability of positioning of the pressure mat under the bridle and repeatability of data collection were confirmed. A camera (Samsung Digital Cam VP-D371W) capturing at 50 frames per second was synchronized with the pressure mat. The mean peak pressures for each direction were plotted against point in the stride.

Horses were warmed up in their usual routine. Readings were obtained from three straight line passes in sitting trot between markers placed 10-m apart. Pressure mat data were captured using Bluetooth technology, and simultaneous video footage was recorded.

Magnitude of peak pressure at each sensor was recorded, and the locations of highest peak pressures during trotting were identified. The timing of peak pressures on each limb was compared with the simultaneous video data to identify the point in the stride at which the peak pressures occurred.

## *2.2. Experiment 2: Effect of Bridle Type on Pressure Distribution and Gait Parameters*

Based on the results of part 1, a bridle was designed to avoid the locations of peak pressure (bridle F). Pressure patterns under the headpiece and noseband and horse gait were compared between bridle F, and the horse's usual bridle (bridle S). All horses were ridden in a crank noseband in bridle S.

Twelve horses (eight dressage, four show jumping; 10 geldings, one stallion, one mare; age range 7 to 13 y; height range 162 to 170 cm) and four elite male and three female riders were used for the study. All horses were ridden by professional riders and were competing at Grade A (show jumping), or Grand Prix (dressage). All were on a regular program of veterinary management and physiotherapy and were deemed fit and without lameness.

Skin markers were placed on each horse using 3M ECE104 reflective tape [7]. Marker locations were identified by manual palpation of anatomic landmarks identifying joint centers and segment ends. Markers were located over the atlas, scapular spine, head of humerus, lateral condyle of humerus, tuber sacrale, lateral condyle of the femur, talus, and ulnar carpal bone, lateral extent of metacarpal and metatarsal condyles, and lateral collateral ligament (LCL) of the distal interphalangeal joint. All horses undertook testing in their standard equipment, with only the bridle altered between tests.

All horses were warmed up for 20 min before testing, in walk, trot and canter, and acclimatized to the testing environment during the warm up. The testing protocol was performed with the horse in bridle S and bridle F in a crossover design. In six horses, bridle S was tested first, and in six horses, bridle F was tested first. Riders were not told which bridle was being used. After changing the bridle, horses were given 20 min to acclimatize to the new bridle before repeating the testing protocol.

For testing, data were collected from three passes in sitting trot. High speed video and pressure mat data were acquired simultaneously. Data were not included if the horse lost straightness, tripped, or made an obvious alteration in gait pattern (e.g., shying) in which case an additional pass was undertaken.

High speed motion capture was carried out using two Casio EX-FH25 cameras, capturing at 240 Hz. The cameras were each placed 10 m from the testing location, parallel to the testing track with a field of view capturing three complete stride cycles from either side of the horse simultaneously. Two 240-W halogen spot lights were used on each side to illuminate the markers, located 10 m from the testing area. High speed video data were processed using Quintic Biomechanics (Quintic). Automatic marker tracking was used to investigate limb protraction and carpal and tarsal flexion during flight as previously described and validated [7]. One whole stride was tracked from 20 frames before point-of-ground contact, using the central stride in the field of view. Marker tracking was cross-checked manually: in cases where markers had been mistracked, then this was corrected with the Quintic Editing Tracking Suite. All data were smoothed using the Butterworth filtering system within Quintic with each "x" and "y" coordinates being filtered independently.

Forelimb protraction was defined as the horizontal distance from the scapular spine to the LCL marker at maximal protraction before ground contact; hind limb protraction as horizontal distance from the tuber coxae marker to the LCL marker at maximal protraction before ground contact. Carpal flexion was defined as the angle between the ulna, ulnar carpal bone, and metacarpal condyle markers at maximal carpal flexion during flight and tarsal flexion as the angle between the lateral condyle of the femur, talus, and metatarsal condyle markers at maximal tarsal flexion during flight [7].

Pressure under the noseband and headpiece was recorded using the same pressure mat and measurement technique as in part 1. Peak pressure and maximum force were recorded.

#### 2.2.1. Repeatability

The repeatability of the pressure mat used has already been described at other locations, and the high speed motion capture technique has previously been shown to be repeatable [7]. To ensure repeatability of pressure mat testing under the bridles specifically, measurements were obtained from three horses for three repetitions after removal and replacement under the same bridle. To confirm correct values, the mat was calibrated at the start of the study and recalibrated during the study to follow manufacturer's guidelines, as well as routinely initialized to 0 between each measurement set.

#### 2.2.2. Subjective Scoring

Riders were asked to score (from 1 = no difference, 2 = slight difference, 3 = moderate difference, 4 = obvious difference to 5 = marked difference) the horse's quality of work compared between the horse's own bridle (bridle S) and bridle F. The following features were graded, based on the FEI scales of training [8]: rhythm, suppleness, contact, impulsion, straightness, and collection.

#### 2.2.3. Data Analysis

Descriptive data analysis was undertaken to investigate the data, and a Shapiro–Wilk normality test was used to determine data distribution. A paired Student's *t* test (for parametric data) or Wilcoxon signed rank test (for nonparametric data) was performed to determine the effect of bridles F and S on the measured pressure mat and gait parameters within each horse. All analyses were performed using a statistical analysis software (Analyse-It for Microsoft Excel version 3) with a significance level of $P < .05$.

## 3. Results

### 3.1. Repeatability

Location of maximum pressure under the headpiece and noseband was the same for all tests and all horses. Repeatability assessment indicated a small coefficient of variance for both peak pressure and maximum force measurements between assessments after removal of the bridle (peak pressure [kPa] CV 0.017 to 0.037; maximum force [N] CV 0.005–0.007). Variations in magnitude of peak pressure and maximum force were considered within a range which was acceptable based on the differences detected between test conditions.

### 3.2. Experiment 1: Assessment of Pressure Distribution Under Horses' Usual Headpiece and Noseband

For all headpieces in all horses, high peak pressures were consistently located near the distal ends of the headpiece on either side, ventral to the base of the ears (sensors A1-4, B2-4, A30-31, B29-32). The exact location of the peak pressure sensors on the mat varied in relation to the size of the horse's head so the peak pressure zones were closer together on the mat in the horses with a smaller width between the base of the ears. For different headpiece designs, additional locations of high peak pressures varied between designs. For wide headpieces (6-cm-wide), there were high pressures on the caudal margin of the headpiece (sensors D7-12, D21-26) at the area of impact with the wings of the atlas on either side. Where the noseband strap was positioned underneath the headpiece, there were increased pressures on the midline over the top of the head (sensors C7-25) with the highest pressures recorded in rolled bridles, where the rolled noseband and bridoon lay on top of one another inducing focal pressures (sensors B7-23; Fig. 3). When the noseband strap was the full width of the headpiece, attaching underneath and crossing the top

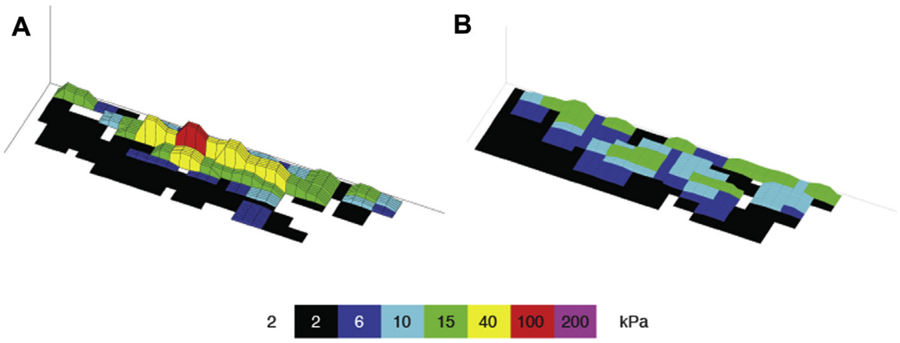


**Fig. 3.** (A) Pressure distribution detected by the headpiece pressure mat located under the usual headpiece (bridle S) of a horse in trot illustrating the consistent pattern of peak pressure locations with the noseband strap under the headpiece. Peak pressures were seen over the midline in this type of headpiece, and consistently located near the ends of the headpiece on either side of the head, ventral to the base of the ears for all headpieces. (B) Pressure distribution on a pressure mat located under the newly designed headpiece (bridle F) of the same horse illustrating the altered pressure distribution and absence of such high peak pressure locations. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location.

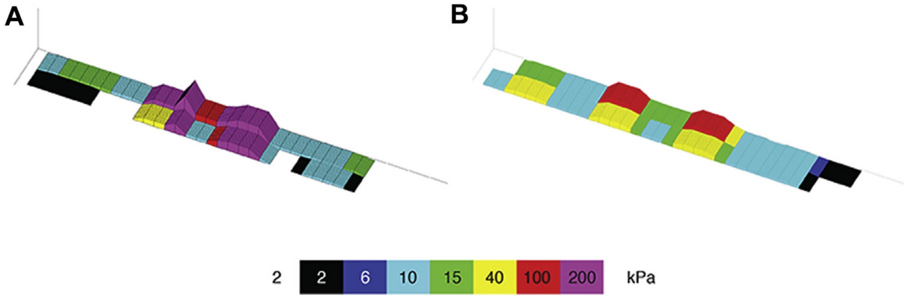


**Fig. 4.** (A) Pressure distribution detected by the noseband pressure mat located under the usual noseband (bridle S) of a horse in trot illustrating the consistent pattern of peak pressure locations. These areas of high peak pressure correspond to locations immediately left and right of the nasal bone. (B) Pressure distribution on a pressure mat located under the newly designed noseband (bridle F) of the same horse illustrating the altered pressure distribution and absence of such high peak pressure locations. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location.

of the head as one unit, there appeared to be greater cranial and caudal movement of the bridle, creating high peak pressures on the cranial margin against the back of the ears, and caudal margin against the wings of the atlas. In addition, there were frequent but intermittent high pressures recorded under the headpiece close to the junction with the brow band, which were still present when the brow band was removed and did not appear to be influenced by the rider.

For all nosebands, peak pressures were consistently located either side of the nasal bone in all horses (Fig. 4). The stiffer nosebands tended to have the pressure distributed slightly further from the nasal bone (sensors seven and 10 in the stiffer nosebands compared to six and nine in

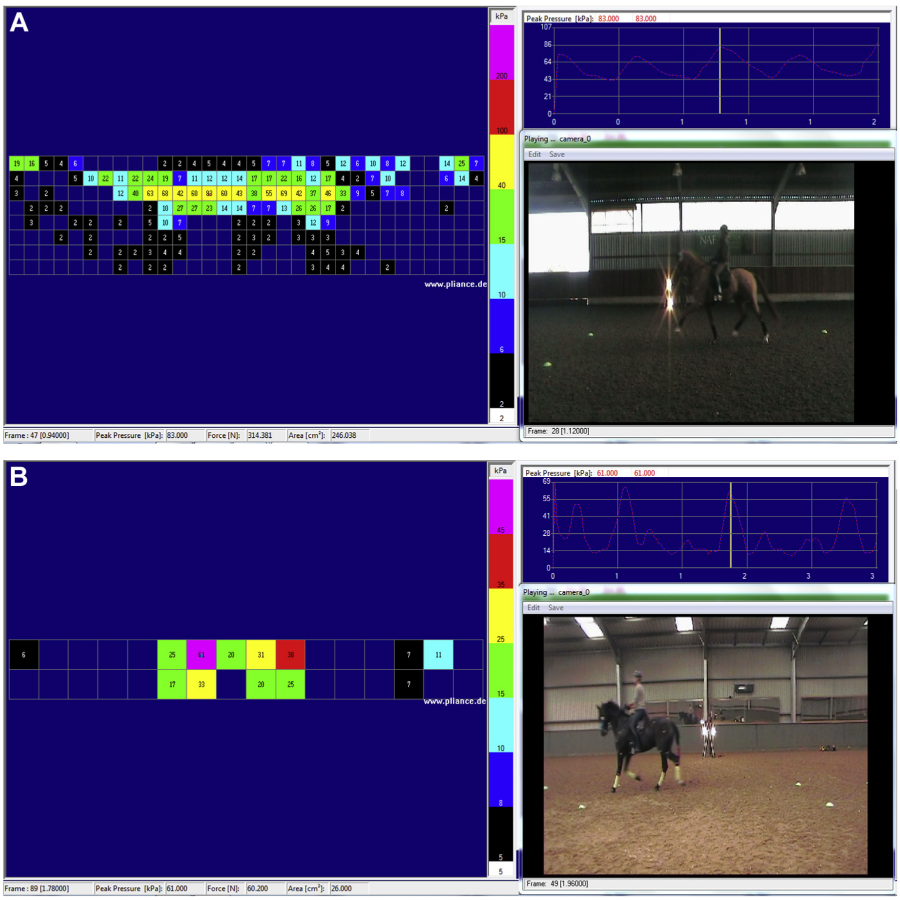


**Fig. 5.** (A) Timing of peak headpiece pressure in relation to stride pattern: Peak pressures occurred after midstance. (B) Timing of peak noseband pressure in relation to stride pattern: Peak pressures were observed in early stance. The pressure distribution under the mat is shown on the left. Top right shows the pressure plotted against time, linked to the video of the horse shown in the bottom right.

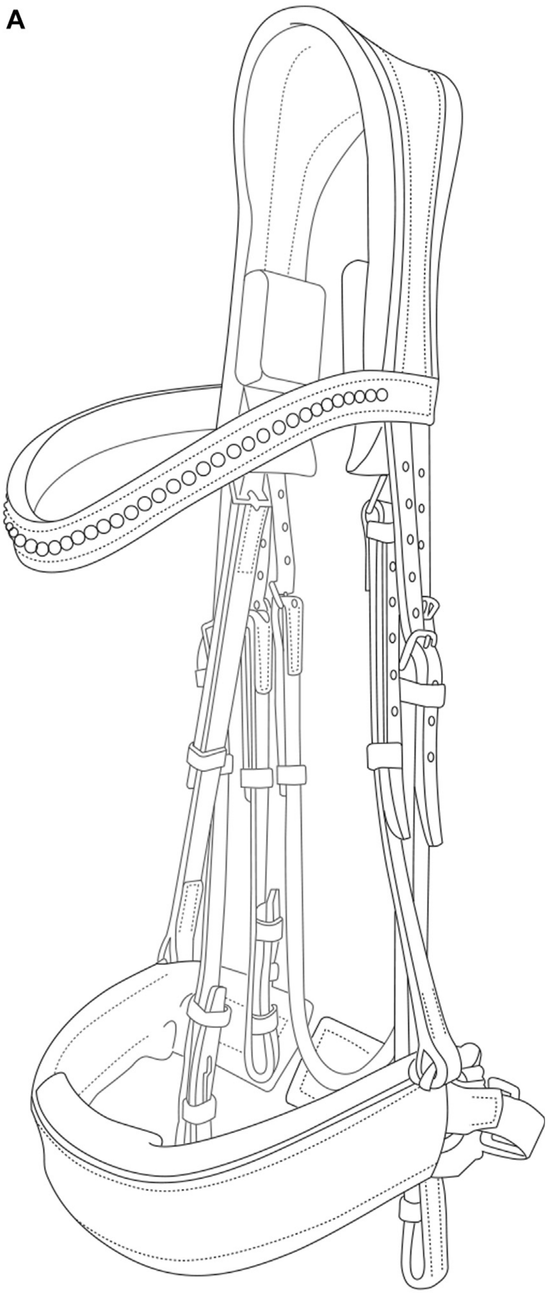



Fig. 6. Design of bridle F, showing how the headpiece and noseband were designed to avoid locations of peak pressure and improve consistency of pressure distribution. (A) Diagrammatic illustration of bridle F. (B) Bridle F seen in position on a horse in the study. The headpiece was shaped with a central lozenge to stabilize it over the poll and stop it moving caudally against the wings of the atlas or cranially against the back of the ears. The sides of the headpiece were narrowed to avoid interference with the wings of the atlas and the back of the ears. The position of the billet split was lowered to increase stability. The noseband was attached to both sides independently (so not over the head) to relieve pressure along the midline. The cushions were positioned at the ends of the headpiece to relieve pressure points at the base of the ear. The headpiece and noseband were lined with a pressure absorbing material to improve the interface with the horse's head and nose. A cushion was positioned in the center of the noseband to relieve pressure peaks on either side of the nasal bone. A ring was inserted into either side of the noseband to enable it to articulate and follow the movement of the head.

the softer nosebands). Show jumping horses (with the held head in a more horizontal position) tended to have greater pressure on the rostral part of the noseband, whereas dressage horses (with the head held in a near to vertical position) tended to have greater pressures on the caudal edge of the noseband.

The peak pressure readings occurred at the same location on the noseband or headpiece irrespective of which limb was in stance. Peak headpiece pressures occurred when one forelimb was immediately after the midstance (75% of stance, with a mean [$\pm$standard deviation, SD] angle of $19.23 \pm 0.97°$ to the vertical) with the contralateral limb protracted (Fig. 5). Peak noseband pressures occurred when one forelimb was in early stance (5% of stance, with a mean [$\pm$SD] angle of $21.97 \pm 4.54°$ to the vertical [Fig. 5]).

### 3.3. Experiment 2: Effect of Bridle Type on Pressure Distribution and Gait Parameters

The design of bridle F to avoid locations of peak pressure is shown in Fig. 6. Cushioned pads were fitted near the distal ends of the headpiece to ensure clearance was maintained at the base of and ventral to the ear where pressure peaks were recorded. A large central lozenge was incorporated in the headpiece to maintain stability, and the sides of the headpiece were narrowed to avoid interference with the wings of the atlas and the caudal margin of the ears. The position of the billet split was lowered to increase stability, and the noseband was attached to both sides independently to avoid high pressures over the midline. The entire headpiece was lined with a high performance pressure absorbing material (Prolite, Fairfax saddles, Walsall, UK).

The noseband was fitted with two large rings and two smaller rings to enable the noseband to articulate and move with the horse's head rather than antagonistically. A cushioned pad was fitted in the center of the noseband to maintain clearance of either side of the nasal bone where peak pressures were recorded. The entire noseband was lined with a high performance pressure absorbing material.

Significantly lower maximum force and significantly lower peak pressure were detected under the headpiece and noseband with bridle F compared to bridle S (Tables 1 and 2, Fig. 6). Measured under the headpiece, peak pressure

**Table 1**
The peak pressure (kPa) and maximum force (N) observed under the headpiece of horses at trot wearing their own bridle (bridle S) or with a specially designed headpiece (bridle F).

| Parameter | Number of Observations | Bridle S | Bridle F | Difference | $P$ Value |
|---|---|---|---|---|---|
| Peak pressure (kPa) mean ± SD | 12 | 46.54 ± 21.4 | 24.53 ± 5.8 | 22.00 (89.7%) | .0016 |
| Maximum force (N) mean ± SD | 12 | 255.91 ± 84.3 | 151.37 ± 58.7 | 104.54 (69.1%) | <.0001 |

Abbreviation: SD, standard deviation.

with bridle S was (mean) 106.7% greater than bridle F, and maximum force was (mean) 59.7% greater with bridle S than ridle F. The timing of peak headpiece pressure occurred with the forelimb during stance at an 11% greater angle to the vertical than for the same horses in bridle S ($P = .011$), indicating some alteration in gait pattern. Timing of peak pressure under the noseband of bridle F (when one forelimb was in stance at 22.51 ± 3.25° to the vertical) was not significantly different from that of bridle S.

Measured under the noseband, peak pressure with bridle S was 47.8% greater than that with bridle F, and maximum force was 41.2% greater with bridle S than that with bridle F. When the newly designed crank noseband was used alone without the designed headpiece, there was a significant reduction in peak pressure compared with the standard crank noseband, but this was less than when this was combined with the newly designed headpiece (Table 2).

Horse speed was on average 1% greater in bridle S than in that in bridle F. However, carpal and tarsal flexion angles were significantly less with bridle F than those with bridle S, indicating greater degree of flexion with bridle F than with bridle S (Table 3). No significant difference between left and right was detected for either bridle F ($P = .6234$) or bridle S ($P = .8879$). Carpal and tarsal flexion angles with bridle S were approximately 4.1% ($P < .0001$) and 3.5% ($P = .0001$) greater than those with Bridle F, respectively, indicating greater degree of flexion with bridle F than with bridle S. Measured from the right side, forelimb protraction was significantly greater with bridle F than with bridle S ($P = .011$), and there was a strong trend to a similar difference when both left and right sides were considered ($P = .057$). Overall, bridle F was associated with 4.2% greater forelimb protraction than bridle S. No difference in hind limb protraction was detected between bridles.

### 3.3.1. Subjective Scoring

All riders reported a difference in work quality between bridles, reporting a positive effect of bridle F (Table 4). A marked difference (grade 5) was reported by 9 of 12 riders for straightness, 8 of 12 for rhythm, suppleness, and impulsion, and 7 of 12 for contact and collection.

## 4. Discussion

The results of this study support the stated hypotheses. To the authors' knowledge, this is the first study investigating pressure patterns under a bridle during the stride, and with different bridle types. Repeatable locations and timings of maximum pressure were detected under different bridle designs. Using a bridle designed to avoid locations of maximum pressure led to lower maximum pressure under the noseband and headpiece compared with the horse's usual bridle and was associated with altered gait features including greater carpal and tarsal flexion in trot compared with the horse's usual bridle.

Peak pressures of >4.67 kPa have been suggested as a cause of damage, based on lack of tissue perfusion, and pressures >30 kPa under a saddle have been associated with back pain [9]. The magnitudes of peak pressure and maximum force recorded under the headpiece and noseband of horses in this study were considerably higher than these figures. This could explain potential discomfort, and results of one study did suggest that tight nosebands could be restricting cutaneous perfusion [4]. However, it has also been suggested that intermittent relief of pressure reduces tissue damage, and the pressures observed under the noseband and headpiece were largely intermittent. No evidence of tissue damage or white hairs were detected under the noseband or headpiece on the horses evaluated, supporting a lack of significant skin damage.

The timing of peak pressure under the noseband and headpiece was found to be different, although both occurred during the stance phase. Peak pressures occurred earlier in the stride for the noseband than the headpiece. Headpiece peak pressures occurred soon after peak loading in the limb, suggesting that ground reaction force was being attenuated and absorbed through the limb and thoracic sling. The head and neck are important in balance

**Table 2**
The peak pressure (kPa) and maximum force (N) observed under the noseband of horses at trot wearing their own bridle (bridle S), with a specially designed noseband (noseband F) with their own headpiece, and with bridle F (specially designed noseband and headpiece).

| Parameter | Number of Observations | Bridle S | Noseband F | Bridle F | Difference | $P$ Value |
|---|---|---|---|---|---|---|
| Peak pressure (kPa) mean ± SD | 6 | 53.3 ± 16.6 | 41.2 ± 11.2 | | 12.1 | .013 |
| | 5 | 44.2 ± 17.0 | | 29.9 ± 13.1 | 14.3 | .0018 |
| | 4 | | 39.0 ± 13.3 | 32.8 ± 13.1 | 6.1 | .023 |
| Maximum force (N) mean ± SD | 6 | 64.2 ± 19.6 | 49.7 ± 12.3 | | 14.5 | .074 |
| | 5 | 57.6 ± 20.4 | | 40.8 ± 17.4 | 16.8 | .0083 |
| | 4 | | 47.9 ± 7.7 | 44.1 ± 18.2 | 3.8 | .27 |

Abbreviation: SD, standard deviation.
There was a significant difference between bridle S crank noseband, noseband F, and bridle F (n = 4; peak pressure $P = .003$; maximum force $P = .01$).

**Table 3**
The carpal and tarsal flexion angles of horses at trot wearing their own bridle (bridle S) or bridle F (with a specially designed noseband and headpiece).

| Parameter | Side | Number of Observations | Bridle F | Bridle S | Difference | *P* Value |
|---|---|---|---|---|---|---|
| Carpal flexion angle (mean ± SD) | Left | 12 | 93.3 ± 6.6 | 97.0 ± 7.2 | −3.69 | .0003 |
| | Right | 12 | 92.8 ± 5.1 | 96.8 ± 5.5 | −3.98 | .0020 |
| | Pooled | 24 | 93.1 ± 5.7 | 96.9 ± 6.3 | −3.84 (4.1%) | <.0001 |
| Hock flexion angle (mean ± SD) | Left | 12 | 112.3 ± 5.0 | 116.1 ± 6.2 | −3.82 | .0266 |
| | Right | 12 | 113.6 ± 6.7 | 117.6 ± 6.3 | −4.04 | .0008 |
| | Pooled | 24 | 112.9 ± 5.8 | 116.9 ± 6.1 | −3.93 (3.5%) | .0001 |

Abbreviation: SD, standard deviation.
There was significantly greater carpal and tarsal flexion with bridle F than with bridle S.

and movement and are closely linked to the thoracic sling in timing of movement during the stride. This timing may be the result of coordinated muscle contractions of the neck and thorax, or related to intermittent increases in rein tensions that occur during the stance phase of the stride [10]. For the noseband, peak pressure occurred at an earlier stage in the stride, immediately after ground contact. This part of the stride tends to be involved in proprioception and muscle contraction during deceleration of the limb. An association between noseband tightness and rein tension has been reported, but it is difficult to tell whether rein tension is a contributor to the timing of peak pressure [11]. It is also possible that increased intranasal pressure during exhalation might be contributing to the timing of maximal noseband pressure, as it has been shown that horses can link the breathing pattern to the stride pattern in trot [12,13]. Further investigation of relationships between noseband pressure, rein tension, and breathing patterns might throw light on the reasons for variations in pressure.

The location of maximum pressure under the headpiece in a standard bridle was located immediately ventral to the base of the ear, overlying the parotid salivary gland superficially; various branches of the facial nerve (including to the ear) and external acoustic meatus more deeply. This region includes areas of muscle attachment for the flexors of the skull. It is therefore understandable that relief of pressure at this location might reduce restriction of movement. As the head and neck are important for balance in the horse, increasing freedom to use different muscle patterns to achieve a training position might improve balance and therefore ability to alter gait. If the bridle design changes the pressure and force distribution on the head, then the change in peak pressure may allow the muscles in that area to work more effectively as they are not having to work against the pressure that was previously placed on them. Future investigations using electromyography might be useful to test this hypothesis.

The intermittent high pressures located under the attachments of the brow band to the headpiece might potentially involve the muscles of the hyoid apparatus, associated movement of the tongue, and swallowing mechanism actively creating pressures against the bridle. It has been reported that an individual horse swallows at a similar frequency while wearing a bridle as when wearing a halter, but the frequency of swallowing varies between individual horses, which could support the intermittent high pressures seen at this location in this study, and a variation between individuals [2]. Further study is required to investigate this further.

For the noseband, it appears that the maximum pressure was located either side of the nasal bone in a standard bridle, which is likely to be related to compression of the soft tissues against the nasal bone by the noseband. This supports the impression of locations of pressure in a previous study where noseband pressures were estimated [5]. Position of the horse's head appeared to influence the location of pressure on the noseband. This could potentially relate to a rostral pull on the noseband occurring during greater head and neck flexion, potentially bringing the caudal edge more in contact. It is possible, therefore, that movement or positioning of a horse's head could be influenced by the horse seeking relief from bridle pressure.

This study has limitations. Using three-dimensional motion analysis would have expanded information on limb movement beyond the two-dimensional motion analysis used. However, intrahorse variation was limited as far as possible using a standardized straight line test with markers to ensure that the horse was perpendicular to the camera at the time of data acquisition. There was potential bias in the subjective grading as it was difficult to successfully blind the riders to which bridle was being used, which does limit how these data can be interpreted.

**Table 4**
Riders were asked to compare the horse's quality of work between the horse's own bridle and bridle F, based on the FEI scales of training.

| Grade | Rhythm | Suppleness | Contact | Impulsion | Straightness | Collection |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 2 | 2 |
| 3 | 0 | 0 | 2 | 2 | 0 | 0 |
| 4 | 4 | 4 | 3 | 2 | 1 | 3 |
| 5 | 8 | 8 | 7 | 8 | 9 | 7 |

This table shows the number of riders choosing each grade for each determinant of work quality. Scale: grade 1 = no difference between bridles to grade 5 = marked difference. In all cases, the difference was considered a positive effect of bridle F.

## 5. Conclusions

High peak pressure and maximum force occurred at specific locations under the headpiece and noseband of ridden horses. These pressures and forces could be reduced by altering the design of the headpiece and noseband, and this altered design was associated with greater carpal and tarsal flexion and increased forelimb protraction. These findings indicate the importance of bridle design in performance and welfare of horses and should potentially be considered in evaluation of horses with performance problems.

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