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Efficacy of spinal manipulation and mobilisation on trunk flexibility and stiffness in horses: a randomised clinical trial

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Summary

Reasons for performing the study: **Spinal mobilisation and spinal manipulative therapy (SMT) are being applied to horses; however, there are limited objective measures of their effects on spinal mobility or stiffness in actively ridden horses.**

Objectives: **To quantify passive spinal movements induced during dorsoventral mobilisation of the trunk and to identify any potential effects of SMT on measures of spinal mobility within the thoracolumbar region in standing horses. We hypothesise that displacement amplitudes will be significantly increased across vertebral levels after SMT, compared to spinal mobilisation only within the control group.**

Methods: **Passive spinal mobility was assessed in 24 actively ridden mature horses once a week for 3 weeks. Peak vertical displacement, loading and unloading velocities, applied force, stiffness and the frequency of truncal oscillations induced during dorsoventral spinal mobilisation were measured at 5 thoracolumbar sites and compared between treatment (n = 12) and control (n = 12) groups. Each week, outcome parameters were measured pre- and post intervention, 10 min apart. Treatment consisted of manually-applied, high-velocity, low-amplitude (HVLA) thrusts directed at the 5 intervertebral sites. Control horses received no additional intervention. A mixed-effects linear regression model was used to assess the interactive effects of treatment group, vertebral level, week and pre-/post intervention.**

Results: **Post intervention displacement amplitudes of the trunk and applied forces were significantly higher in the SMT group, compared to the control group. A similar trend was found for increased spinal stiffness within the SMT group. Across vertebral levels, SMT induced a 40% increase in displacement, a 20% increase in applied force and a 7% increase in stiffness.**

Conclusions and potential relevance: **SMT increased dorsoventral displacement of the trunk, which is indicative of producing increased passive spinal flexibility in actively ridden horses. Further clinical research is needed on the effectiveness of manual therapies in horses with objective measures of back pain, stiffness and poor performance.**

Introduction

Poor performance, stiffness and asymmetrical spinal motion are common clinical features in horses with back pain (Wennerstrand *et al*. 2004, 2009; Girodroux *et al*. 2009). Unfortunately, the clinical assessment of back pain and stiffness is subjective and often based on indirect or regional measures (e.g. gait evaluation or spinal kinematics) and frequently not based on direct or local assessments of spinal stiffness (e.g. vertebral segment range of motion) (Haussler *et al*. 2007), musculoskeletal pain (e.g. pressure algometry) (Haussler and Erb 2006b) or epaxial muscle activity or hypertonicity (Licka *et al*. 2004, 2009). Consequently, back problems are often overlooked during the clinical examination by most practitioners due to the lack of direct or objective measures of spinal flexibility or stiffness (Haussler 2003).

Spinal mobilisation and manipulative techniques are conservative treatment modalities that have been borrowed from man and applied to horses with the intent of improving the diagnosis and treatment of back pain, muscle hypertonicity and altered spinal kinematics. Spinal mobilisation is characterised as the application of rhythmic forces to induce intervertebral segmental displacement within the physiological range of joint motion (Peterson and Bergmann 2002). Spinal manipulative therapy (SMT) consists of the application of high-velocity, low amplitude (HVLA) thrusts at or near the end range of joint motion with the intent of increasing joint motion and reducing pain and muscle hypertonicity (Maigne and Vautravers 2003; Triano 2005). Recent equine studies have reported significant beneficial effects of SMT on trunk mobility (Faber *et al*. 2003; Haussler *et al*. 2007; Gómez Álvarez *et al*. 2008), nociceptive thresholds (Haussler and Erb 2003; Sullivan *et al*. 2008) and epaxial muscle hypertonicity (Wakeling *et al*. 2006). The majority of these studies have used either research horses in an experimental setting (e.g. treadmill locomotion) or have only evaluated the immediate response after a single treatment session. Longer-term evaluation of the effects of repeated SMT sessions on objective measures of spinal function are needed in actively-ridden horses to better simulate the existing clinical environment.

The aim of this project was to compare the immediate and longer-term effects of spinal mobilisation and SMT on passive dorsoventral spinal mobility and stiffness within the thoracolumbar region of the vertebral column of actively ridden horses. We

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hypothesise that dorsoventral displacement amplitudes will be significantly increased within the treatment group (which included both mobilisation and SMT), compared to spinal mobilisation alone.

Materials and methods

Horses

A convenience sample of 24 actively ridden horses was selected from the Oxley Equestrian Center at Cornell University. None of the horses had a current history of acute back problems or lameness. All horses were judged to be clinically sound during in-hand gait evaluation. All horses were studied under animal use protocols approved by the Institutional Animal Care and Use Committee (IACUC) at Cornell University. The horses included 10 females and 14 geldings; with a mean ± s.d. age of 13 ± 4 years and a bodyweight of 469 ± 53 kg. The breeds included 16 Thoroughbreds, 3 Quarter Horses, 2 mixed breeds, one Paint, one Morgan cross, one Connemara-Thoroughbred cross, one Palomino and one Dutch Warmblood. All horses were at the beginning of their training season and participated in either collegiate lessons (n = 12), polo (n = 9), team activities (n = 4), or private ownership (n = 1). Athletic activities of the lesson, team and privately owned horses involved English riding at a walk, trot, canter and jumping. The perceived athletic abilities of the horses were subjectively graded by the trainers and coaches from 1–5 (lowest to highest) within their individual disciplines.

Study design

The purpose of this study was to assess the immediate and longer-term effects of spinal mobilisation and SMT on trunk flexibility in actively ridden horses. Horses were randomised (by restricted lottery) into either treatment (SMT; n = 12) or control (n = 12) groups. In both groups, rhythmic, passive spinal mobilisation was applied in a ventral direction to induce maximum extension at 5 intervertebral sites within the thoracolumbar region in standing horses. Vertical displacement, loading and unloading velocities, applied force, stiffness and frequency of the induced spinal oscillations were measured at the 5 intervertebral sites, once a week for 3 weeks. Each week, these outcomes were measured twice. In the treatment group, SMT was applied between measurements, whereas in the control group, no intervention was applied. Within the treatment group, a single application of manually-applied, high-velocity, low-amplitude (HVLA), dorsal-to-ventral thrusts were applied bilaterally at the 5 intervertebral sites of interest. Spinal mobilisation and concurrent measures of the outcome parameters were repeated to assess the immediate effects of SMT on measures of spinal flexibility. After recording preintervention measurements, the control group horses were quietly restrained in the stocks for 10 min, which was the average time needed to apply the SMT to each treatment group horse. The delayed data collection period within the control group was used to equalise potential temporal effects between pre-/post intervention measurements within both groups of horses. No other forms of therapy were knowingly provided to the horses during the course of the study.

Measurement of vertical trunk displacement

All horses were restrained quietly in stocks with cross ties and were required to stand squarely on all 4 limbs. The examiner stood on an elevated surface positioned beside the stocks to enable the application of a consistent vertical force, oriented perpendicular to the dorsal midline, over the intervertebral site of interest. The peak amplitudes, loading and unloading velocities, and the frequency of the induced vertical displacements of the trunk were measured with a calibrated cable extensometer (Series 161, Miniature positional transducer)[1] attached to a mobile overhead rail in the stocks that allowed cranial-caudal and medial-lateral positioning (Haussler *et al*. 2007). The distal end of the cable extensometer was attached to the examiner's hand, which was placed on the horse's back and used to manually induce cyclic loading and unloading of the vertebral column (i.e. passive ventral spinal mobilisation) (Peterson and Bergmann 2002). A cyclic load was applied ventrally beginning over the T14–T15 dorsal spinous processes and continued caudally at the T17–T18, L1–L2, L3–L4 and L6–S1 intervertebral sites in an effort to induce maximal ventral displacement (i.e. spinal extension). These 5 intervertebral sites were selected because of their locations at consistent intervals within the region of the thoracolumbar spine that readily undergoes passive extension mobilisation. Force was applied until firm resistance to the induced joint motion was felt (i.e. end-range of motion in extension) or a local avoidance reaction was detected. The applied force was immediately released to allow the vertebral column to passively rebound dorsally (i.e. passive flexion). If a local avoidance reaction was detected, the amount of force was reduced until the avoidance reaction was no longer induced by the rhythmic spinal mobilisation. Adverse reactions to the applied pressure included local muscular contractions, active spinal movements (induced lordosis) or stepping away from the applied pressure. If the horse stepped away from the applied pressure or did not stand squarely on all 4 limbs, spinal mobilisation and data collection was repeated at that site. Each intervertebral site was cyclically loaded for approximately 5 s prior to data collection in an effort to condition the horse and the corresponding intervertebral segment to the induced motion. The voltage output of the cable extensometer was recorded at 100 Hz for 10 s.

Measurement of applied forces

The force applied during each cyclic displacement was simultaneously measured with a calibrated pressure-sensing mat (5101 series, I-Scan pressure sensor system)[2] with an overall area of 124.9 cm^2 and a pressure sensitive range of 0–1036 kPa (Kirstukas and Backman 1999). The pressure sensor was laminated with a thin layer of self-adhesive film to improve durability and reduce artifacts. Due to perceived wear, 3 different pressure mats were used sequentially in this project. Prior to use, each sensor was equilibrated at 18, 107 and 196 kPa and a 2-point calibration protocol that used dead weights at 29% (71 kPa) and 80% (196 kPa) of expected maximum load, which was completed according to the manufacturer's recommendations. The pressure sensors were triggered and sampled simultaneously with the cable extensometer at 100 Hz for 10 s. The peak force amplitude applied during each spinal oscillation was calculated from the pressure and contact area measured by the sensor. The typical contact area during peak force application was approximately 48 cm^2.

Spinal manipulative therapy

An elevated bench (approximately 46 cm tall) was positioned next to the horses in the stocks to allow vertical thrusts to be applied to the thoracolumbar spine. In an effort to apply SMT consistently among all horses within the treatment group, a single application of a HVLA thrust was applied bilaterally at the T14–T15, T17–T18, L1–L2, L3–L4 and L6–S1 intervertebral levels, irrespective of clinical signs of back pain, muscle hypertonicity or stiffness. HVLA thrusts were manually applied using a reinforced hypothenar contact and a body-centred, body-drop technique (Peterson and Bergmann 2002). At the T14–T15 intervertebral level, HVLA thrusts were directed lateral to medial (at a 45° angle to the horisontal plane) with a segmental contact near the T15 dorsal spinous process with the intent of increasing extension and lateral bending within the adjacent vertebral segments. At the remaining intervertebral levels (i.e. T17–T18, L1–L2, L3–L4 and L6–S1) HVLA thrusts were directed dorsal to ventral over the associated articular processes (i.e. 2–3 cm abaxial to the dorsal midline, parallel to the plane of the articular facets) with a segmental contact over the thoracolumbar *longissimus* muscle with the intent of increasing extension in the caudal thoracolumbar spine. All SMT and spinal mobilisation was applied in a consistent manner by the same nonblinded investigator (K.K.H), who is experienced in both spinal mobilisation and SMT techniques.

Data processing

For each intervertebral site, the mean amplitude of displacement (in mm), applied force (in N [kg/ms^2]) and the frequency (i.e. spinal oscillations/s [Hz]) induced during passive spinal mobilisation were averaged over 10 s. The velocity of the induced vertebral displacements (i.e. slope of the displacement-time curves) during the loading and unloading phases of spinal mobilisation was also calculated (Kirstukas and Backman 1999). To determine stiffness, the slope of the linear region within the loading phase of the load-displacement curves was used to calculate stiffness (in N/mm) at each intervertebral site. Visual inspection was used to assess rapid or gross changes in the pattern, amplitude or frequency of the typically sinusoidal displacement or force signals. Segments of the displacement or force data that had aberrant or inconsistent signals were discarded and not included in the analysis.

Statistical analysis

The normality of each outcome variable was assessed using Shapiro-Wilk testing, and non-normally distributed variables were log transformed to improve normality. Descriptive statistics were used to determine baseline values for all outcome variables. The effects of treatment were assessed for each outcome using mixed-effects linear regression with horse as a random effect to account for repeated measurements on each horse. All variables potentially affecting the outcome (i.e. treatment group, vertebral level, week, pre-/post intervention and pressure mat used) were assessed individually (without accounting for the effects of other variables) and reported as univariable effects. A multivariable model was then constructed using backwards, stepwise elimination, with a $P>0.05$ as criterion for removal to measure the effect of a specific variable after accounting for the effects of all other variables. Only the variables that were significant remained in the model. A reference value (i.e. intercept of the linear regression equation) for each of the displacement, force and stiffness parameters was created using the following collective parameters: preintervention values, at the T14–T15 vertebral level, during Week 1, in horses in the control group, and using Pressure Mat 1 (if including pressure mat in the model had a significant effect). For each variable added or removed from the model, the effect value is added or removed from the reference value to obtain the estimated amplitude for that combination of effects. All potential 2-way interactions were evaluated, and confounding variables were included in the model if they altered effect estimates by >20%. Treatment was always included in the model, whether significant or not, to address the *a priori* hypothesis of the study. Age and athletic-level distributions between treatment and control groups were assessed with *t* tests. Paired *t* tests were used to evaluate, separately for treatment horses and control horses, whether displacement amplitudes following treatment differed from displacement amplitudes prior to treatment in the following week.

Results

Horses

The age distribution between treatment (12.4 ± 4.4 years) and control (13.5 ± 3.5 years) groups and the subjective grading of athletic abilities between the treatment (3.7 ± 0.9) and control (3.4 ± 0.8) groups were not significantly different.

Displacement

The displacement, force and stiffness parameters were log transformed to improve normality. Baseline displacement amplitudes of the trunk induced during dorsoventral spinal mobilisation increased from cranial-to-caudal within the thoracolumbar region (Table 1). All baseline (Week 1, preintervention) outcome parameters were not significantly different between treatment and control groups. Treatment group did not significantly increase displacement amplitude when evaluated by itself (Table 2), and was not by itself associated with a significant change in displacement amplitude when other

TABLE 1: Baseline outcome parameters measured during dorsoventral spinal mobilisation of the trunk at 5 intervertebral sites in 24 horses

	Intervertebral sites				
Variable	T14–T15	T17–T18	L1–L2	L3–L4	L6–S1
Displacement (mm)*	24 (21–27)	27 (24–30)	29 (26–33)	33 (30–34)	34 (27–37)
Loading velocity (mm/s)	125 ± 27	141 ± 26	146 ± 28	156 ± 32	159 ± 38
Unloading velocity (mm/s)	–109 ± 27	–123 ± 24	–136 ± 29	–156 ± 29	–158 ± 36
Force (N)*	157 (136–187)	171 (138–251)	171 (132–244)	190 (141–257)	198 (170–243)
Stiffness (N/mm)*	24 (17–28)	25 (17–30)	24 (19–31)	24 (15–30)	21 (16–29)
Frequency (Hz)	2.44 ± 0.09	2.41 ± 0.07	2.39 ± 0.09	2.41 ± 0.09	2.40 ± 0.11

Data are mean ± s.d., apart from *: median (25th and 75th percentiles)

TABLE 2: Univariable effects of specified variables on the natural log of displacement amplitude in 24 horses evaluated weekly for 3 weeks, evaluated using linear regression with horse as a random effect

Variable	Value	Ln (displacement)	s.e.	P value
Treatment group	Control	3.47	0.04	–
	Treatment	+0.06	0.05	0.23
Vertebral level	T14–T15	3.31	0.03	–
	T17–T18	+0.14	0.02	<0.01
	L1–L2	+0.23	0.02	<0.01
	L3–L4	+0.29	0.02	<0.01
	L6–S1	+0.32	0.02	<0.01
Week	1	3.40	0.03	–
	2	+0.14	0.02	<0.01
	3	+0.19	0.02	<0.01
Pre-/post intervention	Pre	3.47	0.03	–
	Post	+0.07	0.01	<0.01
Pressure mat used	1	3.36	0.03	–
	2	+0.15	0.02	<0.01
	3	+0.23	0.04	<0.01

variables (vertebral level, week, pre- vs. post intervention) were accounted for (Table 3). However, the interaction between treatment group and pre/post intervention was statistically significant (Table 3), indicating that the post intervention displacement amplitude measurements in horses within the treatment group were significantly higher than post intervention measurements in horses within the control group. This supports the *a priori* hypothesis of the study. Both treatment and control groups had overall increases in displacement amplitudes across vertebral levels from baseline to final measurements: 40% within the SMT group; 19% within the control group (Table 4). In the control horses, displacement amplitudes prior to treatment in Weeks 2 and 3 were significantly higher than displacement amplitudes following treatment in the previous week (Table 5). Across vertebral levels and weeks within the control group, the percent change in pre- vs. post intervention displacement was -0.3 ± 3.3%, compared to a post vs. preintervention displacement of 9.5 ± 4.6%. In treated horses, displacement amplitudes prior to treatment in Week 3 were significantly lower than displacement amplitudes following treatment in Week 2. Displacement amplitudes prior to treatment in Week 2 did not differ significantly from displacement amplitude following treatment in Week 1 (Table 5). Across vertebral levels and weeks within the treatment group, the percent change in pre- vs. post intervention displacement was 15.8 ± 7.1%, compared to a post vs. preintervention displacement of -4.8 ± 4.4%.

Applied forces

The force amplitudes applied during spinal mobilisation did not differ significantly between treatment and control groups when force was evaluated by itself (Table 6) or when other variables were accounted for (Table 7). The applied force was significantly higher at the L3–L4 and L6–S1 vertebral levels, relative to the other vertebral levels, using multivariable analysis and Pressure Mats 2 and 3 were significantly different from Pressure Mat 1 using multivariable analysis (Table 7). Force amplitudes differed significantly between pre- and post intervention measurements, even for horses in the control group (Table 7). However, the interaction between treatment group and pre-/post intervention was statistically significant, indicating that the post intervention force amplitudes applied during spinal mobilisation of horses within the treatment group were significantly higher than post intervention measurements of horses within the control group. The interaction between treatment group and Week 2 and Week 3 was statistically significant, indicating that the force amplitudes applied during Weeks 2 and 3 within the treatment group were significantly higher than forces applied within the control group. The percent change in applied force across vertebral levels from baseline to the final measurement included a 20% increase within the SMT group and a 4% decrease in the control group.

Stiffness

Measures of spinal stiffness did not differ significantly between treatment and control groups or between pre- and post intervention when stiffness was evaluated by itself (Table 8) or when other variables were accounted for (Table 9). Stiffness was significantly reduced at L3–L4 and L6–S1 compared to T14–T15 and during Weeks 2 and 3 (Table 9). The interaction between treatment group and pre/post intervention was not quite statistically significant ($P = 0.06$), but indicated a trend that the post intervention stiffness within the treatment group was higher than post intervention measurements within the control group. The interaction between Week 3 and treatment group was statistically significant (Table 9), indicating that spinal stiffness was significantly higher in horses within the treatment group compared to the control group during Week 3. The percent change in spinal stiffness across vertebral levels from baseline to the final measurement was a 7% increase within the SMT group and a 15% decrease in the control group. The frequency of induced spinal oscillations across vertebral levels varied by <1% in both treatment and control groups between baseline and the final measurements.

Discussion

Post intervention displacement amplitude measurements were significantly higher in horses that received SMT, compared to horses within the control group, which supported the primary hypothesis of the study. Similar beneficial results have been reported in prior studies evaluating the biomechanical effects of SMT on increasing spinal flexibility or normalising spinal motion symmetry in horses with naturally occurring (Faber *et al*. 2003; Gómez Alvarez *et al*. 2008) or experimentally-induced back pain (Haussler *et al*. 2007). In the current study, both spinal mobilisation and manipulation were effective at increasing spinal flexibility at Weeks 2 and 3. SMT produced consistent post intervention increases in displacement within sessions, whereas the effects of spinal mobilisation on increasing displacement was evident between sessions, which indicates 2 possibly different mechanisms of action for spinal mobilisation and SMT. The exact mechanisms by which mobilisation or SMT cause increased passive spinal mobility are unknown (Keller *et al*. 2003). In the current study, spinal mobilisation had a delayed effect on increasing displacement, whereas SMT had an immediate effect and produced larger increases in displacement. Spinal mobilisation is generally considered a more conservative or low-force technique applied in acute pain conditions, whereas SMT is considered a more aggressive form of manual therapy that has shown more beneficial effects for chronic neck or back pain (Bronfort *et al*. 2004). Differences in the magnitude and rate of loading associated with mobilisation vs. manipulation are likely to produce variable therapeutic effects due to the viscoelastic nature of the soft tissues surrounding the vertebral column (Harms and Bader 1997; Keller

TABLE 3: Best-fitting multivariable mixed-effects linear regression model for effects of specified variables on the natural log of displacement amplitudes in 24 horses evaluated weekly for 3 weeks, with horse as a random effect

Variable	Value	Effect	s.e.	P value
Reference value†		3.17	0.04	–
Treatment group	Treatment vs. control group	–0.01	0.05	0.83
Vertebral level	T17-T18	+0.14	0.02	<0.01
	L1–L2	+0.23	0.02	<0.01
	L3–L4	+0.29	0.02	<0.01
	L6–S1	+0.32	0.02	<0.01
Week	2	+0.14	0.01	<0.01
	3	+0.19	0.01	<0.01
Pre-/post intervention	Post vs. pre-intervention	0.00	0.01	0.84
Pre-/post intervention*Treatment group	Additional effect of post intervention in the treatment group	+0.15	0.02	<0.01

†Represents the natural log of the displacement amplitude recorded pre-intervention, at vertebral level T14–T15, during Week 1, in the control group horses.

TABLE 4: Mean ± s.d. pre- and post intervention displacement amplitudes (in mm) at 4 intervertebral sites across weeks

Time	Intervention	T14–T15	T17–T18	L1–L2	L3–L4	L6–S1
Control group						
Week 1	Pre	24.3 ± 5.3	27.9 ± 5.5	30.2 ± 6.5	32.3 ± 8.7	34.4 ± 8.6
	Post	24.9 ± 5.5	28.9 ± 4.8	30.8 ± 5.9	33.5 ± 8.0	33.5 ± 8.3
Week 2	Pre	27.8 ± 5.0	31.1 ± 4.2	35.9 ± 4.4	37.2 ± 2.8	38.5 ± 9.2
	Post	28.2 ± 3.6	30.0 ± 4.1	33.6 ± 5.0	35.7 ± 5.3	38.4 ± 7.1
Week 3	Pre	28.2 ± 4.9	32.6 ± 4.3	36.2 ± 4.8	38.9 ± 6.5	41.5 ± 9.2
	Post	28.6 ± 4.6	33.9 ± 4.7	34.6 ± 5.2	38.2 ± 7.5	41.6 ± 9.1
Treatment group						
Week 1	Pre	23.1 ± 5.1	26.5 ± 4.5	28.1 ± 5.1	32.3 ± 3.5	31.5 ± 6.1
	Post	28.7 ± 4.3	33.2 ± 6.0	35.4 ± 5.7	37.0 ± 7.1	37.3 ± 10.0
Week 2	Pre	26.7 ± 4.4	31.9 ± 5.3	34.0 ± 5.8	37.4 ± 6.8	37.5 ± 5.8
	Post	30.9 ± 4.9	37.9 ± 6.8	41.1 ± 6.8	42.6 ± 6.4	44.5 ± 6.6
Week 3	Pre	30.2 ± 4.6	32.7 ± 5.9	39.5 ± 6.7	38.9 ± 6.1	41.5 ± 6.7
	Post	32.7 ± 4.7	36.5 ± 6.9	41.6 ± 7.0	44.0 ± 7.2	42.3 ± 5.4

TABLE 5: Comparison of mean ± s.d. displacement amplitudes post intervention with displacement amplitudes pre-intervention the following week, in 24 horses evaluated weekly for 3 weeks

Group	Week	Post intervention	Pre-intervention, one week later	P value
Control	1	30.3 ± 0.9	34.1 ± 0.9	<0.01
	2	33.2 ± 0.8	35.5 ± 1.0	<0.01
Treatment	1	34.3 ± 1.0	33.5 ± 0.9	0.36
	2	39.4 ± 1.0	36.6 ± 0.9	<0.01

et al. 2003). Manual therapy techniques may also stimulate peripheral joint receptors and central nervous system pathways, which cause reflex muscle relaxation, altered motor function and improved spinal flexibility (Cassidy *et al*. 1992; Schmid *et al*. 2008). Further biomechanical assessment and quantification of manual techniques are critical to understanding the mechanical events that occur during a HVLA thrust and spinal mobilisation (Kirstukas and Backman 1999). A third group of horses without any additional spinal mobilisation applied, other than at the baseline and the final measurement sessions, would be useful as an additional control group to assess changes over time associated with the current control (i.e. repeated spinal mobilisation required for measuring the passive spinal motion) and treatment (i.e. spinal mobilisation plus HVLA thrusts) groups.

Comparing beginning and ending outcome variables across vertebral levels, SMT induced a 40% increase in displacement, a 20% increase in applied force and a 7% increase in stiffness. How are these 3 parameters related: what is the cause and effect? It is possible that the biomechanical effects of bringing a vertebral

TABLE 6: Univariable effects of specified variables on the natural log of force amplitude in 24 horses evaluated weekly for 3 weeks, evaluated using linear regression with horse as a random effect

Variable	Value	ln (Force)	s.e.	P value
Treatment group	Control	5.19	0.05	–
	Treatment	+0.11	0.07	0.09
Vertebral level	T14–T15	5.20	0.04	–
	T17–T18	+0.02	0.04	0.65
	L1–L2	+0.03	0.04	0.44
	L3–L4	+0.07	0.04	0.07
	L6–S1	+0.11	0.04	<0.01
Week	1	5.24	0.04	–
	2	–0.01	0.03	0.64
	3	+0.04	0.03	0.17
Pre-/post intervention	Pre	5.22	0.04	–
	Post	+0.05	0.02	0.04
Pressure mat used	1	4.71	0.09	–
	2	+0.44	0.03	<0.01
	3	+0.95	0.06	<0.01

TABLE 7: Best-fitting multivariable mixed-effects linear regression model for effects of specified variables on the natural log of the force amplitudes in 24 horses evaluated weekly for 3 weeks, with horse as a random effect

Variable	Value	Effect	s.e.	P value
Reference value†		4.47	0.20	–
Treatment group	Treatment vs. control group	–0.03	0.29	0.92
Vertebral level	T17–T18	+0.02	0.02	0.46
	L1–L2	+0.03	0.02	0.20
	L3–L4	+0.07	0.02	<0.01
	L6–S1	+0.11	0.02	<0.01
Week	2	–0.34	0.03	<0.01
	3	–0.55	0.02	<0.01
Pre-/post intervention	Post vs. pre-intervention	–0.05	0.02	0.02
Pressure mat used	2	+0.82	0.03	<0.01
	3	+1.72	0.06	<0.01
Pre-/post intervention*Treatment group	Additional effect of post intervention in the treatment group	+0.19	0.03	<0.01
Week 2*Treatment group	Additional effect of Week 2 in the treatment group	+0.09	0.03	<0.01
Week 3*Treatment group	Additional effect of Week 3 in the treatment group	+0.12	0.03	<0.01

†Represents the natural log of force amplitude recorded pre-intervention, at vertebral level T14-T15, during Week 1, using Pressure mat 1, in the control group horses.

TABLE 8: Univariable effects of specified variables on the natural log of stiffness amplitude in 24 horses evaluated weekly for 3 weeks, evaluated using linear regression with horse as a random effect

Variable	Value	ln (Stiffness)	s.e.	P value
Treatment group	Control	3.02	0.05	–
	Treatment	+0.06	0.07	0.45
Vertebral level	T14–T15	3.10	0.04	–
	T17–T18	–0.01	0.04	0.81
	L1–L2	–0.03	0.04	0.37
	L3–L4	–0.07	0.04	0.09
	L6–S1	–0.11	0.04	<0.01
Week	1	3.09	0.04	–
	2	–0.08	0.03	<0.01
	3	–0.04	0.03	0.22
Pre-/post intervention	Pre	3.04	0.04	–
	Post	+0.02	0.02	0.42
Pressure mat used	1	2.75	0.06	–
	2	+0.25	0.04	<0.01
	3	+0.53	0.06	<0.01

motion segment to end-range of motion and applying a mechanical thrust (i.e. SMT) caused a direct physiological increase in passive spinal mobility (Colloca *et al*. 2006). However, the significantly increased force amplitudes measured within the treatment group post intervention and at Weeks 2 and 3 may have also had an effect on the increased displacement and stiffness measurements. Another possibility is that the increased spinal displacement allowed the vertebral motion segments to be moved further into end-range of motion, hence the increased stiffness reported within the treatment group. The loading and unloading velocities of the induced displacements had a corresponding increase within the treatment group across weeks, without a significant change in the frequency of the spinal oscillations; indicating that larger displacements occurred over the same time period. It is interesting to note that the oscillations associated with passive spinal mobility have such a consistent frequency across vertebral levels, weeks and intervention, compared to active spinal motion during a walk, trot or canter, which occurs over a wide range of frequencies. Further studies need to evaluate the interaction between these spinal biomechanical variables to further understand the mechanical and physiological effects of SMT on spinal kinematics in horses.

Baseline values of vertical displacements at all vertebral levels were slightly higher, but comparable to those reported in a similar experimental design in horses with induced back pain (Haussler *et al*. 2007). Displacements in both studies increased significantly between vertebral levels in a cranial-to-caudal direction; indicative of increased flexion-extension range of motion near the lumbosacral junction. The forces applied at each vertebral level in the current study were significantly less than those reported in the prior study, using identical force-sensing systems (Haussler *et al*. 2007). These differences were probably due to variability associated with changes in pressure mat calibration and equilibration over time and with increased sensor wear and less due to the practitioner, since the same experienced individual applied spinal mobilisation in both studies. The pressure measurement system used in the present study has inherent variability related to conditioning and calibration of the sensor (Kirstukas and Backman 1999; Bachus *et al*. 2006). Ideally, the pressure mat should have been recalibrated prior to each measurement session to assess known drift in the pressure sensor system. However, a high variability in forces applied during spinal mobilisation (Snodgrass *et al*. 2009) and SMT in man (Ngan *et al*. 2005) and in horses (Haussler *et al*. 2007) has been reported. It is possible that differences in spinal function or responses to SMT between ridden and unridden horses could have also contributed to the substantially lower force and stiffness values measured in the current study (Haussler and Erb 2006a).

A single session of SMT applied to the neck, trunk and pelvic regions in 10 horses produced increased ranges of spinal motion immediately after treatment, but spinal mobility was decreased 3 weeks later compared with before treatment status (Gómez Álvarez *et al*. 2008). The authors proposed that the decrease was due to the recurrence of spinal dysfunction or temporary palliative effects of treatment; suggesting that some horses may require several treatments at intervals to achieve longer-term effects (Gómez Álvarez *et al*. 2008). In the current study, displacement, force and stiffness values significantly differed by week (across both treatment and control groups); however, the interaction between treatment group and week was only statistically significant for applied force at Weeks 2 and 3 and spinal stiffness at Week 3. These findings suggest that a series of SMT sessions may be more effective than a single treatment session within the 'no back pain' horses used in this study. Further studies need to assess the optimal dosage and frequency of SMT in athletic horses with documented signs of back pain, epaxial muscle hypertonicity, and stiffness in an

TABLE 9: Best-fitting multivariable mixed-effects linear regression model for effects of specified variables on the natural log of the stiffness amplitudes in 24 horses evaluated weekly for 3 weeks, with horse as a random effect

Variable	Value	Effect	s.e.	P value
Reference value†		2.66	0.14	–
Treatment group	Treatment vs. control group	–0.06	0.19	0.74
Vertebral level	T17–T18	–0.01	0.03	0.77
	L1–L2	–0.03	0.03	0.28
	L3–L4	–0.07	0.03	0.04
	L6–S1	–0.11	0.03	<0.01
Week	2	–0.31	0.04	<0.01
	3	–0.56	0.04	<0.01
Pre-/post intervention	Post vs. preintervention	–0.02	0.03	0.52
Pressure mat used	2	+0.58	0.04	<0.01
	3	+1.21	0.08	<0.01
Pre-/post intervention*Treatment group	Additional effect of post intervention in the treatment group	+0.08	0.04	0.06
Week 2*Treatment group	Additional effect of Week 2 in the treatment group	+0.07	0.05	0.14
Week 3*Treatment group	Additional effect of Week 3 in the treatment group	+0.21	0.05	<0.01

†Represents the natural log of stiffness amplitude recorded preintervention, at vertebral level T14–T15, during Week 1, using Pressure mat 1, in the control group horses.

effort to develop standards of care in the use of equine manual therapies.

A limitation of the current study is that the horses did not have naturally-occurring back pain. This study used actively-ridden horses without acute signs of back pain, which is one step closer to toward the ultimate goal of objectively assessing the effectiveness of various manual therapy techniques in a clinical population of horses with documented signs of back pain, stiffness or poor performance. Future studies need to continue to incorporate objective methods of evaluating segmental and overall spinal function, especially during ridden exercise and athletic performance.

Within the population of horses used in this study, SMT increased dorsoventral displacement of the trunk during passive spinal mobilisation, which is indicative of producing a beneficial effect of increased passive spinal mobility or flexibility. SMT also increased the amplitude of applied force, indicative of increased tolerance to pressure in the thoracolumbar portion of the vertebral column, which can be interpreted as a beneficial effect in any ridden horse with saddle and ridden-induced pressures along the dorsal trunk. The effect of increased spinal stiffness measured within the treatment group is open to interpretation, pending further clinical research into the effectiveness of manual therapies on improving spinal kinematics in horses with objective measures of back pain, stiffness and poor performance.

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Conflicts of interest

The authors have declared no potential conflicts.

Manufacturers' addresses

[1]SpaceAge Control, Inc., Palmdale, California, USA.
[2]Tekscan Inc., South Boston, Massachusetts, USA.

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