

# Effects of a Heated Vibration Massage Pad on Horses: Randomized, Blinded Measures of Mechanical Nociception, Behavior, and Spinal and Limb Kinematics

Gillian Tabor<sup>1,\*</sup>, Natalie Bennett<sup>1</sup>, Corinna Crosby<sup>1</sup>, Zoe Dunham<sup>1</sup>, Emily Jordan<sup>1</sup>, and Fiona Bloom<sup>1</sup>

<sup>1</sup>Equine Department, Hartpury University, Gloucester, GL19 3BE, United Kingdom

\* Author to whom any correspondence should be addressed; Email: [gillian.tabor@hartpury.ac.uk](mailto:gillian.tabor@hartpury.ac.uk)

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## Abstract

Therapy devices are widely marketed to horse owners, claiming to improve well-being, support musculoskeletal function, and aid injury rehabilitation, though many claims lack scientific evidence. This study evaluated the immediate (part A) and four-week (part B) effects of a heated vibration massage pad applied to the thoracic epaxial region on mechanical nociceptive threshold (MNT), behavior, and kinematics of horses. A randomized, blinded design was employed with a convenience sample of 10 riding horses in treatment and control groups. Inertial motion sensors and limb markers captured kinematic data, behavior was analyzed using EquiFACS, and MNT was measured using pressure algometry. Immediately (part A) following application of the heated vibration massage pad, there were no significant changes in MNT, behavior, or dorsoventral range of motion at the poll, wither, pelvis, or tuber coxae during walk or trot, nor in minimum difference, maximum difference, and range of motion at the poll, wither, and pelvis in trot, in the treatment or the control group (all  $P > 0.05$ ). Similarly, stride length and duration in walk remained unchanged. However, in trot, the treatment group exhibited minor reductions in stride length ( $P = 0.025$ ,  $d = 0.2$ ) and hindlimb retraction ( $P = 0.005$ ,  $d = 0.5$ ), with increased stride duration ( $P = 0.044$ ,  $d = -0.17$ ). After four weeks of regular use (part B), the treatment group showed significant increases in stride length during trot ( $309.8 \text{ cm} \pm 37.8$  vs.  $334.4 \text{ cm} \pm 35.1$ ,  $P = 0.017$ ,  $d = 1.38$ ) as well as increased forelimb retraction, hindlimb protraction, and retraction. While immediate effects were negligible, consistent use of the heated vibration massage pad may enhance limb kinematics, suggesting its potential as a convenient addition to maintenance regimes for riding horses.

## Keywords

Equine; therapy; therapeutic devices; vibration; locomotion

## 1. Introduction

Horse riders, owners, and trainers are responsible for the management of their horses and have a duty of care to engage in practices to optimize equine health and welfare [1]. As in human sport, horses commonly acquire musculoskeletal injuries, such as back pain and soft tissue injuries, that can result in reduced performance and lameness [2]. Although these conditions should be assessed and managed by the correct professional [3], advances in technology have led to therapy devices becoming increasingly accessible and

a popular choice for equine carers, providing a non-invasive and cost-effective therapy device. Devices are generally marketed directly to horse owners with suggestions regarding improvements of well-being, assisting musculoskeletal function, and supporting injury rehabilitation [4]. In human medicine, the use of vibration massage devices has become more popular in the management of musculoskeletal conditions [5], and this trend has extended into equine practice, where such devices are now being adopted based on anecdotal reports of improved muscle relaxation and recovery,

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despite a current lack of robust scientific evidence supporting their efficacy in horses.

The use of massage therapy has been well documented throughout human and veterinary literature and continues to be cited as one of the most popular alternative therapies to provide significant benefits to the treatment and maintenance of the musculoskeletal system [6,7]. Massage involves the application of pressure through movement of soft tissue and has been suggested to elicit an array of positive and therapeutic responses across species, including relaxation, pain reduction, and range of movement and performance improvements [8–10]. Such responses are demonstrated through behavioral, physiological, and biomechanical observations, suggested to stem from increasing parasympathetic activity when the appropriate pressure is applied [10,11].

Manufacturer claims suggest vibration massage improves performance by increasing flexibility and reducing musculoskeletal pain. A blinded controlled study investigating the effects of a vibration massage device applied to the horse's back concluded that there were improvements in thoracolumbar kinematics following use of the device [4]. However, this was a one-off treatment, and it was suggested that further research on longer-term effects was needed. The effect of vibration massage on the stress perception of domestic horses has been examined [12], and although not a targeted regional treatment, whole-body vibration has been shown to increase thoracolumbar epaxial muscle activation [13]. Two further non-peer-reviewed studies have shown improvement in stride length and limb range of motion [14,15]. However, to date, claims for outcomes resulting from the use of electronic vibration massage pads are unsupported in the literature.

While massage therapy has increased in popularity, thermal therapy, such as heat therapy, has also slowly increased in popularity, with similar positive and therapeutic responses reported, including an increase in local circulation [16], leading to muscle relaxation and extensibility [17]. Superficial heat therapy, the application of heat to the skin to affect the soft tissues, has been used as an adjunctive treatment of musculoskeletal conditions [18–21] with physiological benefits documented including improved circulation, allowing greater tissue oxygenation and extensibility, thus reducing muscle spasm and tension to promote relaxation of muscles and reduced joint stiffness [7,17,20]. In addition, prolonged deep heat application has been reported to activate thermoreceptors on the skin, which initiate a neural response that reduces nociception via the pain-gating system [7,22]. The increased nociceptive threshold of nerves and muscle spindles decreases the perception of pain [23] and is an effective method for pain management. Previous research has documented that the most profound physiological effects of superficial heat application occur when tissue temperatures are raised to between 40 °C and 45 °C; however, temperatures above 45 °C may potentially result in tissue damage and pain [24]. Due to these reported physiological benefits, electronic heated pads have therefore been deemed a useful therapy adjunct in equine maintenance and rehabilitation therapy [25].

With both massage therapy and heat therapy demonstrating positive and therapeutic effects when applied separately, it could be suggested that when applied together, they

also produce positive and therapeutic effects, if not similar, then superior results. Both massage and heat therapy are becoming increasingly utilized and available within equine rehabilitation [18]; however, the volume of literature to directly support the claims promoted by many of the device manufacturers within the equine industry continues to be very limited, often with poor methodology, small sample sizes and reliance on anecdotal evidence [12]. This underlines the need for research with well-designed methodologies to bridge the gap between proclaimed device benefits and the current research, reducing speculation within the industry.

The aim of the study was to investigate the short- and longer-term effects of a heated vibration massage pad placed over the thoracic epaxial region. It was hypothesized that the treatment intervention would show a significant difference in mechanical nociceptive threshold, behavior, spinal, and limb kinematics, pre- and post-intervention, when compared to the control intervention.

## 2. Methods

Ethical approval was obtained from the Hartpury University Ethics Committee prior to the start of the study (ETHICS2022-73; ETHICS2023-94).

### 2.1. Experimental Design

Two crossover design studies were conducted, with horses randomly assigned to an experimental intervention group (control or treatment), followed by a two-week washout period, and then undertaking the alternate intervention, to minimize the risk of confounding variables and selection bias. Two individual groups of horses were studied, and the subsequent methods and results refer to part A, which studied immediate same-day effects on Mechanical Nociceptive Threshold (MNT), behavior, and kinematics, and part B, which studied the effects of the heated massage pad being applied six times per week for four weeks on limb kinematics. Blinding of group allocation was maintained for the researchers throughout the data collection and initial analysis period.

### 2.2. Experimental Population

A sample size of 10 was calculated for each experimental group (standard power: alpha = 0.05, beta = 0.8, and using a Cohen's effect size of 1.0). In part A, a convenience sample of 10 mixed-breed riding horses (mean ± SD, age 9 ± 3 years, wither height 159 ± 3 cm, six geldings, four mares) was used in the study, and all horses were housed at the same facility, Hartpury College and University. In part B, a convenience sample of different horses from a livery yard was used, and a total of 11 leisure horses were recruited (mean ± SD, age 12.1 ± 4 years, wither height 152 ± 12 cm, six geldings, five mares). Participation was voluntary, and owners gave informed consent for their horses to be used, and they could withdraw their horse at any point of the study up to data analysis.

Subjects received a pre-assessment physiotherapy palpation and gait assessment (in-hand walk and trot in a straight line on a riding surface) prior to inclusion in the study, assessed by a single independent Veterinary Physiotherapist (registered with the Association of Chartered Physiotherapists in Animal Therapy). Horses who had any contraindications to massage, showed signs of back pain and/or epaxial

hypertonicity ( $>2/5$  palpation score; [26]), were classed as lame ( $\geq 2/5$  AAEP score; [27]) or who had received analgesics in the preceding seven days prior to the study, or during the study, were excluded from participation.

For part A, all horses had carried out their normal exercise duties the day preceding the study, and on the day of the study, prior to data collection, all horses were stabled overnight and had not been exercised. For part B, the pad application was completed before exercise, or at least four hours post-exercise, and these horses were kept in a consistent turnout and exercise routine throughout the intervention and control periods of the study. In both parts of the study, the participants were fitted with the heated vibration massage pad (Heatsense, Equilibrium Products Ltd, Aylesbury, UK) over the thoracolumbar region for 30 minutes. The dimensions of the pad were  $90 \times 40$  cm and  $75 \times 40$  cm, dorsally and ventrally, respectively, with a 5 cm height variation of the pad moving caudally (Figure 1).

The massage motors had three vibration frequency settings: low (17.1 Hz), medium (34.3 Hz), and high (51.4 Hz), all  $\pm 10\%$ , and were set to the medium setting for this study. There were three massage motors on each side, six in total, positioned to target the thoracolumbar epaxial musculature. The inbuilt thermotherapy setting was pre-set by the manufacturer at  $42^\circ\text{C}$  for the first 15 minutes, located bilaterally in the caudal 15–20 cm of the pad, with a gel element directly underlying. Once 15 minutes had passed, the thermotherapy element automatically turned off, while the massage element continued for the full 30-minute treatment time.

Participants receiving the control treatment had the same pad fitted to the thoracolumbar region for 30 minutes, but the pad remained switched off, so no treatment was

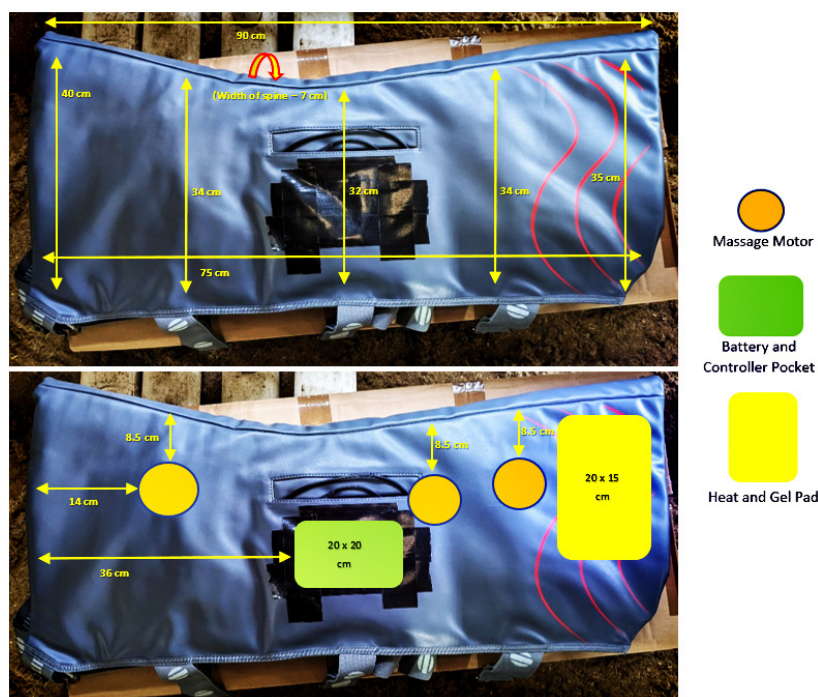
applied, and during both interventions, each horse was either tied up in a stable with a lead rope and head collar or held by their owner.

### 2.3. Part A: Mechanical Nociceptive Threshold (MNT)

Pressure algometry (PA; FDX50; Wagner Instruments, CT, USA) testing was carried out by an ACPAT Veterinary Physiotherapist who was blinded to the grouping of the horses pre- and post-treatment or control intervention to analyze MNT. Testing was located to the caudal trapezius and longissimus dorsi muscles, 10 cm lateral to the T8, T14, T18, and L3 dorsal spinous processes, bilaterally [2,26]. Test locations were determined based on the pad coverage and because the trapezius and *longissimus dorsi* muscles are common areas of tension in the horse [19].

The test location was marked using  $1\text{ cm}^2$  of hypoallergenic kinesiotape at 9 cm lateral from the aforementioned dorsal spinous processes and remained in place throughout treatment and data collection to ensure test location reliability [26]. At each site, three consecutive PA measurements at 3–4-second intervals were recorded, and an average was calculated for each site. Initial contact of the PA to the horse's skin was held for two seconds prior to pressure application, to reduce the likelihood of misinterpreting a startle response as a painful reaction [28].

Each PA measurement was applied at a constant speed, perpendicularly to the horse's skin, and was released at the first sign of a behavioral or physical avoidance reaction, e.g., muscle fasciculation, spinal movement, stepping away, or signs of equine pain face [29,30]. The value at the time of reaction was recorded.



**Figure 1:** The heated massage pad and dimensions, showing the location of massage motors and heated zones.

### 2.4. Part A: Behaviour

To maintain standardization, during the treatments, one testing stall was used for the duration of the study. When receiving treatment, participants were tied up with their bridles and head collars on and were not allowed to eat for the duration of the analysis, based on the need to observe facial expressions.

For both experimental and control treatments, a video camera (60 frames/s, full HD/1080p) was set up on a tripod within the stall to capture video footage, with the horse's head and neck in frame. Video recording started after the pad was positioned on the horse, and recorded for five minutes pre-treatment, for the 30-minute treatment duration, and for five minutes post-treatment. Recordings were reviewed after each session of data collection and were muted to maintain researcher blinding.

Behavior analysis, by an EquiFACS-certified coder, used a scan sampling technique whereby behaviors were observed for 10 seconds at one-minute intervals for the duration of the pre-, during, and post-treatment recordings using an ethogram supported by the EquiFACS [31]. Frequency of behaviors (FoB) within each 10-second observation was reported and used for data analysis. To observe whether there was a trend in FoB while receiving treatment, during analysis, the 30-minute treatment duration was also split into 10-minute segments. Behaviors were selected and grouped into 'positive' and 'negative' within the ethogram (Table 1), based on research suggesting their indication of relaxation or stress, respectively [32,33].

### 2.5. Kinematic Parameters

For both the treatment and control groups, data were collected pre- and post-intervention (part A: after thirty minutes; part B: after four weeks), and the protocol utilized the same environment, handling equipment (bridle or headcollar), arena surface, and equine-specific handler for both data collection episodes. Horses were trotted in hand by their owners for 20 m on a soft surface which had clear open ends. Four trials were carried out in walk and trot; only straight motion cycles were included in the analysis. If a horse lost straightness, altered its gait, or increased or decreased its speed, the trial was repeated.

The horses were allowed to walk and trot at their preferred speed, during which laser-activated timers placed at the start and finish of the experimental track recorded the horses' speed [34]. Gait speeds differing by more than 0.2 m/s from the first valid run were eliminated and repeated until each subject performed the required number of passes (left to right) to gain 8 total passes (4 walk, 4 trot).

A video camera (iPhone 12) was placed at the center of the experimental track (a straight 2m × 25m area) on a free-standing tripod. Data were collected from the right side of the horse at 4K resolution, 60 fps, using a 10m field of view. The camera was positioned 7.2m from the nearest edge of the experimental track at the center of the field of view.

Eleven dome-shaped, 30mm diameter surface markers were positioned at pre-determined locations using double-sided tape by a single researcher, according to palpable surface landmarks [35] on the right side of the horse (Figure 2). Video recording images were analyzed using a digital image annotation tool designed for sports analysis (Kinovea version 0.9.5, 2022).

**Table 1:** The ethogram and indications of behavior with facial code associations.

Behavior	Definition	Indication	EquiFACS facial expression
Head lowered	Nose lower than withers between the abdominal line and carpus	Relaxed (+)	AD54: Head lowered
Ears relaxed or scanning	Ears moving back and forth at varying speeds	Relaxed (+)	Neutral/EAD101: Ears relaxed or scanning
Relaxed eyes	Relaxed eyelids with eyes open or closed. May include slow blinking (eye closure of >1 second)	Relaxed (+)	AU143: Eye closure
Licking and chewing	Tongue extended and retracted into the mouth, accompanied by teeth mashing together and jaw stretched in a horizontal motion to the right and left in a slow, steady motion	Relaxed (+)	AD81: Licking and chewing
Relaxed lower lip or yawning	Lower lip is visibly relaxed, or the mouth slowly opens, and upper and lower jaws are moved back and forth on a horizontal axis	Relaxed (+)	AD160/AD76: Lower lip is relaxed or yawning
Head raised	Nose above withers	Stressed (-)	AD53: Head raised
Repetitive head movement	A repeated, relatively invariant sequence of movements with no obvious function, including movements such as shaking, nodding, bobbing, and/or circling of the head	Stressed (-)	AD84/AD85: Repetitive head movement
Flattened ears	The ears are pulled caudally	Stressed (-)	EAD103: Ears flattened back
Eyes alert	The eyes are wide and may have the white sclera visible	Stressed (-)	AD1: Eye white increase
Nostril dilation	The aperture of the nostril is increased	Stressed (-)	AD38: Nostril dilation

### 2.6. Part A: Inertial Measurement Units

Horses were instrumented for part A prior to application of the heated massage pad with five inertial measurement units (IMUs) (XSens) using a validated sensor-based system (EquiGait Ltd) [36,37]. These were attached over the poll, wither, the midline of the tuber sacrale, and the cranial aspect of the left and the right tuber coxae using double-sided sticky tape. The same individual applied each sensor throughout the study, and to reduce variability, sensors remained on the horse throughout. Sensor data were collected at 60 Hz per individual sensor channel and transmitted via a proprietary wireless data transmission protocol (Xsens Technologies B.V., Enschede, the Netherlands) to a receiver station (Awinda, Xsens) connected to a laptop computer running MTManager (Xsens) software. Details on IMU specifications can be found elsewhere [4,18,36]. Displacement data were segmented into individual strides based on the vertical velocity of the sensors, and average values for the following kinematic variables were calculated over an average of 25 motion cycles in walk and 22 motion cycles in trot. Range of motion (maximum–minimum value over a stride cycle) at walk and trot, minimum difference (MnD; difference between the two minima in dorsoventral (z) displacement observed during the two diagonal stance phases of trot), and maximum difference (MxD; difference between the two maxima in dorsoventral (z) displacement observed after the two diagonal stance phases in trot) were extracted for analysis [38].

### 2.7. Part A: Limb Kinematic Data

Carpal angles were measured on the palmar aspect of the limb using markers 2, 3, and 4 and were measured at peak carpal extension at stance onset (as the toe made initial contact with the surface) and peak carpal flexion at mid-swing. Tarsal angles were measured on the dorsal aspect of the limb using markers 7, 8, and 9, and were measured at peak tarsal extension at lift-off (as the heel left the ground) and peak tarsal flexion at mid-swing. Peak flexion was defined as the smallest carpal or tarsal angle measured during mid-swing [39]. Peak protraction was defined as the frame in which the limb was maximally extended cranially, and peak retraction was defined as the frame in which the limb was maximally extended caudally [39], and was calculated relative to the vertical using either markers 2 and 5 for the forelimb (FL) or markers 7 and 10 for the hind limb (HL). Stride length was calculated in metres and determined from the calibrated known distance travelled for each experimental run, using marker 10 on the fetlock of consecutive whole hoof placements of the right hind limb, with an average calculated [34]. Similarly, stride duration, defined as the time for one complete gait cycle [40], was calculated using the same marker and whole right hind hoof placement, with total known duration divided by the number of strides to give the average stride duration [41]. Kinematic data for analysis were collected from a singular stride in the centre of the field of view per experimental run for each horse, totalling four per gait (4 walk, 4 trot) from those that fell within the individual subjects' standardized speed bracket [42].



**Figure 2:** Anatomical markers used for video data collection: (1) Tuber of the scapular spine; (2) Lateral epicondyle of the humerus, over the lateral collateral ligament of the elbow; (3) Distal aspect of the radius at the lateral styloid process; (4) proximal aspect of the metacarpus at the base of the 4th metacarpal bone; (5) distal aspect of the metacarpus over the lateral collateral ligament of the metacarpophalangeal joint; (6) lateral collateral ligament of the distal interphalangeal joint (designated coronary band marker); (7) proximal aspect of the tibia at the fibular head; (8) mid talus; (9) proximal aspect of the metatarsus at the base of the 4th metatarsal bone; (10) distal aspect of the metatarsus over the lateral collateral ligament of the metatarsophalangeal joint; (11) over the lateral collateral ligament of the distal interphalangeal joint.

### 2.8. Part B: Limb Kinematic Data

Stride length, forelimb protraction and retraction, and hindlimb protraction and retraction in trot were measured by video analysis using Kinovea video software. Stride length was calculated in centimeters (cm) and measured by the calibration of a known distance. A whole stride was measured using a marker on the coronary band of the hoof of the right forelimb. Maximum protraction was measured at the point at which the forelimb or hindlimb was maximally extended cranially, whereas maximum retraction was measured at the point at which the forelimb or hindlimb was maximally extended caudally [39,43].

### 2.9. Statistical Analysis

Inferential statistical analyses were performed in IBM SPSS Statistics (v. 29.0; IBM, Armonk, USA, 2022). All data were tested for normality using a Shapiro–Wilk test, and data were found to be both normally distributed and non-normally distributed. For behavior, MNT, and part A kinematic data, if the dataset was found to be normally distributed, a related (paired) samples t-test was used, with the mean and standard deviation (SD) reported. If the dataset was found to be nonparametric, a Wilcoxon matched-pairs test was used, with the median and interquartile range reported. For MNT data, a Friedman test with post hoc comparisons was used to test repeated measures. Data are presented as mean  $\pm$  standard deviation unless otherwise stated, and results were considered significant if  $P < 0.05$ , with Cohen's  $d$  used to calculate effect size correlations for significant results.

## 3. Results

### 3.1. Part A: Mechanical Nociceptive Threshold (MNT)

MNT measurements for all 10 participants were compared pre- and post- each intervention and between groups, and are summarized in **Table 2**. Analysis of the average MNT at each test location showed no significant differences between pre- and post-intervention figures for any of the locations in both the treatment and the control conditions.

Additional statistical analyses sought to establish whether there were any significant differences between the three measurements at each location, for each horse, to determine whether horses became sensitized or habituated to consecutive testing. The three consecutive PA measurements at each site were compared and showed no significant differences in the experimental group measurements or post-treatment control group measurements. However, for the pre-treatment measurements in the control group, T18 had lower MNTs in the second and third tests (median = 18.25 N/cm<sup>2</sup> and 18.75 N/cm<sup>2</sup>, respectively) compared to the first test (median = 23.5 N/cm<sup>2</sup>,  $\chi^2 = 9.1$ ,  $P = 0.01$ ). Post hoc comparisons indicated that the significance was between the first and second measurement ( $P = 0.04$ ) and the first and third measurement ( $P < 0.001$ ). L3 also showed lower MNTs in the second and third tests (median = 17.75 N/cm<sup>2</sup> and 16.5 N/cm<sup>2</sup>, respectively) compared to the first test (median = 21 N/cm<sup>2</sup>,  $\chi^2 = 6.24$ ,  $P = 0.04$ ), with post hoc comparisons indicating that the significance was between the first and third measurement ( $P = 0.04$ ).

### 3.2. Part A: Behavior

Nine participants' data per group were included in behavioral analysis, as one participant's data were lost in the control scenario, and one participant's data were lost in the experimental scenario. Analysis of behavior showed no significant differences between pre- and post-intervention positive behaviors for either the treatment or control groups (**Table 2**). However, in the control group, participants demonstrated fewer negative behaviors post-intervention (median = 8) than pre-intervention (median = 10,  $T = 1$ ,  $P = 0.02$ ). Analysis of the 10-minute segments during treatment showed no significant differences between the three timeframes.

### 3.3. Part A: Inertial Measurement Unit Data

Data sets were lost due to an IMU system error; therefore, eight horses' data were used for the intervention group, and nine horses' data for the control group in trot, in walk, and nine horses' data were obtained during both the treatment and control intervention groups in walk.

No significant differences were found in the dorsoventral range of motion at the poll, wither, pelvis, and the left and right tuber coxae pre- and post-treatment intervention and pre- and post-control intervention, or between the treatment and control intervention groups in walk.

No significant differences were found in minimum difference, maximum difference, and range of motion at the poll, wither, and pelvis pre- and post-treatment intervention and pre- and post-control intervention in trot.

### 3.4. Part A: Limb Kinematics Data

Data from all 10 equine participants who completed the study protocol were analyzed. No significant differences were found in the analysis of the baseline measures between the treatment and control groups for stride length at either walk or trot, for stride duration at either walk or trot, for FL or HL peak protraction at either walk or trot, for FL and HL peak retraction at either walk or trot, for tarsal peak flexion (PF) and extension (PE) at either walk or trot, or for carpal PF or PE at either walk or trot.

There was no significant difference between the pre- and post-intervention stride length measures in walk; however, there was a significant decrease in trot in the treatment group ( $P = 0.025$ ,  $d = 0.2$ ). In the comparison of the pre- and post-control conditions, there were no significant differences in stride length in walk or trot. A significant increase in stride duration in trot was observed for the treatment group ( $P = 0.044$ ,  $d = -0.17$ ). No significant differences were observed in the treatment group for stride duration in walk, or for either comparison of the pre- and post-control condition in walk or trot.

No significant changes were observed when analyzing pre- and post-intervention control and treatment data for FL or HL peak protraction. A significant reduction was observed for HL peak retraction in trot for horses following receipt of the treatment (pre  $30.9^\circ \pm 2.6$ , post  $29.6^\circ \pm 3.2$ ,  $P = 0.005$ ,  $d = 0.5$ ). No additional significant differences were observed for FL peak retraction for either the control or treatment condition when analyzing pre- and post-intervention measurements.

**Table 2:** Differences between pre- and post-intervention scores in the control and treatment groups for mechanical nociceptive thresholds (MNTs) and behavior (L = left, R = right, IQR = interquartile range, + = positive, - = negative, FoB = frequency of behaviors,  $P$ -value < 0.05).

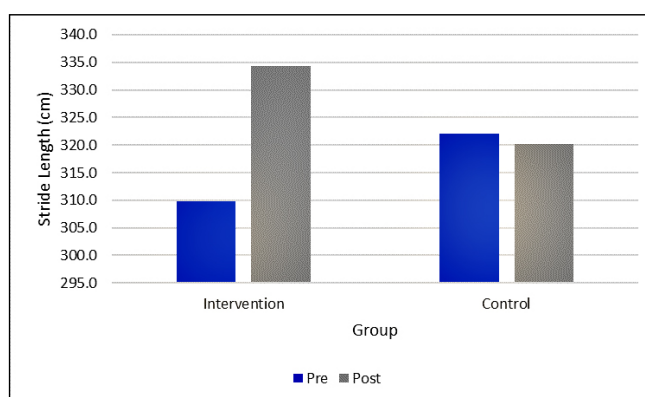
Parameter	Location; landmark/L or R		Control median $\pm$ IQR (N/cm <sup>2</sup> )	Treatment median $\pm$ IQR (N/cm <sup>2</sup> )	Statistical Sig. (2 d.p.)
Pressure algometry (MNTs)	T8	L	2.84 $\pm$ 13.96	-7.17 $\pm$ 16.5	T = 64; $P$ = 0.13
		R	-1.33 $\pm$ 17.7	3.25 $\pm$ 22.71	
	T14	L	-1.25 $\pm$ 8.05	-0.5 $\pm$ 11.51	T = 132; $P$ = 0.31
		R	-1.58 $\pm$ 7.46	2.42 $\pm$ 21.83	
	T18	L	-1.09 $\pm$ 13.29	-2.75 $\pm$ 9.17	T = 78.5; $P$ = 0.32
		R	-1 $\pm$ 5.17	-2.08 $\pm$ 19.67	
L3	L	-3.67 $\pm$ 8.59	1.92 $\pm$ 10.79	T = 121; $P$ = 0.55	
	R	1.75 $\pm$ 10.34	4.09 $\pm$ 22.88		
Parameter	Time	Behavior (+ or -)	Control Median $\pm$ IQR (FoB)	Treatment Median $\pm$ IQR (FoB)	Statistical Sig. (2 d.p.)
Behavior	Pre-Post	Negative	-3 $\pm$ 3	-3 $\pm$ 11	T = 14.5; $P$ = 0.93
		Positive	4.5 $\pm$ 8	3 $\pm$ 7	T = 16; $P$ = 0.78
	During	Negative	38 $\pm$ 35	60 $\pm$ 31	T = 43; $P$ = 0.11
		Positive	46 $\pm$ 26	43.5 $\pm$ 22	T = 32.5; $P$ = 0.61

No significant differences were observed between pre- and post-intervention control and treatment data sets for tarsal PF or PE at walk or trot. When analyzing pre- and post-intervention data sets within each condition (control and treatment), a significant reduction (median (IQR); pre 176.8° (5.8), post 175.4° (6.7),  $P$  = 0.043,  $d$  = 0.2) was observed for carpal PE in trot for horses following the treatment intervention, compared with their pre-intervention baseline measurement. No significant difference was observed under the same experimental conditions in walk ( $P$  = 0.80) for carpal PE.

### 3.5. Part B: Limb Kinematic Data

At the start of the study, there were no statistically significant differences between the treatment and control groups for stride length in trot (control 322.0 cm  $\pm$  41.2 vs. treatment 309.8 cm  $\pm$  37.8), hindlimb protraction (control 5.1°  $\pm$  2.0 vs. treatment 4.6°  $\pm$  1.7), hindlimb retraction (control 23.8°  $\pm$  2.5 vs. treatment 23.3°  $\pm$  2.5), forelimb protraction (control 19.1°  $\pm$  2.6 vs. treatment 19.3°  $\pm$  3.41), or forelimb peak retraction (12.1°  $\pm$  3.1 vs. 12.3°  $\pm$  3.3).

At the end of the four weeks, there was a significant difference in mean stride length between the groups (control 320.2 cm  $\pm$  41.9 vs. treatment 334.4 cm  $\pm$  35.2,  $P$  = 0.007,  $d$  = -0.4). There was no significant change in stride length in the control group (322.0 cm  $\pm$  41.2 vs. 320.2 cm  $\pm$  41.9); however, there was a difference in the treatment group (309.8 cm  $\pm$  37.8 vs. 334.4 cm  $\pm$  35.1,  $P$  = 0.017,  $d$  = 1.38) (Figure 3).



**Figure 3:** Stride length (cm) at the pre- and post-intervention measures in the control and treatment groups.

In the control group trial, there was a significant decrease in hindlimb protraction (5.1°  $\pm$  2.0 vs. 5.0°  $\pm$  2.0,  $P$  = 0.038), whereas in the treatment group trial, there was an increase over the four weeks (4.6°  $\pm$  1.7 vs. 6.9°  $\pm$  2.6;  $P$  = 0.003). Hindlimb retraction was significantly different between the control and treatment groups at the end of four weeks (23.5°  $\pm$  2.6 vs. 26.0°  $\pm$  3.5,  $P$  = 0.007). In the control group, there were no significant changes over time (23.8°  $\pm$  2.5 vs. 23.5°  $\pm$  2.6,  $P$  = 0.062); however, in the treatment group, there was a significant increase of 2.7°  $\pm$  3.0 (23.3°  $\pm$  2.5 vs. 26.0°  $\pm$  3.5,  $P$  = 0.017).

Forelimb protraction increased from 19.3°  $\pm$  3.4 to 20.1°  $\pm$  2.8 for the treatment group and from 12.1°  $\pm$  3.1 to 12.4°  $\pm$  3.1 in the control group; however, neither of these differences was statistically significant.

Forelimb retraction was statistically significantly different between the control and treatment groups at the end of four weeks ( $12.4^\circ \pm 3.04$  vs.  $14.5^\circ \pm 3.17$ ,  $P = 0.006$ ). In the control group, there was a non-significant increase of  $0.4^\circ \pm 1.0$  in forelimb retraction, and in the treatment group, there was an increase of  $2.2^\circ \pm 2.1$  ( $12.3^\circ \pm 3.24$  vs.  $14.5^\circ \pm 3.17$ ,  $P = 0.009$ ).

## 4. Discussion

The aim of this study was to investigate the effects of a heated massage pad on equine thoracolumbar MNTs, behavior, spinal motion, and limb kinematics. Based on the current literature, it was hypothesized that the pad may positively influence these parameters. In the short term, results suggest that within the sample used, the pad had no significant effect on thoracolumbar MNTs, behavior, or spinal motion. There were changes in trot for stride length (reduced), stride duration (increased), and hindlimb retraction (reduced) after 30 minutes of treatment. However, with regular use over a period of four weeks in the second group of horses, there were significant increases in stride length, forelimb peak retraction, hindlimb peak retraction, and hindlimb peak protraction.

### 4.1. Part A: Mechanical Nociceptive Threshold

The pressure algometer (PA) has been consistently reported as a repeatable measurement tool for quantifying pain and targeting MNTs within testing [30,44]. Given that massage and heat are reported to impact mechanoreceptors and nociceptors, it was considered an appropriate outcome measure for use in the present study. However, a reported limitation of PA is that repeated use may increase sensitization of the area [30]; however, ; however neither was observed for either group within this study.

When analyzing MNTs within the present study's healthy equine sample, the comparison to previously reported normal values seemed noteworthy. The present study's baseline values showed that the sample entered the study with MNT values much lower than other reported normal samples; at L3, the present study's average MNT was  $20.85 \text{ N/cm}^2$ , whereas values of  $51.9 \text{ N/cm}^2$  and  $142.2 \text{ N/cm}^2$  have been reported in [30,45], respectively. All studies followed parallel protocols and endpoints of PA testing and included samples of sound, healthy horses of similar ages, although breeds varied between studies. Differences in tester experience with behavior recognition between studies are not known; therefore, it may be postulated whether the tester's sensitivity to behavioral avoidance signs differed between studies and contributed to differences in reported normal values. Future research on the pad could include additional, comparable outcome measures, such as palpation scoring [26,44].

### 4.2. Part A: Behavior

The EquiFACS coding system was used to give an objective foundation to a subjective field of study [46], categorizing the codes and behaviors into 'positive' and 'negative' to distinguish whether participants were undergoing a pleasant or unpleasant experience. Categorization was based on research indicating such behaviors could be signs of relaxation or stress, respectively [32,33]. Three of the participants in the present study demonstrated excessive licking and chewing throughout recordings of both the control and experimental treatments, and licking and chewing were categorized as a

'positive' behavior given its association with stress relief, relaxation, and a shift from sympathetic to parasympathetic activity [32,47]. However, it was suggested that licking and chewing could be associated with a negative affective state in horses when presented alongside agitated behaviors, such as ears back, stepping away, and tail swishing [48–50]. Given the ambiguity and varying scenarios in which licking and chewing have been presented within the literature, and the conflicting conclusions drawn from these scenarios, it would be unwise to conclude that the behavior was definitively positive or negative within the present study. Instead, it further highlights the need to analyze whole-horse behavior holistically to ascertain a more accurate affective state. In part B, the device was applied to each horse in the treatment group by their owners, and due to the risk of bias in recording behavioral responses, these data were not collected for analysis.

### 4.3. Part A: Inertial Measurement Unit Data

This study found no differences in the vertical displacement range of motion between pre- and post-measures in either group after 30 minutes. Using a similar methodology with IMUs, it was found that an increase in range of motion at the wither in a vertical direction and an additional increase in range of motion in the 13<sup>th</sup> thoracic segment in a medio-lateral direction [4]. The differences in vibration frequency and intensity between the unit used in this study compared with [4] are not known, and therefore, repeating IMU measurements before and after the application of the pad, using the different settings, may result in a different outcome. Knowing which frequency and intensity, i.e., what the dose-response is, would be useful when recommending the use of the pad to aid training or rehabilitation of an injured horse.

### 4.4. Part A: Limb Kinematic Data

Differences were observed in the analysis of the pre- and post-difference values compared between the intervention and control group data sets, for stride length and stride duration. The literature reports that even a slight change in the horse's stride length can have a positive influence on desired gait patterns, aiding peak performance [41]. Trot stride length was observed to significantly decrease, coinciding with a significant decrease in hindlimb peak retraction and carpal peak extension, whereas stride duration significantly increased in trot post-intervention. This potentially implies that greater time (s/stride) was taken to cover a shorter distance (m/stride) during a recorded stride. It could be postulated that this may be due to an increase in stride collection, reducing the longitudinal distance traveled per stride. However, dorsoventral displacement of the IMUs did not show any significant differences, and when considering the effect sizes, these statistically significant results can be considered not clinically relevant [51].

### 4.5. Part B: Limb Kinematic Data

This part of the study did not investigate stride duration or velocity, nor specific joint ROM; however, stride length was found to have increased significantly by 24.7 cm following treatment. A proposed explanation for the increased stride length could be the improvement in hindlimb protraction and retraction, which would increase the overall distance covered and therefore propulsion. Hindlimbs often have a higher peak propulsive force and a larger propulsive impulse

than forelimbs, due to large muscle groups such as the hamstrings creating large forces [52].

Research into the carryover of physiological effects of massage and heat is limited, but it is thought that the effects can last anywhere from a few hours to a few days in humans [10] and horses [53], suggesting that the effects do not tend to last long term. There was no effect on MNTs after 30 minutes, but when the pad was used on a regular basis, the accumulation of effects may result in MNT changes. The kinematic results of this study support the theory of longer-term benefit, and it is more likely that a pad will be used on a consistent basis over a longer period by owners as part of a maintenance regime, rather than as a single treatment.

Pad settings within the present study were pre-set by the manufacturer. This allowed for standardization and increased reliability across the treatment that all participants received. However, given that pain perception varies between individuals and pain is often quantified by testing pressure thresholds [54], it may be fair to consider that pressure preferences within massage may also vary between individuals. It was demonstrated that graduated massage significantly increased MNTs in the equine caudal thoracolumbar spine, with massage that was manually applied and adjusted according to the hypertonicity and myofascial pain presenting in each individual horse [55]. Such tailoring varied the duration of massage and muscles treated, whereas the present study kept these specifications the same throughout. One way in which the present study could have somewhat tailored treatment would have been to utilize the different frequencies available, rather than only using the medium setting (34.3 Hz), which was selected based on the suggestion that 30–50 Hz promotes muscle relaxation [11,56].

Though it is also notable that although the sample size met the power requirements, the 10 participants still represent a small sample, meaning a Type II error, where the null hypothesis is incorrectly accepted, was possible [57]. The sample was comprised of participants considered 'normal', in that they showed no signs of back pain (among other criteria), which may influence the transferability of results to those with back pain. Given that massage and heat have previously been suggested to dampen nociception [7,22,58], it may be fair to postulate whether a significant result would be seen if nociception was already stimulated, i.e., the more nociception is activated, the greater the nociceptive excitability there is to dampen. The same may be considered for relaxation; the more tense a horse is, the more effect of relaxation there is to gain. To test this hypothesis, future studies would need to include samples of normal, pain-free horses and horses with varying levels of back pain.

Kinematic data collection was obtained from the horses in hand and not ridden, to reduce the known effects from ridden assessments and the equipment used on the horse [59]; however, some effect from the handler may be inevitable. The handler may, to a varying degree, influence the head and neck positioning of the horse, indirectly influencing the back and therefore limb kinematics through head and neck

position [60,61]. The methodology of the current study attempted to minimize the effect of the handler through the use of the same handler for each horse during the experimental period, standardization of speed, and the test environment. To further improve data collection methodology and accuracy, the use of a high-speed camera, 3D motion analysis, and/or wearable sensor-type devices could be considered [62].

The study did not measure any physiological parameters to record changes in circulation, which is reported to increase with heat application [7,22]. Therefore, refuting previous suggestions that 40–45 °C heat application for 30 minutes elicits positive physiological responses (via a local increase in circulation) would be premature based on the present results. Further study could clarify the effect and level of contribution of both heat and massage treatment by comparing the heated massage pad with a non-heated massage pad and a control group. However, to gain a better understanding and further clarification of how temperature influences circulation, studies should include temperature monitoring and direct measurements of circulation.

## 5. Conclusions

In conclusion, the results from this study suggest that after four weeks of regular application of a heated vibration massage pad, there was an increase in stride length, forelimb retraction, and hindlimb protraction and retraction. Therefore, heated vibration massage pads may be a convenient method of improving limb kinematics when used as part of a maintenance regime on a regular basis, using the recommended manufacturer protocol of 30 minutes, six times per week. The present study was unable to report any short-term mechanical nociceptive threshold differences, behavioral changes, spinal locomotion, or gait symmetry effects when comparing pre- and post-treatment interventions with a control group. Significant changes in stride length, stride duration, and hindlimb retraction in trot were seen immediately post-treatment, but were numerically small, and therefore the cumulative effects appear to be more relevant to the horse.

While the heated vibration massage pad did not elicit any positive effects on the measurements taken for pain or behavior, it did not elicit negative effects either. Therefore, the results of the present study suggest that owners can use such devices on horses free of back pain, without detrimental effects, with the potential for longer-term benefits. Future studies could investigate habituation to the device and assess changes in behavioral responses with frequent use. As the pad combines heat and vibration massage, further work is needed to underpin the biological significance of vibration and heat therapy in the horse and to distinguish the clinical relevance for the industry.

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## Authors' Contributions

G.T.: Conceptualization, Methodology, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Project administration. N.B.: Methodology, Writing – review & editing. C.C.: Methodology. Z.D.: Methodology. E.J.: Methodology. F.B.: Methodology, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

## Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## Conflicts of Interest

All authors declare that the research was conducted in the absence of any financial or commercial relationships that could be construed as a potential conflict of interest.

## Ethical Approval

Ethical approval was obtained from the Hartpury University Ethics Committee prior to the start of the study (ETHICS2022-73; ETHICS2023-94).

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#### How to Cite

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