Journal of Equine Veterinary Science 152 (2025) 105654

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

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

Tight nosebands apply high pressures on the horses' face and alter stride kinematics

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ARTICLE INFO

Keywords:
Kinematics
Kinetics
Equine
Equitation science
ISES taper gauge
Noseband tightness

ABSTRACT

Background: Noseband tightness has received increasing attention within equitation science, however, there is little research into how this effects equine behaviour or performance.
Aims/objectives: 1) determine the peak pressures under noseband *in vivo* at three different tightness; 2) assess limb and back kinematics at different noseband tightness.
Methods: Noseband tightness ($n = 8$ horses) was set using an International Society for Equine Science (ISES) taper gauge with the three settings being; "two fingers (2F)", "one finger (1F)" and "zero fingers (0F)". Peak pressure under noseband was determined using pressure sensors under. Motion capture was used to analyse kinematics of limb and back.
Results: Peak pressures at 1F (40.9 ± 7.2 kPa) and 0F (115.8 ± 52.6 kPa), when compared to 2F (26.4 ± 7.2 kPa), showed a 54% and 338% increase, respectively ($F(1.027, 7.192) = 21.012$, $P = 0.002$). As the noseband tightness increased, stride length decreased, showing a statistically significant negative correlation ($r_s(22) = -0.592$, $P = 0.004$). A mean decrease in stride length of 6.2% was seen with the 1F when compared to 2F and an 11.1% decrease was seen at 0F when compared to 2F.
Conclusion: In conclusion, as the noseband was tightened, peak pressure increased and this has a detrimental effect on horses' kinematics, markedly stride kinematics.

1. Introduction

The intended purpose of tightening nosebands relates to closure of the mouth to avoid penalisation (dressage) and to enhance control of the animal [1,2]. Noseband over-tightening is commonly cited as being a welfare concern by industry participants [3,4]

Despite the noseband not having any essential function, fit is often commented on for being "too loose" [5]. Riders and trainers also often resort to increasing pressure on other parts of the head by tightening the noseband as an alternative means of forcing the horse to adopt the desired posture when changing the bit or increasing pressure in the mouth has been unsuccessful [6,7]. Such trends develop further when anecdotal evidence suggests that the short-term response of keeping the mouth closed with a noseband increases lightness of rein responses, making the horse appear more submissive, a desirable trait for many disciplines [6]. At the same time, standard recommendations for noseband tightness suggest that two adult human fingers need to fit under the nosepiece of a bridle (FEI), despite the origin of this method of assessment being unknown [8].

In recent years, excessive noseband pressures have emerged at the forefront of equestrian welfare issues following publications suggesting increased stress responses, nasal and mandibular bone changes, lips/oral injuries, changes in the pharyngeal region, decreased vascular perfusion, nerve damage and decreased performance are all negative manifestations of pressure applied to the delicate facial structures by tight nosebands [1,8–14]. Response to such findings included the call for the introduction of mandatory testing of noseband fit at competitions by 30 internationally recognised animal protection groups and the realisation that further research into the subject is critical [15] but rider compliance or awareness of the importance of correct noseband fit for horse welfare remains under desirable levels [3]. In one small survey, 68 riders were asked what is the correct noseband fit, with 85.3% of the riders responding 2-fingers, which is the correct recommendation. However, when the same 68 riders were asked to tight their horses nosebands, and

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https://doi.org/10.1016/j.jevs.2025.105654
Received 15 April 2025; Received in revised form 11 June 2025; Accepted 19 July 2025
Available online 19 July 2025
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the ISES noseband taper gauge was used to check the tightness, only 14.7% of the riders had actual tightness of 2-fingers or above, showing that despite being aware of the correct fitting, there is little awareness on how the correct fit is achieved [16]. The recent survey by the FEI Equine Ethics and Wellbeing Commission has raised concerns around the noseband tightness and the one of the FEI early recommendations around tack was "nosebands should not be tight – A uniform method of measurement including an agreed definition of 'too tight', should be used based on the available science" [4], stressing the need of more scientific evidence on this area.

Aside from human research, much of the equine research to date regarding areas subjected to maximal pressure peaks, has been mainly focused on saddle pressures [17]. Here there is a much larger surface area for pressure to be dissipated over when compared to the noseband. However, when focusing on a specific area for example the wither area, [18], maximal pressures ranging from 38.9 to 56.0 kPa were enough to cause acute clinical signs of back pain. Even studies investigating the entire area of the saddle, which would give a lower maximal pressure value as a result of lower pressures in the peripheral region, reducing the average, have reported values of only 31.5 kPa capable of causing back pain [19]. Another considered pressure peaks of just 10.8 kPa measured under a poorly fitting saddle to be potentially harmful [20]. More recently, noseband pressures evidence has received some interest in research and it has been found that design and tightness of noseband can affect pressures [21], but the possible effects on biomechanics have not been studied.

The aim of this research was to determine the extent to which different noseband tightness exert pressures on the nasal bone and consequently, the effects this has on spinal and limb kinematics. Our hypothesis is that tighter nosebands will exert higher pressures and affect the horse kinematics.

2. Materials and methods

2.1. Ethical approval

The data has been acquired according to modern ethical standards and has been approved by the Animal Welfare and Ethics Committee of Writtle University College, approval number 446/2018 from 26th November 2018 (*Supplementary File S1*). Data collection methods, although not considered a regulated procedure, heeded the guidelines laid out in the Animal (Scientific Procedures) Act 1986 (UK Home Office, 2020). Horses were monitored throughout for any signs of discomfort or lameness and welfare protocols were in place to have them removed from the trial and seen by a veterinarian if any distress would arise from the trial.

2.2. Sample size selection

Eight healthy and clinically sound riding school horses of varying heights (159 ± 6 cm), ages (14.9 ± 5.3 years) and breeds were used for the trial. This number was determined using the resource equation approach [16] for sample size calculation in animal studies, where the equation indicated a range of five to eight subjects (*Supplementary file S2*). The maximum number of subjects were used to increase reliability and has been deemed sufficient in similar published studies assessing equine noseband pressures which achieved adequate statistical discrimination with a sample of eight horses [22]. Assuming the methods differ slightly in their intervention and outcomes, estimates by 10%, for Type I and II errors of 0.05 and 0.20, respectively, using the Bland-Altman Test, we estimated a sample size of between 6 and 14 horses was needed (MedCalc® Statistical Software version 20.115). All horses were based on site and were accustomed to their surroundings and being ridden in the indoor arena. The workload of all horses used was light to moderate as riding school horses.

2.3. Experimental design

Horses were analysed as part of a within-subject randomised cross-over trial in order to quantify forces exerted under different noseband settings (0F= zero finger; 1F= one finger; 2F= two fingers) and any resulting changes in 2D gait variables relating to limb and back motion.

All data was collected in a 24 m x 55 m indoor arena, at ARU Writtle Equine Training and Development Centre, Writtle UK, with a levelled waxed, multi-washed silica sand, polypropylene, polyester and elastic fibre blend (Pro-Wax, Andrews Bowen) surface.

2.3.1. Experimental set up

Each horse was warmed up before the trial. A standard lunging cavesson was used over the top of the individual horse's own bridle, without reins, and the middle ring of the noseband was used to attach the lunge line. A standardised warm up routine lasting 15 min on an approximately a 20-metre radius or diameter circle was performed by each horse, controlled by the same handler who handled and lunged all horses. This comprised 4 min in walk and trot and 2 min in canter on the left and right reins [22]

All horses were studied in their own bridles consisting of their normal bits, most commonly a simple snaffle and all with a simple Cavesson noseband that had the ability to be tightened and/or loosened to the desired settings. A lunge line was run through the bit for the purposes of leading the horses during the trial. The order of treatments (0F, 1F or 2F) was predetermined by a random number generator to help reduce the risk of bias and any patterns in results due to carry over effect (see Table 1). Both the 2F and the 1F (Fig. 1) settings were standardised using an ISES taper gauge [23] on the midline of the nasal planum. The taper gauge was slid under the noseband in a rostro-caudal direction as far as the finger indicative lines without causing dorsal displacement of the noseband itself of any elevation of the head. When fixing the noseband to the tightest setting of 0F the horse was closely monitored for any signs of resentment or discomfort such as mouth opening, abnormal tail movements or pulling away [24] so that the noseband could be loosened immediately in response; however, none of these signs were observed.

Data were obtained from five straight line passes in trot led from the left hand side for each noseband setting as an average of three to five strides has been suggested as a suitable amount for kinematic analysis [25]. Horses were led in hand, by the lunge line, as this has been proved to have less influence on the stride than when ridden [26] and the handler was blinded to the condition being tested and remained the same throughout the entire trial to ensure as consistent a pace as possible. The handler has been instructed to lead the horses by holding the lunging line, not the reins, without applying pressure on the lunge line. On any of the runs, if the horse tripped, lost regularity, changed the gait or made any other obvious deviations to the stride, or if the handler was applying any noticeable pressure (backward/forward/downward) the pass was repeated, and the prior results discarded. Horses had ten minutes break between conditions, which comprised the adjustment of the noseband tightness to the next conditions to be tested and in hand walk at slow pace to complete ten minutes break, keeping the time in-between conditions always consistent.

Table 1
Randomly allocated order of the three noseband tightness's (0F= zero finger; 1F= one finger; 2F= two fingers) for each horse.

Horse	Conditions order		
1	0F	1F	2F
2	2F	0F	1F
3	2F	1F	0F
4	0F	2F	1F
5	2F	1F	0F
6	2F	1F	0F
7	1F	2F	0F
8	1F	2F	0F

Fig. 1. Noseband fastened to 2F= two-finger space (left) and 1F=one-finger space (right) using the ISES Taper Gauge.

2.3.2. Kinematics data collection

Markers consisted of 15 polystyrene balls covered in reflective adhesive tape, attached via the use of double-sided adhesive tape, were placed on specific bone landmarks. Eight spherical markers were placed at points along the spine including the wing of atlas, spinous processes of the sixth, tenth, thirteenth and eighteenth thoracic vertebrae (T6, T10, T13, T18), spinous processes of the 3rd and 5th lumbar vertebrae (L3, L5), lumbo-sacral joint (LS) and spinous process of the 3rd sacral vertebrae (S3) (Fig. 2A). This allowed for measurement of four spinal angles: thoracic cranial (T6-T10-T13 angle); thoracic caudal (T10-T13-T18 angle); lumbar (T18- L3-L5 angle) angle; lumbosacral angle (L5-LS-S3 angle).

Proximal and distal hindlimb markers consisted of seven hemispheres placed at the proximal aspect of the tuber coxae, greater trochanter of the femur, lateral epicondyle of the distal femur, midtalus, distal aspect of the third metatarsal bone over the collateral ligament of the metatarsophalangeal joint and the lateral collateral ligament of the distal interphalangeal joint (designated coronary band) provided data for the measurement of the hip, stifle, hock and hindlimb fetlock joints (Fig. 2B). The same researcher (EH) applied the markers to each horse in order to decrease the chances of marker placement variation.

A high-speed camera (Quintic High-Speed USB3 1.3MP, Quintic Consultancy, Birmingham, UK), recording at 300 frames per second, was used to collect the data via mocap software (Quintic Biomechanics, v. 33, Quintic Consultancy, Birmingham UK). A light emitting diode (LED) was situated above but slightly behind the camera. These were set up six metres away, and perpendicular to, a ten-metre track made up of parallel ground poles. This ten-metre long and 3 meters wide track gave enough room for approximately three strides, providing at least one complete stride in the centre of the view of the camera that could be analysed (Fig. 3).

Calibration of the software was carried out according to the software instructions. Five high-speed videos were collected from each horse at each noseband tightness.

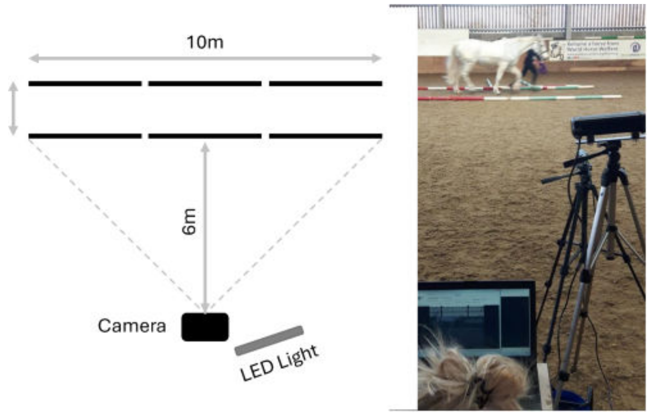

Fig. 3. Diagram and photo showing the set-up for data collection.

Figure 2. Anatomical marker placements; A) back, B) hindlimb.

2.3.3. Noseband pressure data collection

For sub-noseband pressure measurement, a pressure mapping system (F-scan system, Tekscan, Boston USA) was utilised, paired with a high sensitivity pressure mat (3500E, Tekscan, Boston USA) containing 25 sensels/in^2 and 100 Hz sampling rate. The pressure mat was calibrated according to the manufacturer instructions. The pressure sensor was trimmed down to a sensing area of 60 × 40 mm and the mat was applied with its centre aligned with the dorsal midline, over the nasal bone, covering the curve of the nasal bone, lying against the nasal bone and accompanying its curve, to the underside of the noseband for each horse. This was secured with the use of three pieces of tape, one either side and one centrally over the nasal bone (Fig. 4).

All nosebands were adjusted to fit an inch between the upper edge of the noseband and the distal portion of the facial crest, ensuring pressure applied was kept off the soft tissues. The sensor was then attached to a connector which in turn was attached to the left cheekpiece and connected to the wireless transmitter carried by the handler by a wire.

2.4. Data analysis

Videos for kinematic analysis were digitised using video analysis software (Quintic Biomechanics, v 33, Quintic Consultancy, Birmingham, UK). Pelvic limb stride length, hindlimb protraction and retraction, and maximum flexion and extension angles of hip, stifle, hock and fetlock were calculated and the range of motion (ROM) was calculated from 5 strides (one per video) and an average taken.

Fig. 4. Fitting of the pressure sensor mat under the noseband.

Pressure data was analysed with a specific software (F-Scan® 6.10 software, Tekscan), which analysed the peak pressures for each stride and calculated an average. Mean peak pressures were recorded in kPa- - a derived unit of the International system of units (SI), where Pascal (Pa) is the base unit for pressure (Newton per square meter).

2.5. Statistical analysis

IBM SPSS Statistics was used for all statistical tests. All data was assessed for normality using a Shapiro-Wilk normality test. As preliminary scoping analysis, we have tested if there was a difference between testing order, regardless of the noseband pressure, to exclude the effect of the order or interval between conditions. None of the outcome variables have shown an effect of the order. Stride length was slightly shorter on the third condition the horse was tested, regardless of the pressure. However, it is to note that by the random allocation, the third condition tested had more 0F trials. However, this was not statistically significantly different from conditions orders 1 and 2 ($p > 0.05$). We have then proceeded to test for differences between the different noseband tightness. Where normality was found, a one-way repeated measures analysis of variance (ANOVA) test was conducted to establish the presence if the different noseband settings had a significant difference for sub-noseband pressures, stride length, spinal and pelvic limb kinematics. If Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, a Greenhouse-Geisser correction was applied using the calculation for epsilon (ε) to correct the ANOVA. When data was non-parametric, a Friedman's test was applied to determine whether there was an overall effect of the noseband setting on stride length, spinal or pelvic limb kinematics. For all analysis (kinetics and kinematics), a Bonferroni post hoc test was carried out to determine differences between pairs of conditions (0F, 1F and 2F) and a significance level set at $P < 0.05$. Instead of applying the Bonferroni correction on the significance level, alpha, this study reported the SPSS Bonferroni adjusted *P*-values. This allows assessment of significance with reference to the traditional alpha of 5%, without increasing type II errors. A Spearman's rank-order correlation was run to determine the relationship between stride length and sub noseband pressure values.

3. Results

3.1. Noseband peak pressures

An example of noseband pressure tracing and mapping over time for 0F, 1F and 2F for horse $n = 2$ is shown in Fig. 5. Noseband peak pressures increased from 26.4 ± 7.2 kPa at 2F noseband setting to 40.9 ± 7.2 kPa at the 1F setting and increased again to 115.8 ± 52.6 kPa at the 0F noseband setting. Sub-noseband pressure was statistically significantly different with the different tightness ($F(1.027, 7.192) = 21.012$, $P = 0.002$). Post-hoc analysis with Bonferroni adjustment revealed that noseband pressure was statistically significantly increased with 0F setting when compared to 2F noseband setting (89.354 (95% CI, 32.703 to 146.005) kPa, $P = 0.005$) and to 1F (74.938 (95% CI, 6.790 to 22.043) kPa, $P = 0.002$). There was also a statistically significant increase in noseband pressure with 1F noseband setting when compared to the 2F noseband setting (14.416 (95% CI, 6.790 to 22.043) kPa, $P = 0.002$) (Fig. 6). The 0F represented an increase of 338% in the sub-noseband pressures in comparison with 2F

3.2. Stride length

Stride length increased from 1.90±0.13 m at 0F 2.00±0.12 m at 1F and to 2.14±0.13 m at 2F ($F(2,14) = 45.195$, $P < 0.001$). Post-hoc

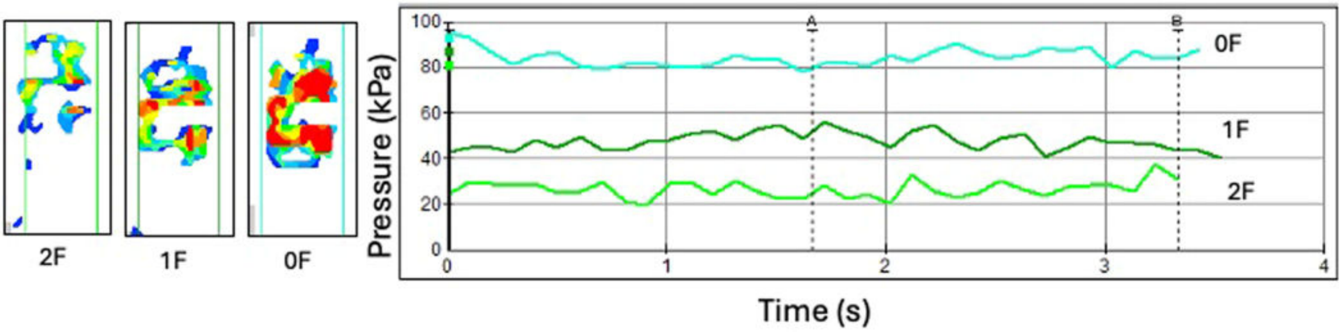

Fig. 5. Pressure mapping data and graph (pressure (kPa) vs. time (s)) showing pressures (kPa) exerted under different noseband settings (2F= two fingers; 1F= one finger; 0F= zero fingers) for horse 2 during trot.

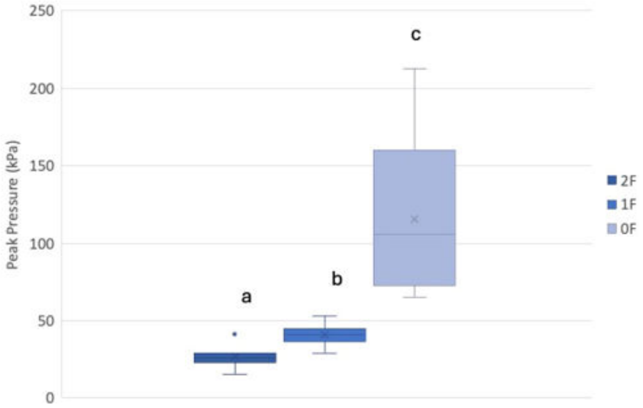

Fig. 6. Sub-noseband peak pressure (kPa) with two-fingers (2F), one-finger (1F) and zero-fingers (0F) noseband fitting settings. The whisker lines extending from the boxes vertically indicate the minimum and maximum of all the data for each of the conditions. The bottom line of each box is the first quartile, the line within the box is the second quartile and the median, and the line at the top of the box if the third quartile. X is the mean. Letters indicate significant differences between means by repeated measures ANOVA (n = 8) with different letters indicating significant difference (P < 0.05).

analysis with a Bonferroni adjustment revealed that stride length was statistically significantly increased from 1F to 2F (0.132 (95% CI, 0.044 to 0.220)°, P = 0.007), from 0F to 2F (0.239 (95% CI, 0.154 to 0.323)°, P < 0.001) and from 0F to 1F (0.107(95% CI, 0.047 to 0.167)°, P = 0.003) (Fig. 7).

A Spearman's rank-order correlation showed the existence of a moderate, negative correlation between stride length and sub-noseband pressure values, which was statistically significant ($r_s(22) = -0.592$, P = 0.004) (Fig. 8).

3.3. Spine and hindlimbs joint kinematics

None of the variables measured on the spine and hindlimb joints have shown a significant difference (P > 0.05). Table 2 shows the values in degrees for the hindlimb joints flexion, extension and ROM with the three different noseband tightness.

4. Discussion

To our knowledge, this is the first study to quantify sub-noseband pressures, under different settings of tightness, simultaneously with kinematics measurements in trot using the standardised ISES noseband taper gauge.

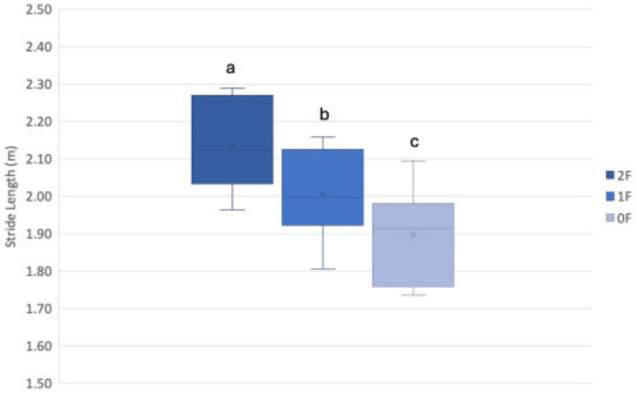

Fig. 7. Stride length (m) with two-fingers (2F), one-finger (1F) and zero-fingers (0F) noseband fitting settings. The whisker lines extending from the boxes vertically indicate the minimum and maximum of all the data for each of the conditions. The bottom line of each box is the first quartile, the line within the box is the second quartile and the median, and the line at the top of the box if the third quartile. X is the mean. Letters indicate significant differences between means by repeated measures ANOVA (n = 8) with different letters indicating significant difference at p < 0.05.

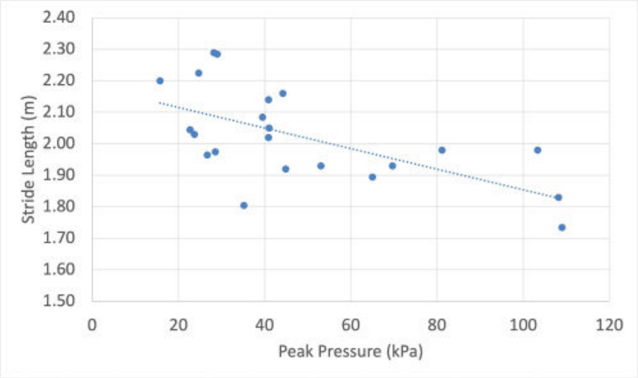

Fig. 8. Correlation between sub-noseband pressures (kPa) and stride length (m). ($r_s(22) = -0.592$, P = 0.004).

4.1. Noseband peak pressures

Sub-noseband pressures increased significantly by 338%as the noseband increased from 2F to 0F with a negative impact on stride length, accepting our alternative hypothesis.

The pressures detected in our trial were considerably higher than those found in previous trials which monitored the pressures exerted by

Table 2
Limb joint angles (mean±SD) (°) of the hindlimb of horses (n = 8) with two-fingers (2F), one-finger (1F) and zero-fingers (0F) noseband fitting settings.

Joint	Variable	2F	1F	0F	*P*-value
Hip	*Flexion (°)*	75.7 ± 11.5°	76.1 ± 12.4°	76.0 ± 12.5°	0.288
	Extension (°)	96.5 ± 13.5°	95.7 ± 13.3°	95.8 ± 12.8°	0.167
	ROM (°)	20.8 ± 2.3°	20.3 ± 1.8°	19.8 ± 1.4°	0.056
Stifle	*Flexion (°)*	103.0 ± 11.3°	103.3 ± 12.3°	102.9 ± 11.2°	0.833
	Extension (°)	151.4 ± 11.0°	150.7 ± 11.5°	150.4 ± 10.6°	0.661
	ROM (°)	48.4 ± 5.4°	47.4 ± 4.9°	47.4 ± 3.0°	0.223
Hock	*Flexion (°)*	107.0 ± 7.5°	107.2 ± 8.3°	106.8 ± 7.1°	0.580
	Extension (°)	159.2 ± 3.3°	159.4 ± 3.2°	159.3 ± 3.3°	0.468
	ROM (°)	52.2 ± 5.6°	51.2 ± 6.0°	51.5 ± 5.1°	0.543

crank nosebands [4] However, they used estimated, not directed, therefore lower pressure values would be expected, as areas of lower pressure, for example over the lateral aspect of the face, would reduce the average. As well as this, measurements were taken with the horse stationary, moving backwards and during mastication of differing feedstuffs rather than moving forward in trot. Nonetheless, it brings important information as nosebands fit to tight can lead to high pressures even during mastication and possibly other oral behaviours such as moving the tongue to dissipate pressure of the bit. Pressures corroborating those found in the present study were recorded by Murray et al. [6] who also found that by using a small format pressure mat positioned centrally over the nasal bone, beneath a cavesson crank noseband, as in our study, maximal pressures of at least 200 kPa were evident in trot. Furthermore, a recent study has found that nasal and mandibular pressures increased with noseband tightness, with 1.0 finger laxity or less associated with significantly and incrementally higher pressures than 1.5 or 2.0 finger tightness [21] particularly at mandibular level.

Higher sub-noseband pressures of up to 830 kPa were recorded [25] using a digital taper gauge that they developed based on a model of the nose-noseband interface. The use of a device that takes shape of the nose into consideration and provides a better distribution of pressure as the one used in our study may have given more reliable pressure values, deeming the ones found in our study being lower than [25] using a probe. However, corroborating results demonstrated in our study, their results showed a similar upward trend in noseband applied force from a two-finger space to a half-finger space. Although a zero-finger space was not measured, they predicted a non-linear increase in normal force components at this setting, as was demonstrated in our study, due to decreasing soft tissue accommodation. Tejwani et al.

[26] suggested that the minimum effective tourniquet pressure when applied to the human thigh, a fleshy and well-muscled area, measures at 90 to 100 mm Hg with 200 mm Hg recommended as the maximum pressure. Based on the pressures recorded in our study, [1,27] we can infer that that nosebands tightened to this extent could potentially cause a decrease in vascular perfusion, a speculation that is supported by reports of a decreasing trend in skin temperature under a noseband tightened without a taper gauge, although not statistically significant [28]. Again, this study found that higher levels of pressure were associated with higher probabilities of patient injury.

[17–20] The amount of pressure needed to activate nociceptors in horses has proved difficult to measure, however a range of studies investigating the level of force required to stimulate nociceptors in laboratory and farm animals have been reported with cattle and sheep demonstrating relatively high thresholds [29]. Mean mechanical thresholds for the stimulation of nociceptors in the hindlimbs of cattle and sheep were found to be 6.9 N (69 kPa) and 4.9 N (49 kPa) respectively [30,31]. Interestingly, the device that was employed to measure these forces was designed to cut out at 20 N (200 kPa) to prevent the occurrence of tissue damage. From the pressures measured in this trial, at localized sites on the horse's head, the forces can be considerably higher than this cut off threshold, implying that pain could undoubtedly be induced. Not only this but histological tissue damage and muscle injury has been seen in rabbits after application of pressures between 125 and 350 mmHg (16.66 – 46.66 kPa) [32,33]. However, to make these assumptions more accurately, and be able to make a correct link between pressure and nociception in equine, more studies specific for horses nociceptive thresholds need to be carried out.

When compared to more superficial tissues, muscle tissue shows the lowest tolerance to pressure injuries [34]. This could perhaps be the reason that horses can withstand such high pressures applied to the head, as when compared to other parts of the body, such as those where pressure has been associated with pain, for example the paraspinal muscles, there is less muscle mass and smaller skeletal muscle structures for the pressure to be applied to; with it instead being applied to tissues with a higher tolerance. This fact could also explain why we did not observe conflict behaviours in the horses used in our study, and possibly also why riders may fail in identify the noseband as a welfare issue. It is also suggested that the increased tolerance to pressure seen in horses compared to pressures applied to humans could be a result of the nature of exposure; humans confined to wheelchairs or beds developing pressure related issues experience constant pressure whereas the time a horse is exposed to pressure from pieces of tack is transient, negating effects [35]. However, studies conducted on the skeletal muscle of rats have shown this may not be the case and the magnitude of pressure determines whether time is a critical factor [36]. Pressures greater than 32 kPa were shown to cause a loss of cross striation in skeletal muscle, indicating cell death, after exposure for just 15 to 60 minutes; a time that many horses would spend wearing a noseband on a daily basis. For a time of over 120 minutes; not an uncommon time length for a horse to be wearing a noseband, a pressure magnitude of only 9 kPa was seen to cause cell death. Between these two time lengths; 60 minutes to 120 minutes, time appeared to be the critical factor with the magnitude of cell death strongly dependant on time of exposure, with the critical pressures dropping from 32 to nine kPa [34,36]. These changes to the mechanical properties of the muscle affect the distribution of stresses in soft tissues underlying bony prominences and has the potential to expose previously uninjured regions of muscle tissue to intensified stress; proving that pressure to the nasal structures can affect more than just that specific area through causing tension and stiffness.

4.2. Kinematics

This is the first study to elucidate that increasing sub-noseband pressures through increasing tightness, as measured by the ISES taper gauge, negatively impacts stride length in trot. With increasing sub-noseband pressures; 26.4 kPa to 115.8 kPa, stride length significantly decreased by a mean of 24 cm, a considerable amount in terms of athletic performance. Generally, long strides are desirable for equine athletes [37–40] No other studies have reported such effects as no other studies, to the authors' knowledge, have monitored them, making findings from this trial influential.

The stomatognathic system (SS) is a functional kinematic chain existent in all vertebrates, characterized by several structures, the integrity of which may be compromised by the fastening of a tight noseband; the maxilla and mandible, dental arches, the temporomandibular joint (TMJ) and masticatory muscles. Of particular interest here is the function of the TMJ and the muscular and ligamentous attachments to the cervical region forming the functional complex 'cranio-cervico- mandibular system'. The TMJ is highly innervated because of its dual function in mastication and its contribution of postural information [38]. Temporomandibular disorders are the main disorders that affect the cranio-cervico-mandibular system, and these are often determined by problems with the masticatory muscles, TMJ and surrounding structures. Afferent and efferent innervations for the SS are extensively represented in the orofacial area t and considering the pressures exerted on this area by the noseband it is not a surprise that an extensively tightened noseband can influence stride length through an effect on the SS and consequently the development of dynamic postural disorders. In humans, mandibular position can affect body posture and gait stability [39], if this could be translated to horses is a question to be further elucidated in other studies, but it could explain the correlation of reducing stride length with increasing pressures.

Nosebands also lie directly over branches of the trigeminal nerve. Numerous anatomical connections have been described between trigeminal systems and nervous structures that have a role in maintaining posture. Pressure, and therefore damage, to this nerve has been suggested to strongly influence the co-ordination of posture and sight through imbalance in the vestibular and oculomotor systems in humans [41]. The superior colliculus is a relay centre in the midbrain responsible for receiving visual, somatosensory and proprioceptive signals from afferent nerves, making it involved in eye movements but more pertinent to this trial, motor and gait control. The lateral part of this relay centre receives somatic afferent signals from the trigeminal nerve giving another possible reason for the adjustments to stride length if the noseband were to be causing damage to this nerve, therefore distorting signals to the superior colliculus and as a result having an inhibitory effect on gait control [42]

The existence of muscle-fascial chains alongside the SS and trigeminal system could also explain the decrease in stride length recorded. Fascia exists throughout the entirety of the body as connective tissue that responds to mechanical stress and has been seen to possess the ability to actively contract in a smooth, muscle like manner, consequently influencing musculoskeletal dynamics [43]. This provides a possible explanation for why restricting masticatory muscles and TMJ movement can be transmitted to distal musculature which, in our case, affected stride length.

Contrary to our expectations, there was not a significant difference in hindlimb joints ROM, and therefore the null hypothesis for ROM is accepted. A large ROM in the limbs is desired as it indicates effective and efficient performance with regards to quality, energy expenditure and aesthetics. Changes to the active range of motion for all joints in this study, including values for maximum extension, flexion and full range of motion, were not statistically significant. However, there were small non-significant trends in joints kinematics outcomes which may have contributed to the 24 cm decrease in stride length, still retains biological significance.

The mean overall ROM of the hip joint decreased by a total of 1.0° (5.0%) from the 2F setting to the 0F setting, this may not seem particularly substantial however when combined with a recorded decrease in mean stifle ROM of 1.0° (2.2%) there is a possibility that, in combination, this contributed to the decrease in stride length seen as it will have potentially decreased hind limb protraction. Interestingly, the horses that had the wider, softer nosebands showed a lesser decrease in overall hip ROM than those with the narrower cavessons and also showed the smallest decrease in stride length. ROM of the more distal joints; hock and fetlock, did not demonstrate any trends and remained similar throughout the different treatments therefore the assumption could be made that the effects of the tightening noseband manifest more proximally than distally.

4.3. Limitations and future studies

Our study was not without limitations. The use of 3D motion analysis or IMUs in the place of 2D would have given information on both limb and spinal movement beyond what was possible here. Likewise, the use of 3D kinematics analysis for the hindlimbs joints motion, would have brought information on the other planes of movement, besides of the sagittal plane which was the only plane of motion analysed here. However, every effort was made to reduce parallax (perspective) errors: ensuring the horse was perpendicular to the camera during data collection, that the camera was positioned at six meters of the collection area, and the 2D analysis was performed on the stride that was at the middle of the recording field. We ensured the same researcher applied the markers to reduce errors in placement Aside from this, even with the most accurate marker placement, skin displacement cannot be avoidable [44,45]. To overcome these issues, in the future, general correction models may be implemented for the measurements of the more proximal joints [46] or a more invasive method or marker placement could be used which would eliminate any displacement such as using Steinmann pins through the bone, which is not possible due to ethical concerns.

Another limitation was the large variability between horses in terms of working level. Although similar welfare issues are present in horses working at lower levels as are present in those at higher level [47], in the future it may be recommended that horses of similar capabilities, conformation and age are used to reduce variability and obtain more accurate data.

Future studies could explore the pressures occurring beneath different noseband designs rather than just a cavesson to determine whether application of pressure to different areas has any effect. A more in-depth study could employ the use of electromyography in order to monitor muscle activity to determine if the negative impacts on stride length and ROM result from decreases here. Furthermore, ridden studies, which replicate more the real-life in equestrian sports are ensured.

5. Conclusion

The key finding taken from this study is that the tighter the noseband, higher the pressures exerted under it. And higher pressures exerted onto the nasal bone by a cavesson noseband have the potential to affect gait, particularly stride length at trot, and possibly performance. These effects manifested predominantly as a significant decrease in stride length, possibly as a result of combined minor reductions noted in hip ROM, stifle ROM, particularly extension, and overall pelvic limb ROM. This study has demonstrated that constriction of the SS/TMJ systems via a tightly fitted noseband may lead to alterations in postural balance and locomotor patterns, including reduced stride length in trot. From this, the conclusion can be drawn that a noseband should not be tightened over the ISES recommended ‘two-finger’ space as this can significantly decrease performance. Finally, this this paper has added knowledge in developing a better understanding the collective interplay of various biomechanical systems in the horse for the purposes of welfare and performance.

Ethics in publishing statement

The authors confirm that this manuscript is original, has not been published previously, and is not under consideration for publication elsewhere. All authors have contributed substantially to the work, reviewed the final version of the manuscript, and agree to its submission.

The study was conducted in accordance with internationally accepted ethical standards. Ethical approval for the research was obtained from the Animal Welfare and Ethics Committee of Writtle University College (approval number 98354633/2018, dated 30th October 2018). All procedures involving animals were carried out in compliance with the Animal (Scientific Procedures) Act 1986 (UK Home Office, 2020) and adhered to high standards of animal welfare. Horses were monitored closely throughout the study, and protocols were in place to address any signs of discomfort or distress.

There are no conflicts of interest—financial or otherwise—that could have influenced the results or interpretation of this work. All data were collected and analysed with integrity and transparency, and the authors uphold the highest standards of research ethics and scholarly publishing.

CRediT authorship contribution statement

E. Hopkins: Writing – review & editing, Investigation, Formal analysis, Conceptualization. **S. Whitrod:** Writing – review & editing, Investigation, Data curation. **D. Marlin:** Writing – original draft, Formal analysis. **R. Blake:** Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization.

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.

Data availability statement

Dataset available on request from the authors

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jevs.2025.105654.

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