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Reducing peak pressures under the saddle at thoracic vertebrae 10-13 is associated with alteration in jump kinematics

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RESEARCH ARTICLE

Abstract

There is little information about horse-saddle interaction at take-off for a fence, although there is potential that this could have an influence on performance. It was hypothesised that (1) maximum peak pressure under the saddle would occur in the phase of maximum thoracolumbar flexion prior to hindlimb take-off; and (2) limb and trunk kinematics at take-off over the fence would be affected by reducing peak pressure at Thoracic vertebrae (T)10-13 at the point in the stride where peak pressures occur. The peak pressures under the usual saddle (Saddle S) and a saddle modified to reduce peak pressures at T10-13 (Saddle F) were measured during approach and take-off over a 1.30 m upright fence in 12 elite jumping horses. The timing of peak pressures was determined by comparison with simultaneous video data. Shoulder, carpal flexion angle and trunk angle to the horizontal at hindlimb take-off, take-off distance from the fence and fetlock height above the fence were determined using high speed motion analysis. Peak pressures under the saddle at T10-13 and kinematic data were compared between Saddles S and F. Maximum peak pressures occurred at forelimb vertical, during hindlimb protraction, consistent with thoracolumbar ventroflexion. Saddle F was associated with significantly lower peak pressures at T10-13, greater shoulder and carpal flexion, a steeper trunk angle, and higher fetlock height above the fence than Saddle S. Forelimb take-off distance from the fence was not different between saddles, but hindlimbs were significantly closer to the fence with Saddle F, indicating potential increase in ventroflexion through the thoracolumbosacral region. These findings suggest that reducing peak pressures under the saddle at T10-13 are associated with altered kinematics during the approach and take-off over a fence, which may have a positive effect on jumping performance.

Keywords*:* kinematics, equine, pressure mat, gait analysis

1. Introduction

Take-off over a fence is considered a vital period for determination of the quality of the entire jumping effort (Fercher 2017; Hay, 1985; Powers and Harrison, 2002; Powers *et al.*, 1999). It has been suggested that back kinematics are very important for jumping performance (Cassiat *et al.*, 2004; Walker *et al.*, 2018), with evidence that back kinematics are different between good and poor jumpers (Cassiat *et al.*, 2004; Powers and Harrison, 2000). It has also been demonstrated that there is an effect of training and rider on kinematics during jumping (Fercher, 2017; Lewczuk, 2007; Powers and Harrison, 2002; Santamaria *et al.*, 2005, 2006; Wejer *et al.*, 2013). However, there is little information about horse-saddle interaction at take-off or over a fence.

There is increasing recognition of the importance of horse-saddle interaction (De Cocq *et al.*, 2004; Greve and Dyson, 2013, 2015; Meschan *et al.*, 2007; Murray *et al.*, 2017; Von Peinen *et al.*, 2010). Alterations in the pressure pattern under the saddle during different gaits, and peak pressure under the saddle at thoracic vertebrae 10-13 (T10-13) at trot has been related to limb kinematics (Fruehwirth *et al.*, 2004; Murray *et al.*, 2015). It therefore seems likely that specific pressure patterns and magnitude may occur

between saddle and horse at take-off for a jump. In order to understand the influences on the horse, both in relation to performance and injury, it is important to understand the pressure pattern and magnitude during approach and take-off for a jump. However, investigation of the effect of different saddles on pressure patterns/magnitude and kinematics for horses taking off over a fence have not been reported.

It is possible that maximum pressures under the saddle might relate to the timings of the ground reaction force and maximum thoracic flexion. Back kinematics through the approach and take-off has been described (Walker *et al.*, 2018), showing variation in flexion of different parts of the spine, which would potentially alter the interaction between the saddle and the horse at different points of the approach and take-off. It is reported that maximum thoracic flexion occurs as the hindlimbs swing forwards towards the forelimbs in the suspension phase prior to hindlimb propulsion, so it is possible that this stage of the approach could be associated with alteration in pressure patterns under the saddle (Cassiat *et al.*, 2004; Walker *et al.*, 2018).

In the dressage horse at trot, alteration in peak pressures under dressage saddles at T10-T13 was associated with alteration in limb kinematics (Murray *et al.*, 2017). Alterations in back shape under the saddle at T13 with exercise were influenced by saddle fit and work quality in a separate study (Greve *et al.*, 2015), suggesting that the area around T13 may be important in the relationship between the saddle and horse. Limb and back kinematics of horses taking off over a fence have been described (Cassiat *et al.*, 2004; Clayton and Barlow, 1989, 1991; Deuel and Park, 1991; Santamaria *et al.*, 2004; Walker *et al.*, 2018), but associations between pressures under the saddle and limb kinematics have not been investigated. It is possible that alteration in peak pressures under the saddle at T10-13 in the approach stride and take-off might affect back or limb kinematics at take-off, in a similar way to the effect in the dressage horse, but this has not previously been investigated.

This study aimed to investigate peak pressure under the saddle of elite jumping horses during the approach and take-off over a fence, and to determine the point at which the maximum peak pressure occurs during the approach stride and take-off. It was hypothesised that: (1) maximum peak pressure would occur in the phase of maximum thoracolumbar flexion prior to hindlimb take-off; and (2) forelimb and trunk kinematics at take-off over the fence would be affected by reducing peak pressure at T10-13 at the point in the stride where peak pressures occur. The objectives of this study were to: (1) determine timing of maximum paraspinal peak pressure at T10-13 during the approach stride and take-off for a fence under saddles fitted to Society of Master Saddler (SMS) guidelines; and (2) investigate the effect of reducing paraspinal peak pressures under the saddle at the point of maximal pressure at T10-13 in the approach stride/take-off on forelimb and trunk kinematics at take-off for a fence.

2. Materials and methods

The study was approved by the ethical review committee of the Animal Health Trust (14/2016, approval date 11 February 2016) and there was informed owner consent. Twelve elite show jumping horses (four mares and eight geldings: age range 9-14 years: height 162-172 cm) competing internationally at small and big tour level were used. All horses were on a regular program of veterinary management and physiotherapy and deemed fit and without lameness. All horses were ridden by their usual rider: six elite professional riders (three male, three female; height 1.63-1.80 m, weight 50-73 kg, age 22-54 years). All riders were right handed.

Experimental method

All the jumping saddles used in the study on the 12 sample horses were independently assessed by four qualified registered SMS saddle fitters using SMS criteria for fitting saddles (City and Guilds, 2007; Murray *et al.*, 2017). Saddle fit was assessed in a straight line and on a circle in walk, trot, and canter on both reins. Saddle position, and presence or absence of saddle movement in medial-lateral, dorsal-palmar and cranial-caudal planes was recorded.

For each horse, both the usual saddle for the horse (Saddle S) and a modified design Saddle F were assessed. Saddle F was based on a design shown previously by this group to reduce peak pressures under the saddle at T10-13 in dressage horses at trot (Murray *et al.*, 2017). Saddles were included in the assessment process after ruling out structural faults (including loss of integrity of the tree) and confirming that the panel flock or foam was in good condition. All saddles on the 12 horses had been regularly assessed by qualified saddle fitters prior to the study.

Each horse underwent a warm up period of 20 minutes of walk, trot, and canter followed by three practice fences on each rein. Following this, horses jumped a 1.30 m upright fence on the left rein. The fence was positioned in the centre of the school and had a ground pole located directly underneath. Two parallel poles were laid on the ground either side of the fence, angled perpendicular to the fence to ensure correct positioning of the approach. Horses were given five strides before and after the fence before turning. All measurements were performed in an indoor school on the same wax-coated sand and fibre surface, which was groomed prior and in between each horse trial in the same way. If the horse lost straightness, tripped or faulted (e.g. refusal or knocking of fence) the trial was repeated.

A cross over design was used for the testing protocol. In six horses Saddle S was tested first and in six horses Saddle F was tested first. After changing the saddle, horses were given 20 min to acclimatise to the new saddle before repeating the testing protocol.

Data collection

Pressure mat data were acquired under the panel either side of the gullet of the saddle using a pressure mat (600 mm long and 200 mm wide for left and right side, 256 sensors arranged in 16 columns and eight rows for each of left and right sides) (Sensor Elastisens MSA600, Pliance, Novel GmbH, Munich, Germany) (sampling rate 50 Hz) positioned under the saddle. Pressure data was acquired under the panel during the final approach stride and take-off at the level of T10-13 (Cells A4-7 left/right) (Murray *et al.*, 2017). Pressure mat data was captured using blue tooth technology and simultaneous video footage was recorded (50 Hz Panasonic, Kadoma, Japan). Data were recorded three times on the left rein. The mat was initialised to zero without the saddle, rider or girth, ensuring that the mat remained central. 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 initialised to zero on the horse between each measurement set.

The timing of peak pressures was compared with the simultaneous video data to identify the point in the final approach stride and take-off at which the peak pressures occurred for all horses in all saddles.

24 marker locations were identified by manual palpation of anatomical landmarks identifying joint centres and segment ends; each reference point was subsequently marked with white skin paint. Skin markers were placed on each location using 3M ECE104 reflective tape (3M, Saint Paul, MN, USA) (Murray *et al.*, 2017). Markers were located over the scapular spine, head of humerus (cranial), lateral condyle of humerus, ulnar carpal bone, lateral metacarpal condyles, tuber sacrale, lateral condyle of the femur, trochanter major of the femur (caudalis), talus, and lateral metatarsal condyles on both sides of the horse. To reduce variability, the horse's usual bridle and girth were used for all comparisons, with only the saddle being altered. No breastplates were used.

A high-speed camera (spatial resolution 1,300×400, 240 fps at 10 m distance) was positioned on either side of the jump, located 10 m from the experimental track, and centred on the jump. The field of view allowed for one approach stride and jump take-off. Two 240 W halogen spot lights were used on each side to illuminate the markers, located 10 m from the testing area. Data were collected at 240 Hz three times with the horse on a left approach. High speed video data was processed using two-dimensional motion capture (Quintic Biomechanics, Sutton Coldfield, UK). Automatic marker tracking was used to investigate carpal flexion and shoulder flexion at hindlimb take-off, and distance from the base of the fence to the toe of the leading forelimb and leading hindlimb at take-off. Thoracolumbar angle to the horizontal was measured using manual tracking. Take off was defined as the frame immediately after the trailing hindlimb left the surface, when the dorsal aspect of the trailing hind foot was vertical (Figure 1). To determine height of fence clearance, the vertical distance between the top of the fence pole and the forelimb fetlock marker was recorded. All raw data were smoothed using a Butterworth high-pass filter with a cut off frequency 10 Hz.

At the point in the approach stride/take-off where maximum peak pressure was consistently detected, peak pressures under the saddle at the level of T10-13 and limb kinematics at take-off were compared between the horses usual saddle (Saddle S), and a modified saddle shown to reduce peak pressures at T10-13 in horses at trot (Murray

Figure 1. Take off was defined as the frame immediately after the trailing hindlimb left the surface, when the dorsal aspect of the trailing hind foot was vertical.

et al., 2017) (Saddle F). Carpal and shoulder flexion angle, thoracolumbar angle to horizontal at hindlimb take-off, fence clearance height and forelimb and hindlimb take-off distance were compared between Saddle S and Saddle F.

Repeatability

The repeatability of the pressure mat used has already been described at this and other locations, and the high-speed motion capture technique has previously been shown to be repeatable (De Cocq *et al.*, 2006; Murray *et al.*, 2013, 2015, 2017).

Data analysis

Descriptive data analysis was undertaken to investigate the data, and a Shapiro Wilks normality test was used to determine data distribution. A Paired Student's *t*-test (for parametric data) or Wilcoxon sign rank test (for nonparametric data) was performed to determine the effect of saddles 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, Redmond, WA, USA) with a significance level of $P<0.05$.

3. Results

There were 12 different usual saddles used by horses included in the study. Saddles were made by four different manufacturers, and were sized 17.5 inch. These included six saddles with flocked panels, six saddles with moulded foam panels, and were all twin flap saddles. All saddles assessed were considered by all four assessors to fit the horses following industry guidelines, so no saddles were excluded from the study.

Stride point of maximum peak pressure at T10-13

Maximum peak pressures in the region of T10-T13, at sensor numbers A4-A7 (right side) and H4-H7 (left side) were consistently detected at 'trailing forelimb vertical' (Walker *et al.*, 2018) of the final approach stride (approach stride 1) (Clayton, 1989) in all saddles (Figure 2). This is the stride point when the hindlimbs are in the cranial part of the swing phase and the trailing forelimb is vertical, immediately prior to the suspension phase which is followed by hindlimb propulsion.

Comparison between Saddles S and F

Peak pressure under the saddle at T10-13 at trailing forelimb vertical

Peak pressures on the left were significantly greater than the right for Saddle S ($P=0.0398$), and there was a trend towards greater peak pressures on the left for Saddle F ($P=0.0755$) (Table 1).

Mean peak pressures were significantly less with Saddle F than Saddle S for left peak pressures, right peak pressures and total of peak pressures per side and pooled between left and right sides data (Figure 3). With Saddle F, peak pressure was on average approximately 79% less than S for A4, 67% for A5, 66% for A6 and 62% for A7, on the left side. On the right, Saddle F, peak pressure was on average approximately 82% less than S for A4, 76% for A5, 75% for A6, and 76% for A7.

Limb and trunk kinematics

Mean speed for horses with Saddle F was 0.469±0.070 m/s and Saddle S was 0.463±0.067 m/s. No significant difference in speed was detected between the two saddles within individual horses ($P=0.16$).

Figure 2. Timing of maximum peak pressure under the saddle at cells A4-A7/H4-H7 during the approach to a jump. This was consistently detected at trailing forelimb vertical in approach stride 1.

Table 1. The peak pressure (kPa) observed under the saddle at T10-13 of jumping horses at hindlimb take-off, wearing their usual saddle (Saddle S) or with a saddle modified to reduce pressure at T10-13 (Saddle F).

Location	Side	No. observations	Saddle F: mean (SD)	Saddle S: mean (SD)	Difference (F-S)	*P*-value
A4	Left	12	6.18 (6.66)	29.95 (20.23)	-23.77	0.0023
A5	Left	12	12.41 (12.29)	39.64 (22.47)	-27.23	0.0020
A6	Left	12	13.68 (15.68)	39.91 (24.63)	-26.23	0.0024
A7	Left	12	13.27 (13.65)	34.68 (22.63)	-21.41	0.0023
A4	Right	12	3.86 (6.06)	20.91 (18.52)	-17.05	0.0078
A5	Right	12	7.18 (8.68)	30.36 (19.84)	-23.18	0.0039
A6	Right	12	7.77 (8.62)	30.68 (22.58)	-22.91	0.0020
A7	Right	12	5.77 (7.28)	24.05 (19.63)	-18.27	0.0020
A4	Left and right	24	5.02 (6.33)	25.43 (19.49)	-20.41	<0.0001
A5	Left and right	24	9.80 (10.72)	35.00 (21.23)	-25.20	<0.0001
A6	Left and right	24	10.73 (12.71)	35.30 (23.54)	-24.57	<0.0001
A7	Left and right	24	9.52 (11.34)	29.36 (21.38)	-19.84	<0.0001

There was no significant difference between left and right for carpal flexion with any saddle type (Table 2). For shoulder flexion, left had significantly less angle (i.e. was more flexed) than right using both Saddle F (P=0.01) and Saddle S (P=0.007).

When saddle types were compared, carpal flexion angle was significantly smaller (i.e. there was more carpal flexion) on the left and right with Saddle F. When left and right observations were pooled, there was stronger significance (Table 2). Use of Saddle F was associated with an average of >6 degrees more carpal flexion than with Saddle S.

There was significantly smaller right shoulder flexion angle (i.e. increased shoulder flexion) for Saddle F than the Saddle S (Table 2). When the left and right were pooled, stronger significance in the difference was present in the same pattern. Use of Saddle F was associated with approximately 3.4 degrees more shoulder flexion than with Saddle S.

When thoracolumbar angle to horizontal was compared between saddles, Saddle F was associated with a significantly steeper angle at take-off than Saddle S (P=0.0001) (Table 2). Distance between the base of the fence and the leading forelimb at take-off was not different between Saddle S and Saddle F. However, the take-off distance from the base of fence to both leading (P=0.018) and trailing (P=0.03) hindlimbs was significantly less with Saddle F than with Saddle S (Table 2). Fetlock height above the fence was significantly higher with Saddle F than Saddle S (P<0.0001) (Table 2).

4. Discussion

The results of this study support the stated hypotheses. The timing of maximum peak pressures was close to the point of maximum thoracolumbar flexion during the approach stride, supporting hypothesis 1. Using a saddle that reduced peak pressures under the saddle at this point in the approach stride was associated with alteration in forelimb kinematics and trunk inclination at take-off, supporting hypothesis 2.

The timing of maximum peak pressure in the approach stride was close to the point of maximum flexion of the thoracolumbar region (Walker *et al.*, 2018). It is likely that maximum peak pressure occurs because of a combination of increased thoracolumbar flexion and muscle expansion and activation at this point in the approach to a fence. The epaxial musculature at T10-13 has considerable activity related to posture, stabilisation and limitation of dynamic spinal movement (Licka *et al.*, 2001a,b, 2004, Peham *et al.*, 2001). It has been reported that T12 was the best place to take electromyographic recordings, suggesting that there is considerable muscle activity at this location (Licka *et al.*, 2004). There is increased longissimus dorsi activity in the second half of the stance phase, which coincides with the timing of the highest peak pressures that we detected. If this pressure becomes very high, this could result in local discomfort, resentment of full range of movement or restriction, or result in localised tissue damage (Von Peinen *et al.*, 2010). It has been reported that use of a saddle alone or weighted saddle increases overall back extension, which was suggested as a contribution to soft tissue injuries (De Cocq *et al.*, 2004). It is not unusual to detect thoracic epaxial discomfort in horses undertaking jumping exercise (Dyson *et al.*, 2018; Murray, 2014), so it is possible that muscular discomfort may be associated with horse-saddle interaction at this location even in well-fitting saddles,

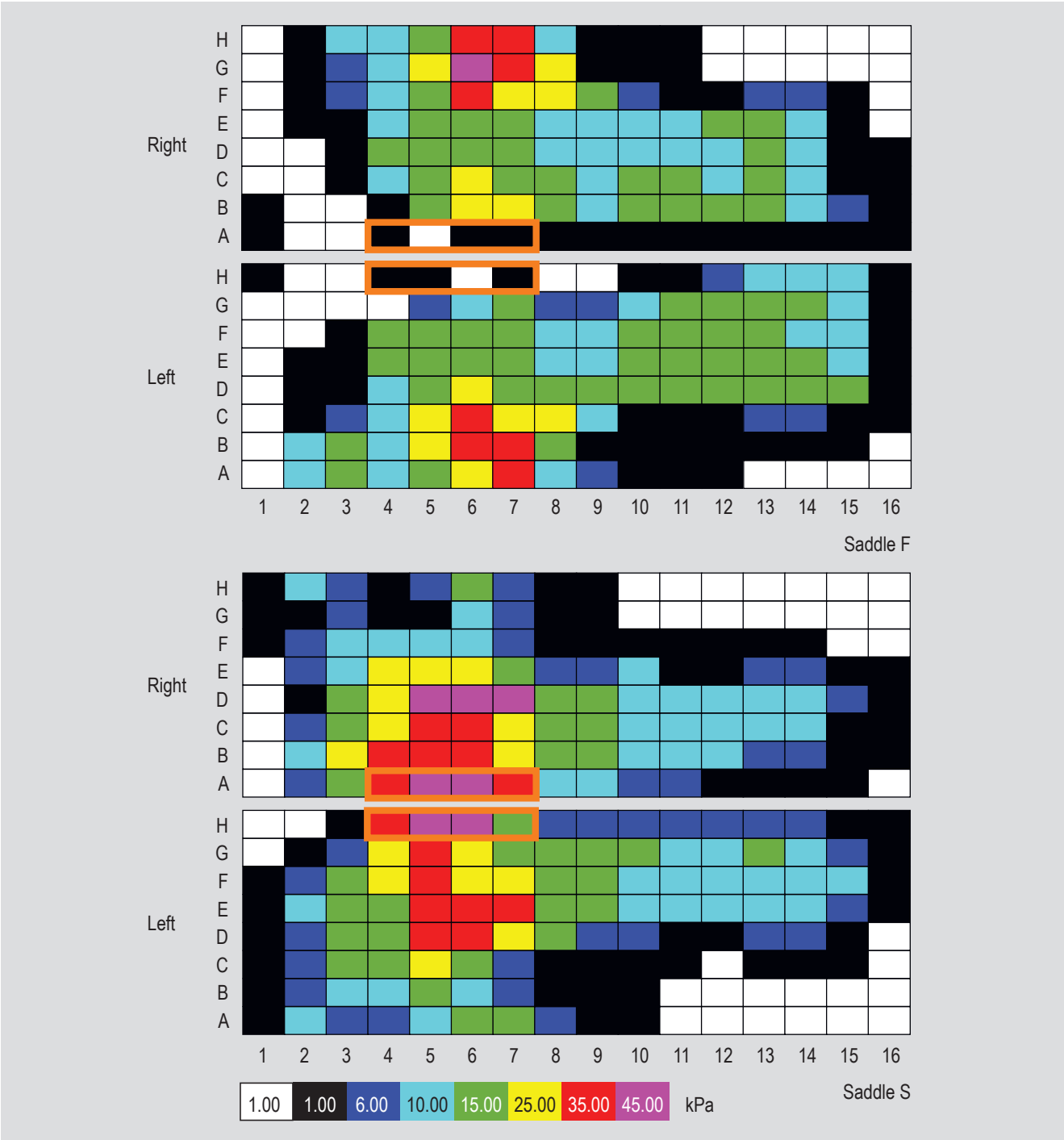

Figure 3. Peak pressure distribution detected using a pressure mat under Saddle S and Saddle F trailing forelimb vertical of approach stride 1, showing high peak pressure at cells A4-A7/H4-H7 under Saddle S either side of the spine, but absence of these high peak pressures and more even peak pressure distribution under Saddle F. Cranial is to the left of the picture. The scale at the bottom of the picture shows the scale for peak pressure measurements at each location.

as the peak pressures detected under Saddle S exceeded those reported to be associated with tissue damage (Von Peinen *et al.*, 2010).

The approach and take-off phase of the jump affects the outcome of the rest of the jumping effort (Powers and Harrison 1999, 2002). Limb and back kinematics, and inclination of the trunk to the horizontal at take-off has been related to jumping success (Clayton *et al.*, 1995; Godoi *et al.*, 2014, 2016; Powers *et al.*, 1999). In this study, alteration in forelimb kinematics and trunk inclination appeared to correspond with alteration in pressures under the saddle at T10-13. Saddle F, which had significantly lower peak pressures at T10-13, was associated with increased shoulder and carpal flexion, and increased steepness of trunk angle at take-off compared with the horses' usual

Table 2. The carpal and shoulder flexion angles, thoracolumbar angle to horizontal, and distance to the base of the fence of the leading and trailing hindlimbs at hindlimb take-off, the leading forelimb at take-off and clearance height of the fetlock marker above the fence of jumping horses wearing their usual saddle (Saddle S) or with a saddle modified to reduce pressure at T10-13 (Saddle F).

Parameter	Side	No. observations	Saddle F: mean (SD)[1]	Saddle S: mean (SD)[1]	Difference (F-S)	*P*-value
Carpal flexion angle (°)	left	12	52.75 (12.5)	58.89 (12.5)	-6.14	0.0088
	right	12	47.67 (10.5)	53.97 (10.6)	-6.29	0.0353
	pooled	24	50.21 (11.5)	56.42 (11.8)	-6.21	0.0007
Shoulder flexion angle (°)	left	12	109.7 (9.3)	112.7 (6.7)	-3.01	0.0992
	right	12	115.9 (8.7)	120.4 (7.2)	-4.41	0.0101
	pooled	24	112.8 (9.4)	116.5 (7.8)	-3.42	0.0023
Thoracolumbar angle to horizontal (°)		12	152.5 (3.7)	156.0 (3.7)	-3.5	0.0001
Distance to base of fence at take-off (m)	leading forelimb	12	1.215 (0.05)	1.212 (0.05)	-0.004	0.1089
	leading hindlimb	12	1.18 (0.11)	1.24 (0.06)	0.06	0.0177
	trailing hindlimb	12	1.16 (0.14)	1.21 (0.08)	0.06	0.0303
Clearance height of fetlock marker above fence (m)		12	0.175 (0.04)	0.139 (0.04)	0.036	<0.0001

[1] SD = standard deviation.

saddles. In addition, the distance between the hindlimbs and the leading forelimb was significantly less in Saddle F than in Saddle S, based on the distance to the base of the fence. This could suggest that horses were increasing back ventroflexion and bringing the hindlimbs further under the body in the phase where the peak pressures under the saddle were lower. It is possible that reduced pressure at T10-13 could be providing less restriction to thoracolumbar flexion and placement of the hindlimbs further forward under the body. Saddle F was associated with lower peak pressures at T10-13 immediately prior to hindlimb propulsion. Hindlimb propulsion is important for successful jumping, which is supported by horses in Saddle F clearing the fence by a greater height than horses in Saddle S, a feature which has been associated with increased jumping success. This suggests that saddles applying more or less pressure at T10-13 could be affecting approach and take-off movement pattern, and potentially affecting performance.

Shoulder flexion was different between left and right limbs in both saddles. This is likely to reflect that the horses were all approaching on the left rein, in left lead canter. The leading and trailing forelimbs leave the ground at different times (Clayton, 1989) so it might be expected that these limbs are at different stages of flexion at hindlimb take-off, and therefore the shoulder flexion would be expected to be different between the two limbs when the horses were leading with the left forelimb on the approach to the fence. There were greater peak pressures on the left side at trailing forelimb vertical, which may be explained by the different timing of leading and forelimb loading and take-off. It is possible that this is related to rotation of the left side of the ribcage up against the saddle, as we observed in dressage horses at trot when maximum peak pressures were detected on the contralateral side to the limb in stance (Murray *et al.*, 2017). It is interesting that the difference between left and right saddle pressures that was seen in Saddle S was less evident in Saddle F, suggesting more symmetrical loading in the T10-13 paraspinal region with Saddle F.

Limitations

Using three-dimensional motion analysis would have expanded information on limb movement beyond the two-dimensional motion analysis used. However, intra-horse variation was limited as far as possible by using elite performance riders that were experienced at defining take-off distance. It has been reported that individual horses have a repeatable movement pattern at take-off between jumps, both around a single course of fences (Barrey and Galloux, 1997) and over a 1.50 m vertical (Bogert *et al.*, 1994), and that horse jumping technique is not strongly influenced by the rider (Powers and Kavanagh, 2005). All

horses had data recorded with an approach from the left rein, with a left leading leg. Although it would have been ideal to repeat this on the right rein with a right lead also, we considered that it would be inappropriate to undertake the increased number of jumping efforts that would have been required because of potential fatigue effect or to add more variables by repeating the study on the right rein on a different day.

5. Conclusions

Alterations in pressure under the saddle at T10-13 appear to be related to equine kinematics during approach and take-off over a fence.

Conflict of interest

Vanessa Fairfax is employed by Fairfax Saddles Ltd.

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References

Barrey, E. and Galloux, P., 1997. Analysis of the equine jumping technique by accelerometry. Equine Veterinary Journal Suppl. 23: 45-49.

Cassiat, G., Pourcelot, P., Tavernier, L., Geiger, D., Denoix, J.M. and Degueurce, D., 2004. Influence of individual competition level on back kinematics of horses jumping a vertical fence. Equine Veterinary Journal 36: 748-753.

City & Guilds (in association with the Society of Master Saddlers), 2007. Certificate in saddle fitting (4750-80). City and Guilds, NPTC, London, United Kingdom. Available at: http://tinyurl.com/y82f9at2.

Clayton, H.M., 1989. Terminology for the description of equine jumping kinematics. Journal of Equine Veterinary Science 9: 341-348.

Clayton, H.M. and Barlow, D.A., 1989. The effect of fence height and width on the limb placement of show jumping horses. Journal of Equine Veterinary Science 9: 179-185.

Clayton, H.M. and Barlow, D.A., 1991. Stride characteristics of four Grand Prix jumping horses. Equine Exercise Physiology 3: 151-157.

Clayton, H.M., Colborne, G.R. and Burns, T.E., 1995. Kinematic analysis of successful and unsuccessful attempts to clear a water jump. Equine Veterinary Journal S18: 166-169.

De Cocq, P., Van Weeren, P.R. and Back, W., 2004. Effects of girth, saddle and weight on movements of the horse. Equine Veterinary Journal 36: 758-763.

De Cocq, P., Van Weeren, P.R. and Back, W., 2006. Saddle pressure measuring: validity, reliability and power to discriminate between different saddle-fits. The Veterinary Journal 172: 265-273.

Deuel, N.R. and Park, J., 1991. Kinematic analysis of jumping sequences of Olympic showjumping horses. Equine Exercise Physiology 3: 158-166.

Dyson, S., Tranquille, C., Walker, V., Guire, R., Fisher, M. and Murray, R., 2018. A subjective descriptive study of the warm-up and turn to a fence, approach, take-off, suspension, landing and move-off in 10 showjumpers. Equine Veterinary Education 30: 41-52.

Fercher, C., 2017. The biomechanics of movement of horses engaged in jumping over different obstacles in competition and training. Journal of Equine Veterinary Science 49: 69-80.

Fruehwirth, B., Peham, C., Scheidl, M. and Schobeberger, H., 2004. Evaluation of pressure distribution under an English saddle at walk, trot and canter. Equine Veterinary Journal 36: 754-757.

Godoi, F.N., De Almeida, F.Q., Toral, F.L., De Miranda, A.L., Kaipper, R.R. and Bergmann J.A., 2014. Repeatability of kinematics traits of free jumping in Brazilian sport horses. Livestock Science 168: 1-8.

Godoi, F.N., Toral, F.L., De Miranda, A.L., Menzel, H.J., De Almeida, F.Q. and Bergmann, J.A., 2016. Kinematic and morphological traits and the probability of successful jumps of young Brazilian Sport Horses. Livestock Science 185: 8-16.

Greve, L. and Dyson, S., 2013. The horse-rider-saddle interaction. The Veterinary Journal 195: 275-281.

Greve, L. and Dyson, S., 2015. A longitudinal study of back dimension changes over 1 year in sports horses. The Veterinary Journal 203: 65-73.

Greve, L., Murray, R. and Dyson, S., 2015. Subjective analysis of exercise-induced changes in back dimensions of the horse: The influence of saddle-fit, rider skill and work quality. The Veterinary Journal 206: 39-46.

Hay, J.G., 1985. Biomechanics of sports techniques, 3rd ed. Prentice Hall, Engelwood Cliffs, NJ, USA, pp. 31-44.

Lewczuk, D., 2007. The effect of training on linear jumping parameters in young stallions. Equine and Comparative Exercise Physiology 4: 159-165.

Licka, T., Peham, C. and Frey, A., 2004. Electromyographic activity of the longissimus dorsi muscles in horses during trotting on a treadmill. American Journal of Veterinary Research 65: 155-158.

Licka, T., Peham, C. and Zohmann, E., 2001a. Range of back movement at trot in horses without back pain. Equine Veterinary Journal Suppl. 33: 150-153.

Licka, T.F., Peham, C. and Zohmann, E., 2001b. Treadmill study of the range of back movement at the walk in horses without back pain. American Journal of Veterinary Research 62: 1173-1179.

Meschan, E.M., Peham, C., Schobesberger, H. and Licka, T.F., 2007. The influence of the width of the saddle tree on the forces and the pressure distribution under the saddle. The Veterinary Journal 173: 578-584.

Murray, R.C., 2014. Veterinary aspects of training the showjumping horse. In: Hinchcliff, K.W., Kaneps, A. and Geor, R. (eds.) Equine sports medicine and surgery. 2nd ed. Saunders Elsevier Ltd, Philadelphia, PA, USA, pp. 1127-1136.

Murray, R.C., Guire, R., Fisher, M. and Fairfax, V., 2013. Girth pressure measurements reveal high peak pressures that can be avoided using an alternative girth design that also results in increased limb protraction and flexion in the swing phase. The Veterinary Journal 198: 92-97.

Murray, R.C., Guire, R., Fisher, M. and Fairfax, V., 2015. 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. Journal of Equine Veterinary Science 35: 947-955.

Murray, R.C., Guire, R., Fisher, M. and Fairfax, V., 2017. Reducing peak pressures under the saddle panel at the level of the 10th to 13th thoracic vertebrae may be associated with improved gait features, even when saddles are fitted to published guidelines. Journal of Equine Veterinary Science 54: 60-69.

Powers, P. and Harrison, A.J., 1999. Models for biomechanical analysis of jumping horses. Journal of Equine Veterinary Science 19: 799-806.

Powers, P. and Harrison, A.J., 2000. A study on the techniques used by untrained horses during loose jumping. Journal of Equine Veterinary Science 20: 845-850.

Powers, P. and Harrison, A.J., 2002. Show jumping: effects of the rider on the linear kinematics of jumping horses. Sports Biomechanics 1: 135-146.

Powers, P.N. and Kavanagh, A.M., 2005. Effect of rider experience on the jumping kinematics of riding horses. Equine and Comparative Exercise Physiology 2: 263-267.

Powers, P.N.R., Harrison, A.J. and Storey, N.B., 1999. Kinematic analysis of take-off parameters during loose jumping in young untrained horses. In: Saunders R.H. and Gibson, B.J. (eds.) Proceedings 17th International Symposium on Biomechanics in Sports. Edith Cowan University, Perth, Australia, pp. 101-104.

Santamaria, S., Bobbert, M.F., Back, W., Barneveld, A. and Van Weeren, P.R., 2005. Effect of early training on the jumping technique of horses. American Journal of Veterinary Research 66: 418-424.

Santamaría, S., Bobbert, M.F., Back, W., Barneveld, A. and Van Weeren, P.R., 2004. Evaluation of consistency of jumping technique in horses between the ages of 6 months and 4 years. American Journal of Veterinary Research 65: 945-950.

Santamaría, S., Bobbert, M.F., Back, W., Barneveld, A. and Van Weeren, P.R., 2006. Can early training of show jumpers bias outcome of selection events? Livestock Science 102: 163-170.

Van den Bogert, A.J., Jansen, M.O. and Deuel, N.R., 1994. Kinematics of the hind limb push off in elite show horses. Equine Veterinary Journal Suppl. 17: 80-86.

Von Peinen, K., Wiestner, T., Von Rechenberg, B. and Weishaupt, M.A., 2010. Relationship between saddle pressure measurements and clinical signs of saddle soreness at the withers. Equine Veterinary Journal Suppl. 38: 650-653.

Walker, V.A., Tranquille, C.A., Harris, P., Roberts, C., McEwen, J. and Murray, R.C., 2018. Back kinematics at take-off in elite showjumping horses over an upright and parallel-spread fence forming part of a three-fence combination. Comparative Exercise Physiology 14: 161-171.

Wejer, J., Lendo, I. and Lewczuk, D., 2013. The effect of training on the jumping parameters of inexperienced warmblood horses in free jumping. Journal of Equine Veterinary Science 33: 483-486.