

Equine spinal kinematics derived from different riding positions during asymmetrical bareback riding

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Hippotherapy in patients with neuromuscular dysfunction creates high focal pressure on the pony's back due to bareback riding and an asymmetrical riding position. This study aimed to investigate the acute effect of asymmetrical bareback riding on the pony's spinal kinematics, blood lactate, serum creatine kinase, heart rate, and temperament score. Eight ponies were selected, and they were walked on a treadmill for 45 min on each experimental day, including warm-up (5 min), weight-loading by mannequin (30 min), and cool-down (10 min) sessions. During the weight-loading session, three different weight distributions on the pony's back were applied between the left and right side: 50:50 (treatment M), 70:30 (treatment L), and 30:70 (treatment R) on the first, second, and third day of the experiment, respectively. The spinal kinematics at the end of the weight-loading session revealed a slight reduction in range of motion in both flexion-extension and lateral bending during treatment R. Stride length and stride duration showed no differences between treatments. The levels of blood lactate and serum creatine kinase and results of a back examination were normal. Heart rates and temperament scores revealed that all ponies were calm throughout loading of the mannequin. This information suggests that asymmetrical bareback riding did not cause acute or serious back injury, which indicates good equine welfare in ponies used for hippotherapy.

Key words: asymmetrical bareback riding, equine welfare, hippotherapy, kinematics, pony

J. Equine Sci.
Vol. 32, No. 3
pp. 81–89, 2021

Hippotherapy is a form of neuromuscular treatment that makes use of the movement of the equine back. A key technique of hippotherapy is the application of bareback riding to promote direct contact between a horse's back and a patient's pelvis [18], so the rhythmic and repetitive movements from the horse's back will improve the gross motor function, balance, posture, and sensory stimula-

tion of patients with neuromuscular dysfunction [9]. A study on the wheelchair found that the sitting posture of patients is usually asymmetric, with the patients leaning on the less-paretic side because the core muscle of a patient with neuromuscular dysfunction is not strengthened as in the case of a normal rider [11]. It has also been found that bareback riding usually results in a poor weight distribution and creates focal pressure along the equine spine [2], which may cause back injury in the therapeutic pony. Unfortunately, information about equine welfare in ponies used for hippotherapy remains limited.

A previous study showed that back muscle stiffness was slightly increased after therapeutic sessions in equine-assisted therapy for a lightweight autistic child [17]. However, subtle changes of vertebral movement could

Received: November 30, 2020

Accepted: June 7, 2021

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not be detected by the human eye. In order to evaluate the effects of asymmetrical bareback riding, an ancillary tool with good accuracy and precision is required. Kinematic analysis of vertebral movement has been proven to be an adequate tool that can detect subtle changes of vertebral movement in horses [23, 24].

To determine if the welfare of therapeutic horses is good when they are used for hippotherapy, this study aimed to investigate the acute effects of asymmetrical bareback riding on the back of ponies. Moreover, other ancillary methods, such as serum creatine kinase (CK), are valuable means of evaluating muscle damage [19]. Blood lactate measurement is a method for monitoring the intramuscular acidity resulting from anaerobic glycolysis. The blood lactate level can also be applied as one of the indices for evaluating exercise intensity [20]. Furthermore, the psychological status of the working horses was considered to examine equine welfare. Temperament and heart rate, which have been widely used for evaluating stress in horses [16, 17], were also evaluated in this study. Our hypothesis was that short-term asymmetrical bareback riding with a weight limit might cause back injuries and induce stress in ponies.

Materials and Methods

Ethical review

The protocol for animal care and use in this experiment was approved by the Institutional Animal Care and Use Committee of Mahidol University (MUVS-2016-06-25).

Animals

Eight healthy crossbred native Thai ponies were selected for this experiment. The ages of the ponies ranged from 6 to 15 years old. Weight and withers height were measured by using a measuring tape (EQUIVET, KRUSE, Langeskov, Denmark). The weights and withers heights of the ponies ranged from 208 to 298 kg and from 118 to 129 cm, respectively. Health assessments were performed by a veterinarian to ensure that none of the ponies were lame, had back pain, or had neurological problems. All ponies were cared for in the Mahidol University stable. Each pony was acclimated to a treadmill (Säto, Löfstabruk, Sweden) for at least 7 days. The protocol was adapted from Franklin and Allen [5].

Mannequin

A custom-made mannequin was used to mimic a patient with neuromuscular dysfunction. It was made from a metal core structure and sponge covered by fabric. The core structure inside the upper body comprised a stack of rectangular metal plates (width \times length \times height = $9.8 \times 22 \times 1$ cm, 2 kg per each) above a pair of cylindrical metal bars (2.5 cm in radius and 13 cm in length, 2 kg per each). These two

cylindrical metal bars simulated the *ischial tuberosities* of a patient to create focal pressure points. The surface area of the cylindrical metal bars was calculated as the area of a cross section (πr^2). Thus, the area of the focal pressure point beneath each metal bar was 19.7 cm². The distance between the centres of two metal bars was 13 cm. A rectangular piece of ethylene propylene diene monomer (EPDM) rubber (width \times length \times height = $14.5 \times 20 \times 0.9$ cm) was inserted into a custom-made pocket underneath the mannequin's bottom to protect the pony's back and simulate a patient's gluteal tissue.

This study focused on the effects of the weight of a rider's upper body on a pony's back because Clayton *et al.* reported that the most predisposing area for equine back injury was beneath the rider's ischial tuberosities [2]. Furthermore, the weight of a rider's lower body was not a concern because the pressure from the rider's lower body is laterally distributed to the sides of the pony's body, which does not directly affect the pony's back.

Powell *et al.* recommended a maximal rider weight of 20% of the horse's body weight [19]. Tözeren reported that the weight of the upper body in humans was estimated to be 60% of the total body weight [21], so to calculate the weight of the mannequin used as a rider's upper body in this experiment, the weight was calculated as 60% of maximal loading weight. This calculation led to a mannequin weight equivalent to 12% of the pony's bodyweight. The weight of the mannequin was adjusted according to each individual pony before the start of each experiment.

Force sensors

A force-measuring device was custom-made to monitor the weight distribution of the mannequin on a pony's back. The weight of the mannequin was transferred to a pair of force sensors (FlexiForce[®] A502, Tekscan, Boston, MA, U.S.A.) wired to a receiver box. Real-time data was transferred by Bluetooth from the receiver box to a laptop and displayed on its screen. This custom-made device needed to be calibrated before use in the experiment. The calibration protocol began with the placement of a force sensor beneath EPDM rubber. Then serial amounts of force at 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30 kg were applied using a digital force gauge (model FSA-MSL-4, Imada[®], Toyohashi, Japan). The serial output from the force sensor converted the force (kg) into voltage (V). Then a linear calibration curve between voltage (V) and force (kg) was plotted (Fig. 1). The linear equation was then extracted for inclusion in software (Visual Studio 2013, Microsoft, Redmond, WA, U.S.A.) which could show the real-time amount of force affecting the pony's back on a screen during the experiment.

Experimental design

This study was separated into three experimental days. Each day consisted of 3 study sessions: warm-up, weight-loading, and cool-down. The experiment began with a pony walking on a treadmill set at 1.1 m/sec and a 0% incline for 5 min (warm-up). Next, the mannequin was mounted over a saddle cloth on the pony's back, and the pony then continued walking for 30 min (weight-loading). The ratios of weight distribution on the pony's back between the left and right sides on the first, second, and third days were 50:50 (treatment M), 70:30 (treatment L), and 30:70 (treatment R), respectively. The sitting position of the mannequin was manually manipulated by a side-helper(s) into an upright

position during treatment M; the mannequin was leaned to the left and right sides during treatments L and R, respectively (Fig. 2A). To accurately monitor the amount of weight distribution, a pair of force sensors was inserted underneath the two focal pressure points of the mannequin (Fig. 2B). After that, the pony walked without the mannequin for 10 min (cool-down). Lameness and back examinations were performed after each day of the experiment. A rest period of at least 48 hr was used between treatments as a washout period. The back examination and blood variables were used to assess the health status of the pony's back and confirm that there were no residual effects or back injuries before starting the next treatment.

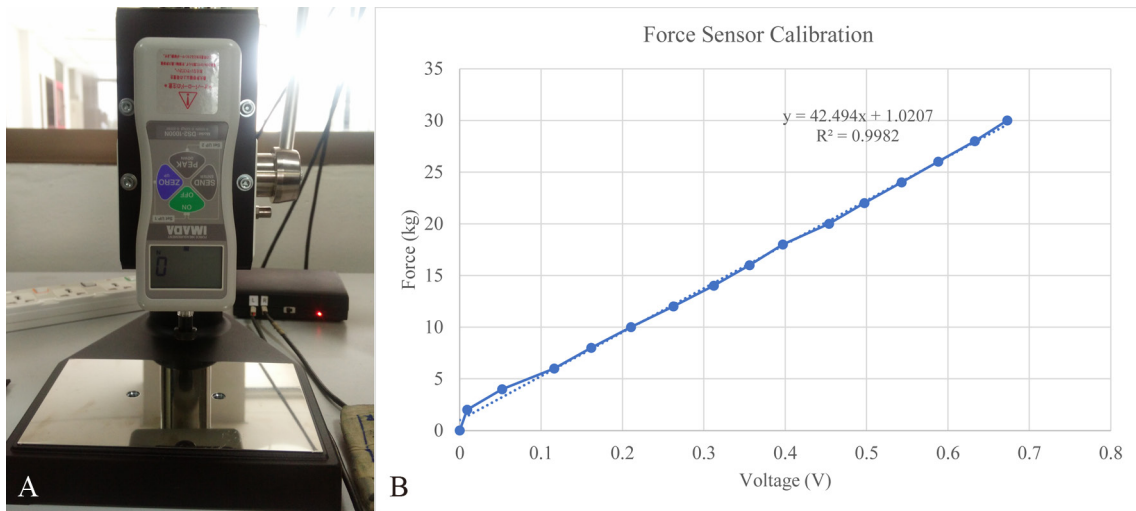


Fig. 1. A) Digital force gauge model FSA-MSL-4. B) Linear calibration curve and equation between voltage (V) and force (kg).

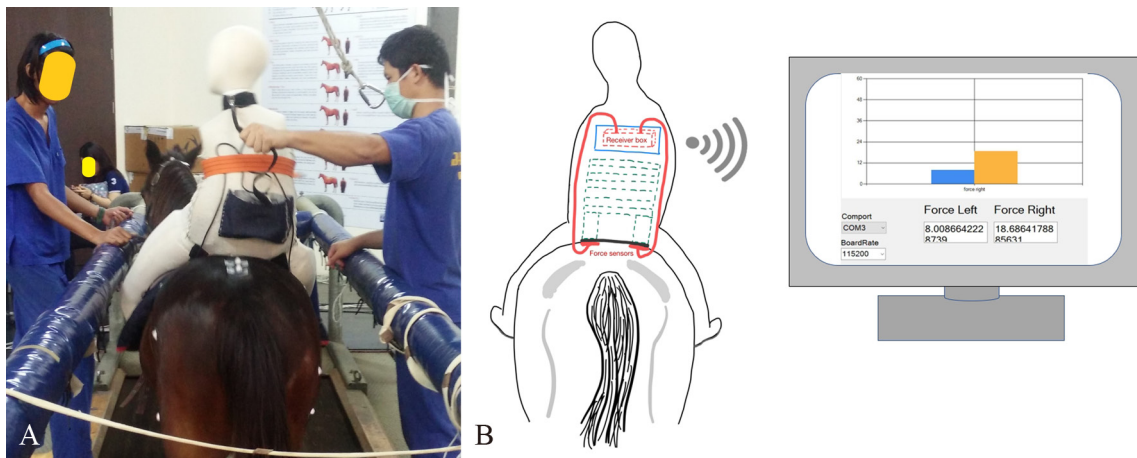


Fig. 2. The mannequin was manipulated by a side-helper during weight-loading session. B) The internal core structure of the mannequin comprised a stack of metal plates and metal bars (dash line). The weight from the metal core structure was transferred to the EPDM rubber (thick black line) and force sensors (thick red lines). Both force sensors were wired to a receiver box (dashed red box). Real-time amounts of force (kg) were shown on a screen to monitor the weight distribution on the pony's back.

Acquisition of kinematics data

Kinematics data were collected from 10 optoelectronics cameras (BTS SMART-DX 5000, BTS Bioengineering, Milan, Italy). Spherical markers of 1.5 cm in diameter were attached over the dorsal spinous process at the thoracic (T), lumbar (L), and sacral (S) vertebrae: T18, L2, L4, L6, S2, and S4 (Fig. 3A). A hemispherical marker was attached below the coronet of the right and left hind hoof. Data were collected during walking at the ends of the warm-up and weight-loading sessions. They were recorded for 10 sec with sampling rate at 200 Hz. A leader and side-helper stood on the left side of the pony during data collection.

Processing of kinematics data

Biomechanics analysis software (SMART Analyzer, BTS Bioengineering) was used for data processing. Data on the spinal kinematics and spatiotemporal variables were derived and averaged from at least 5 stride cycles. The beginning and end of each stride cycle were defined as the consecutive initial ground contacts of the right hind hoof, which were determined using the vertical displacement of the right hind hoof [23]. The data were filtered by a 10 Hz Butterworth low-pass filter. Then absolute angles and ranges of motion (ROMs) were extracted from the spinal kinematics data. Absolute angle refers to the angle relative to an external spatial reference [25]. This study calculated the absolute angles relative to reference axes in the biomechanics analysis software. A vector was drawn from a caudal adjacent marker to the marker of interest. According to the direction of the reference axis, flexion-extension referred to the angle between a vector and a reference Y-axis, with positive values indicating back extension. Lateral bending referred to the angle between a vector and a reference Z-axis, with positive values indicating left bending (Fig. 3B). ROM was calculated by subtracting the minimum value from the maximum value derived for an absolute angle within

each stride cycle. To reduce the inter- or intra-variability of spinal kinematics data between horses, a normalization process was performed within the individual ponies [7] by subtracting all of the kinematics data at the end of the warm-up session from those at the end of weight-loading session. Other kinematics parameters were spatiotemporal variables. Stride length was the summation of the stance and swing phases for the same hoof and was calculated from the movement distance of the treadmill belt. The distance during the stance phase was directly extracted from a marker on the right hind hoof. The distance during the swing phase of the right hind hoof was indirectly extracted from the stance phase of the left hind hoof; the distance during the overlapping of the stance phases of both hind hooves was subtracted. Stride duration referred to the amount of time required to complete each stride cycle of the right hind hoof.

Heart rate and temperament

Heart rate and temperament of the ponies were recorded every 5 min during the weight-loading session. Heart rate was recorded by a heart rate sensor (Polar® H7, Polar, Kempele, Finland). A temperament score was used to assess pony safety during the weight-loading session (Table 1). The temperament score was adapted from King *et al.* and comprised 4 scores [8]. A score of 1 means that the pony was relaxed and accepted the mannequin. A score of 2 means that the pony took some time to settle down with the mannequin. A score of 3 means that the pony did not settle down and the rhythm of their walking gait was inconsistent. The pony also showed stressful behaviour(s), i.e., tail swishing, ear pinned back, whinnying, and/or defecation. A score of 4 means that the pony attempted to remove the mannequin by bucking. In addition, the heart rates of ponies with scores of 1 or 2 were less than 80 bpm. The heart rates of those with scores of 3 or 4 were over 80 bpm. If the temperament score reached level 3 or 4, the pony was rested for a while.

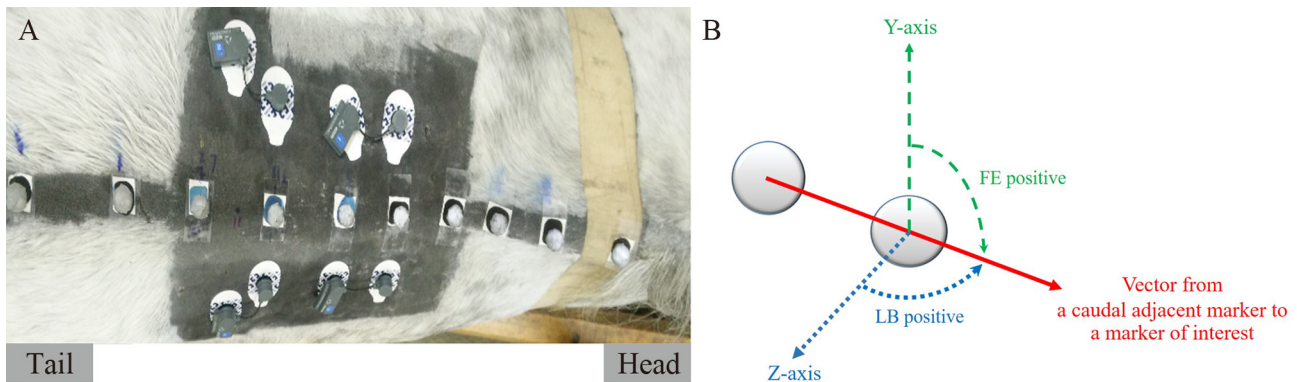


Fig. 3. A) Spherical markers along a pony's spine. B) Absolute angles of flexion-extension (FE) and lateral bending (LB).

Blood lactate, serum CK, and back examination

Blood samples were collected from the jugular vein at the beginning of the experiment, the end of the weight-loading session, and the day after the experiment. Fresh whole blood was used to analyse blood lactate (Accutrend® Plus, Roche, Mannheim, Germany). Serum was utilized for measuring the CK level (Reflotron® Plus, Roche).

A back examination was performed on the day after each experiment. The protocol for the back examination was as follows: The pony was encouraged to trot in a straight line to check for lameness or a shortened stride length. Then the pony was inspected and palpated on both sides of its back muscles while standing, to detect muscle pain or swelling sites. The back was also manipulated to induce spinal flexion, extension, and lateral bending.

Statistical analyses

Prism version 6.0 (GraphPad Software, San Diego, CA, U.S.A.) was used for statistical analyses. The Shapiro-Wilk and Duncan tests ($P < 0.05$) were used to evaluate the normality of the data and determine differences. Absolute angles, ROMs, blood lactate, and serum CK were compared among treatments M, L, and R by Kruskal-Wallis test. Multiple comparisons were interpreted by Dunn's test. The data for this dataset are presented as medians and interquartile range (IQR) calculated from 8 ponies. Furthermore, stride durations, stride lengths, and heart rates were compared among treatments M, L, and R by one-way repeated measures ANOVA. Multiple comparisons were analysed by Tukey's test. Data are presented as the mean \pm SD calculated from 8 ponies. Statistical significance was accepted at $P < 0.05$.

Results

Force and pressure affecting on the pony's back

To convert the weight of the mannequin (kg) into pressure (kPa), the weight of the mannequin (kg) was divided by the surface area of the cylindrical metal bar (19.7 cm²).

Then the weight of the mannequin per area (kg/cm²) was multiplied by 98.0665 to convert it into pressure (kPa). The median pony body weight was 248.5 kg (IQR, 222.0–275.8 kg). The median weight of the mannequin was 29.8 kg (IQR, 26.6–33.1 kg), which was equivalent to a pressure of 148.9 kPa (IQR, 133.0–165.2 kPa). The median pressures affecting the left and right sides of the backs of the ponies during treatments M, L, and R were 74.45 and 74.45, 104.2 and 44.7, and 44.7 and 104.2 kPa, respectively.

Spinal kinematics and spatiotemporal variables

The kinematics data for the whole stride cycle at the end of the weight-loading session were compared among treatments M, L, and R. The datasets for ROM and absolute angle were normalized by subtracting the data for during the warm-up session. The ROMs for flexion-extension and lateral bending during treatment R were less than those during treatments M and L in the lumbosacral area ($P < 0.05$; Fig. 4). Meanwhile, the absolute angles, stride lengths, and stride durations showed no differences among the treatments. The absolute angles for flexion-extension and lateral bending are shown in Fig. 5. The mean stride lengths in treatments M, L, and R were 1.1 ± 0.1 , 1.1 ± 0.1 , and 1.1 ± 0.1 m, respectively. The mean stride durations in treatments M, L, and R were 1.1 ± 0.1 , 1.1 ± 0.1 , and 1.0 ± 0.1 sec, respectively.

Heart rate and temperament

The mean heart rates during treatments M, L, and R were 60.0 ± 3.4 , 57.8 ± 3.1 , and 57.7 ± 3.3 bpm, respectively. The temperaments of all ponies were calm throughout the weight-loading session in all treatments. The median temperament scores during treatments M, L, and R were 1.1 (IQR, 1.0–1.3), 1.1 (IQR, 1.0–1.3), and 1.0 (IQR, 1.0–1.3), respectively.

Blood lactate, serum CK, and back examination

The blood lactate and serum CK levels showed no differences among treatments. Both variables were consistent

Table 1. Description of temperament scores (adapted from King *et al.* [8])

Score	Description
1	Pony was calm and accepted the mannequin during walking on the treadmill. Relaxed behavior might be detected, i.e., snorting, chewing, or licking. Heart rate was less than 80 beats per min.
2	Pony took some time to settle with the mannequin during walking. Pony showed a resistant behavior(s), i.e., tail swishing, ear pinned back, whinnying, and/or defecation, but it did not affect spinal or stride kinematics. Heart rate was less than 80 beats per min.
3	Pony did not settle down while walking with the mannequin. The rhythm of the walking gait was inconsistent. Pony showed a behavior(s) that affected the spinal kinematics, i.e., ataxia, continuous head shaking, continuous head tossing, and/or standing with a wide-based stance. Heart rate was over 80 beats per min.
4	Pony would not accept the mannequin and attempted to remove it by bucking. Heart rate was over 80 beats per min.

with normal reference values (Table 2). Back examinations on the day after each experiment showed no signs of back injury or delayed-onset muscle soreness for any treatment.

Discussion

This study simulated sessions of hippotherapy in patients with neuromuscular dysfunction by simulating asymmetrical

bareback riding. Our hypothesis was that ponies might have back injuries and show stress after the experiment. Overall, the results did not support our hypothesis because the ponies did not show signs of back injury based on an examination of spinal kinematics, serum CK, blood lactate, heart rate, and temperament.

This study was performed within a treadmill room to reduce the environmental factors. A mannequin was used to

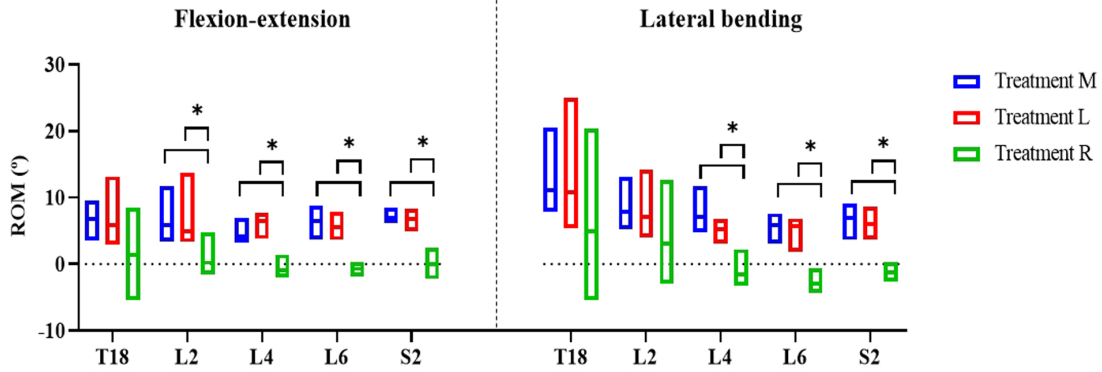


Fig. 4. Ranges of motion in flexion-extension and lateral bending at the end of the weight-loading session. Data are presented as medians (interquartile range). *Statistically significant ($P < 0.05$).

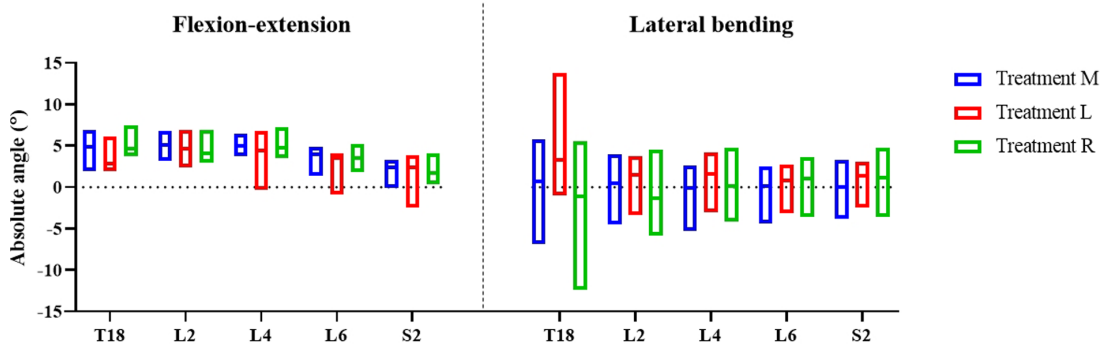


Fig. 5. Absolute angles in flexion-extension and lateral bending at the end of the weight-loading session. The values of the absolute angles were averaged for the whole stride cycle. The beginning and end of the stride cycle were defined as the initial ground contacts of the right hind hoof. The left figure is for flexion-extension. Positive values indicate back extension, and negative values indicate back flexion. The right figure is for lateral bending. Positive values indicated left bending, and negative values indicate right bending. Data are presented as medians (interquartile range).

Table 2. Serum creatine kinase (CK) and blood lactate level during treatments M, L, and R

Parameters	References*	Treatment M			Treatment L			Treatment R		
		Beginning of experiment	End of experiment	Day after experiment	Beginning of experiment	End of experiment	Day after experiment	Beginning of experiment	End of experiment	Day after experiment
Serum CK (mg/dl)	60.0–330.0	112.5 (92.7–134.5)	119.5 (110.3–132.8)	146.0 (125.8–175.8)	119.0 (95.2–142.8)	124.5 (110.5–132.0)	116.0 (100.9–151.5)	117.5 (90.9–154.5)	126.5 (91.0–163.8)	136.0 (120.3–148.8)
Blood lactate (mmol/l)	<4.0	1.1 (0.8–1.5)	1.1 (0.9–2.3)	1.6 (1.1–1.8)	1.0 (0.8–1.8)	1.8 (1.1–2.1)	1.4 (1.1–2.7)	1.1 (0.8–1.7)	1.0 (0.8–1.8)	1.2 (1.0–1.6)

Data are presented as medians (interquartile range). *Reference ranges from Franklin and Peloso [4] and Krimer [10].

mimic a patient with neuromuscular dysfunction for safety reasons and humane ethics. The weight of the mannequin was set at 12% of the pony's body weight, which could be representative of a child's upper body weight. The weight distribution of the mannequin on the pony's back was adjusted to apply symmetrical or asymmetrical weight loading according to the treatment. The order of treatments M, L, and R was fixed in order to minimize any factors that could affect the spinal kinematics. Moreover, treatment M had the lowest risk of inducing back injury, as it applied a symmetrical pressure distribution [6]. The washout period between each treatment was set to at least 48 hr to assure that there would be no residue effects of the previous treatment. According to a study in humans by Trost *et al.*, delayed-onset muscle soreness can be detected within 48 hr after exercising [22], so if any injuries occur, alteration of back physical properties, blood lactate, or serum creatine kinase should be detected.

Although the average of stride frequency from our ponies was 9 strides per 10 sec, kinematics data were extracted from at least 5 stride cycles because some raw data were missing during data collection. This appeared to be because the cameras could not capture the light from some reflective markers in some cases. The bars of the treadmill bar might have obscured the visibility of markers during movement, as the heights of the ponies were on par with those of the bars of the treadmill. Nevertheless, de Cocq *et al.* and Nankervis *et al.* showed that data extraction from at least 5 stride cycles was sufficient to analyze the spinal kinematics in horses [3, 15].

The kinematics patterns from this experiment revealed a reduction of ROM in lateral bending during treatment R, but it did not affect the absolute angle. The present finding is in agreement with a finding of Wennerstrand *et al.*, who induced unilateral back stiffness in walking horses. In their study, the ROM in lateral bending at L5 decreased without a change in the angular motion pattern within one hour after injecting lactic acid; however, this previous research was performed in horses without a rider [23]. MacKechnie-Guire *et al.* studied spinal kinematics in horses with riding asymmetry during a rising trot. Their results demonstrated that the horses adapted their kinematics by increasing the ROM in lateral bending at T18 and L3 [13]. Interestingly, a kinematics adaptation was only found in treatment R in the present study. This might be because the global guidelines in equine practice usually recommend training horses to be led or mounted from the left side [14]. Therefore, the ponies showed greater habituation to deal with challenging activities on the left side than right side.

The spatiotemporal variables had direct relationships with the spinal kinematics. Wennerstrand *et al.* reported that the function of the equine back would be limited in horses

with clinical back pain. In their study, horses compensated by shortening their stride lengths to limit the ROM in flexion-extension [24]; however, Wennerstrand *et al.* also revealed that alterations of stride length and stride duration were not detected in horses with unilateral back pain because the horses were able to maintain their back function [23], which is in agreement with our results.

Our findings for temperament and heart rate were in agreement with those of Nobbe, who evaluated the behaviour and heart rates of horses participating in one or two lessons comprising 30 min of equine-assisted activities and therapies. The horses' behaviours were satisfied, and their heart rates were in the normal range throughout study sessions [16]. Temperament and heart rate are widely used for monitoring the physiological and psychological changes in horses during exercise on a treadmill [8], so the current results showed that the ponies were able to adapt themselves and accept asymmetrical bareback riding during hippotherapy.

Linder-Ganz *et al.* reported that the application of 32 kPa of direct pressure on a rat's *Gracilis* muscle for 15 min to 1 hr could induce muscle cell injury [12]. The present experiment applied over 32 kPa of pressure to the backs of ponies for 30 min; however, the serum CK and back examinations indicated that the ponies did not have acute back injuries or delayed-onset muscle soreness in any treatment. The reason for this might be the application of the EPDM rubber to mimic human gluteal tissue and protect the pony's back in our study. Another reason for this might be variations among species, such as in skin thickness or the durability of back muscle; however, there are no reports about the threshold of pressure that induces muscle injury in horses. Further study should be conducted on this topic.

The accumulation of lactate increases the acidity in skeletal muscle, which inhibits the contractile processes and reduces exercise performance [1]. According to a previous study, a blood lactate level exceeding 4 mmol/l is considered the lactate threshold indicating that muscle is rapidly depleting glycogen via anaerobic glycolysis when an individual's exercise intensity increases [20]. The blood lactate level of our ponies was less than 4 mmol/l, which might reflect that the workload intensity of hippotherapy was low.

A limitation of this study was that the pelvis of the mannequin did not exhibit three-dimensional motion like the pelvis of a patient taking part in real hippotherapy. In addition, the order of treatments M, L, and R was not selected by random sampling, which may have caused some bias; however, the use of an adequate resting gap between treatments could minimize the residual effects of serial treatments. Another limitation was that this experiment only focused on the physical effects from the patient's weight;

however, the ponies in real hippotherapy also face the challenges of the psychological effects from the emotional status of the patient.

The results of the present study suggest that the welfare of therapeutic ponies is good, as asymmetrical bareback loading on the backs of the ponies in this study did not induce acute or serious back injuries. Even if the alteration of the spinal kinematics during treatment R is considered a minor effect, therapists should maintain the alignment of the patient's trunk in a symmetrical riding position, as it could improve the patient's balance and sensory stimulation [18]. The weight of the patient should be limited to within the range of the maximal loading weight to minimize the effect on the pony's back. Finally, this study monitored the acute effects of asymmetrical bareback riding but did not investigate the cumulative effects of asymmetrical bareback riding in the long term. The effects of a full course of hippotherapy for real patients with neuromuscular dysfunction on therapeutic horses should be investigated to evaluate equine welfare in a real situation.

Acknowledgments

This research work was partially supported by RA scholarship for Academic Year 2018 from the Faculty of Graduate Studies, Mahidol University, Nakhon Pathom, Thailand. The researchers also received research funds from Perfect Companion Group Co., Ltd., Bangkok, Thailand. The experiment was performed by the Equine Clinic team. The Faculty of Veterinary Science, Mahidol University, Nakhon Pathom, Thailand, provided support for equine resources and facilities. The College of Sports Science and Technology and SMART Lab, Department of Biomedical Engineering, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand, provided support for biomechanics-related equipment. Details and critical comments relating to this manuscript were proofed by Dr. Norberto Asensio.

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