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Biomechanical responses of the back of riding horses to water treadmill exercise

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ABSTRACT

There is a lack of evidence for the presumed beneficial effects of water treadmills on the movement of the horse's back. The aim of the study was to evaluate the effects of water treadmill exercise on axial rotation (AR), lateral bending (LB) and pelvic flexion (PF) in horses. The back kinematics of a group of riding horses were studied at the walk in a water treadmill at different depths of water (hoof, fetlock, carpus, elbow and shoulder joint levels) over a period of 10 days. Skin markers were placed at anatomical locations on the back. AR, LB and PF were measured on days 1 and 10 using two high-speed video cameras. There was a significant increase in AR compared to baseline at the level of the carpus and at higher water levels, whereas LB was significantly lower than baseline values at water levels that reached the elbow and shoulder joints. PF was significantly higher than baseline values at each water depth other than hoof water depth. At increasing water depths, there were significant increases in flexion and rotation of the back. At the highest water levels, there was reduced bending of the back. After 10 days, horses exhibited more bending of the back.

Introduction

Water treadmills are used widely in rehabilitation centres for horses with poor performance caused by a stiffened back. Water provides buoyancy and assists the horse in lifting the limbs in the vertical plane, but it may also create resistance to movement of the limbs in the sagittal plane (King et al., 2013). Scott et al. (2010) showed that stride frequency decreases and stride length increases as horses are trained in a water treadmill at increasing water depths.

Biomechanical responses of the back to training include axial rotation (AR), lateral bending (LB) and pelvic flexion (PF). AR is rotation around the craniocaudal axis, LB is rotation around the dorsoventral axis and PF is rotation around an axis perpendicular to the sagittal plane (Fig. 1). Each horse uses an individual triangular combination of AR, LB and PF (Pourcelot et al., 1998; Audigié et al., 1999; Van Weeren, 2009; Warner et al., 2010). In kinematic studies, the degree of motion of the horse's back in flexion and extension is usually visualised using a bow and string analogy (Fig. 2; Van Weeren, 2009). Often a treadmill is used for these kinematic studies, since this device offers a stable and controlled scenario (Sloet van Oldruitenborgh-Oosterbaan and Clayton, 1999; Weishaupt et al., 2002; Gómez Alvarez et al., 2009; Back and Clayton, 2013). Vertebral column kinematic studies have also been conducted over ground (Pourcelot et al., 1998; Audigié et al., 1999; Warner et al., 2010).

In the present study, the biomechanical responses of the back and pelvis of horses were examined by measuring changes in the range of AR, LB and PF of the back and pelvis during water treadmill exercise at different depths of water using the hoof as a baseline and control level.

Materials and methods

Horses

Twelve riding horses with no previous experience of water treadmill training were used in this study. They comprised five mares, six geldings and one stallion (10 Warmblood and 2 Baroque horses) with a mean (± standard deviation, SD) age of 7.4 (± 2.1) years (range 5–11 years) and a mean (± SD) height at the withers of 1.66 (± 0.08) m (range 1.51–1.86 m). The horses were all routine patients of a privately owned clinic, using the water treadmill at the request of and with informed consent of the owners. It was considered that there was no need for Animal Care and Ethics Committee approval according to Dutch law.

Experimental design and data collection

Horses were trained four times over 10 days on a water treadmill (Bogenhard; Fig. 3) at different depths of water (Scott et al., 2010). Recordings were made on days 1 and 10 while the horses walked in the water treadmill at a belt speed of 0.8 m/s at a range of depths of water (Peham et al., 2001). For each

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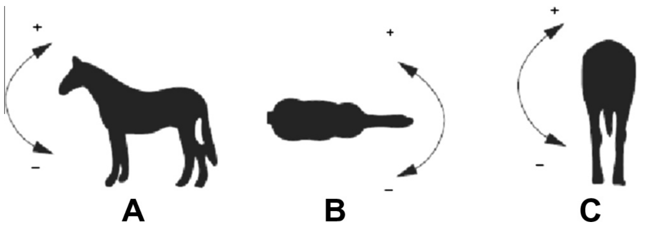

Fig. 1. The three planes of movement of the back. (A) Pelvic flexion (PF): rotation around an axis perpendicular to the sagittal plane. (B) Lateral bending (LB): rotation around the dorsoventral axis. (C) Axial rotation (AR): rotation around the craniocaudal axis (Van Weeren, 2009).

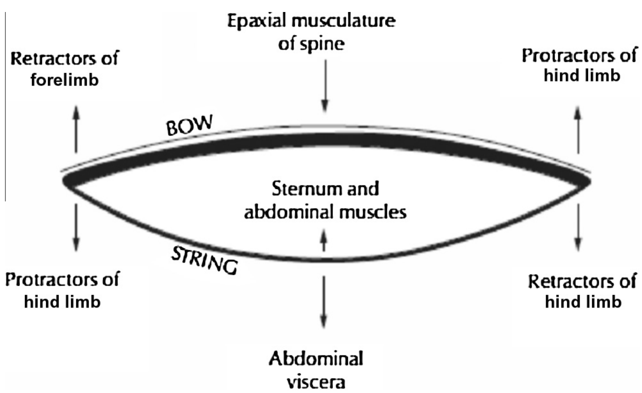

Fig. 2. The 'bow and string' analogy. The bow is the thoracolumbar vertebral column and the string is formed by the linea alba, rectus abdominis and related structures (Van Weeren, 2009).

Table 1
Marginal means (± standard errors and *P* values) for the effect of water height on the range of motion of axial rotation, lateral bending and pelvic flexion of horses walking in a water treadmill.

Water level	Axial rotation (cm)	Lateral bending (°)	Pelvic flexion (cm)
Hoof (control)	4.5 ± 0.3	9.1 ± 0.5	13.6 ± 0.6
Fetlock	5.2 ± 0.3*	8.8 ± 0.5	14.4 ± 0.6*
Carpus	5.9 ± 0.3*	8.4 ± 0.5	15.2 ± 0.6*
Elbow	5.4 ± 0.3*	7.6 ± 0.5*	16.2 ± 0.6*
Shoulder	5.5 ± 0.3*	6.4 ± 0.5*	17.7 ± 0.6*

* Values that are significantly different from the control (baseline value) at the hoof water level: $P < 0.05$.

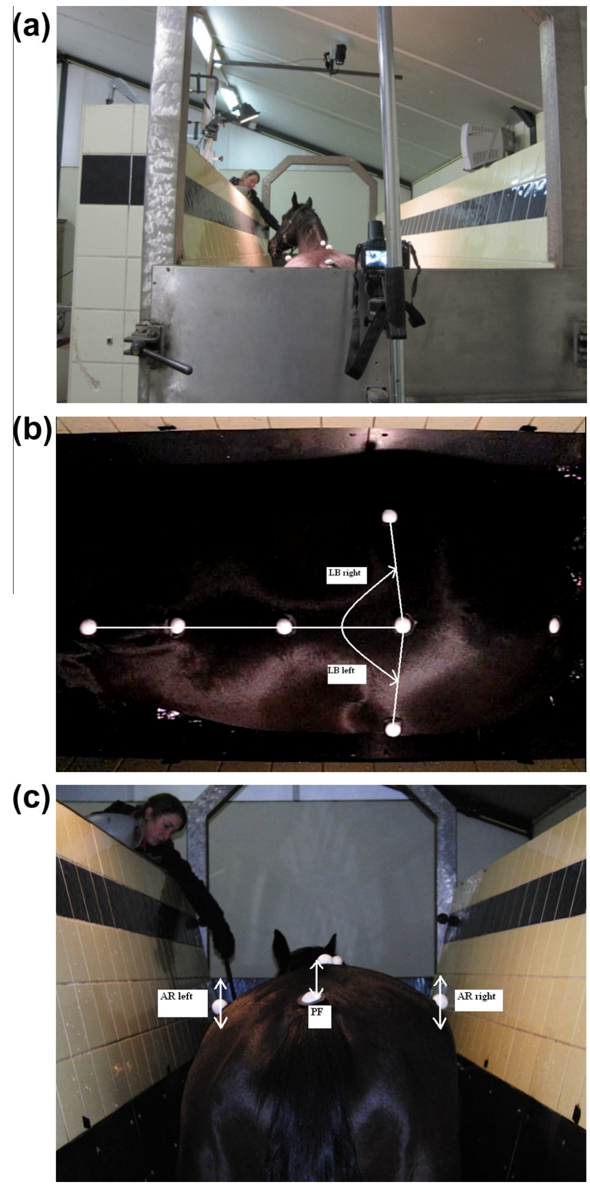

Fig. 3. (a) Recordings with both cameras were performed simultaneously when the horse was walking in a steady state. (b) Schematic representation of the calculation of the left and right lateral bending (LB) angles using the camera from above the treadmill. (c) Schematic representation of the calculation of the left and right axial rotation (AR) and the pelvic flexion (PF) distances using the camera from behind the treadmill.

recording, white spherical markers (diameter 40 mm) were glued to a piece of black paper, which was attached to the skin using double-sided adhesive tape at seven defined locations along the vertebral column. These shaved areas were identified by digital palpation and were defined as the highest point of the withers (T5–6), lowest point of the withers (T10–T11), thoracolumbar junction, tuber sacrale, left tuber coxae, right tuber coxae and tail base.

The water treadmill was filled with water to the level of the shoulder joint and recordings were made over a period of 20 min as the water level increased, with the water level being held constant for 2 min at each of five selected depths: midline of the shoulder, elbow, carpus and fetlock joints and at the level of the coronary band of the hoof. Recording was performed over a period of 1 min at each water depth using two high speed (300 frames/s) video cameras (Casio) and an artificial light source. The lighting was controlled to provide sufficient contrast between the edge of the markers and the surroundings. The cameras were aligned perpendicular to each other, whereby one camera was placed 3 m above the water treadmill to record the LB of the horse's back and the other camera was placed behind the water treadmill to record the AR and PF (Fig. 3). Twenty strides were analysed at each water depth on days 1 and 10.

Data analysis

To process the captured data, the vertical and horizontal axes of the field of view were defined and quantified, and external calibration files were created. For the camera that was placed behind the treadmill, the distance between the two sidewalls of the treadmill was measured at a fixed point in the treadmill for the horizontal axis. For the vertical axis, a wooden stick with a known size was measured at a fixed point in the treadmill for the camera that was placed above the treadmill. These external calibration files were then analysed using standard analysis software (Quintic) in which the markers were tracked automatically into frames recorded during 1 min at each water depth and converted into spreadsheet files (MsExcel, Microsoft) after data smoothing using a Butterworth filter. The vertical ranges of motion (ROM) of the left and right tuber coxae were calculated during 20 strides at each water depth. The AR of the pelvis is given by the mean left and right values during these 20 strides recorded with the camera behind the treadmill (Fig. 3c). The ROM of the angle between the craniocaudal axis, tuber sacrale and tuber coxae on the left or right indicates the LB of the back. This was calculated from recordings of the camera placed above the treadmill (Fig. 3b). The camera behind the treadmill was also used to record the distance between the tuber sacrale marker and the tail base marker, representing the PF of the back (Fig. 3c).

Statistical analysis

Statistical analyses were performed using SPSS (IBM). A linear mixed model was applied with AR, LB and PF as outcome variables, five levels of water depth, days 1 and 10 as times, left and right sides and the two-way interaction between these three variables as explanatory categorical variables. The outcomes were assumed to have a normal distribution. The random effect of individual horse was used to take repeated measurements into account. Akaike's information criterion (AIC) was used in a backward selection procedure to select the best model. Residual analysis was performed to check assumptions for normality and variance. The hoof water depth was set as the control (baseline) level and the minimum level of statistical significance was set at $P < 0.05$.

Results

Effect of water depth

At different water depths, there were no statistically significant differences in the measured parameters between the left and right sides. There were significant differences in kinematic variables among the water depths for AR, LB and PF (Table 1; $P < 0.05$). Relative to hoof depth, AR ROM increased significantly at each successive water depth (hoof control 4.5 ± 0.3 cm, fetlock 5.2 ± 0.3 cm, carpus 5.9 ± 0.3 cm, elbow 5.4 ± 0.3 cm, shoulder joint 5.5 ± 0.3 cm; $P < 0.05$; Fig. 4a). Relative to hoof depth, LB ROM decreased significantly when water depths were at the levels of the elbow and shoulder joints (hoof control 9.1 ± 0.5°, elbow 7.6 ± 0.5°, shoulder joint 6.4 ± 0.5°; $P < 0.05$), but not at the levels of the fetlock or carpal joints (hoof control 9.1 ± 0.5°, fetlock 8.8 ± 0.5°, carpus 8.4 ± 0.5°; Fig. 4b). Relative to hoof depth, PF ROM increased significantly at each successive water depth (hoof control 13.6 ± 0.6 cm, fetlock 14.4 ± 0 6 cm, carpus 15.2 ± 0.6 cm, elbow 16.2 ± 0.6 cm, shoulder joint 17.7 ± 0.6 cm ($P < 0$ 05; Fig. 4c).

Effect of repeated water treadmill exercise

AR, LB and PF did not change significantly over time and there were no significant differences in AR or LB between the left and right hind limbs. LB ROM was slightly greater at day 10 (8.3 ± 0.5°) than at day 1 (7.8 ± 0.5°; $P = 0.008$), but these changes were not significant after Bonferroni correction ($P = 0.11$). LB to the right (8.2 ± 0.5°) was slightly greater than LB to the left (7.9 ± 0.5°; $P = 0.04$), but these changes were not significant after Bonferroni correction ($P = 0.56$).

Discussion

The aim of this study was to determine the effects of increasing water depth during water treadmill exercise and the effects of repeated water treadmill exercise on the ROM of the equine back. Water treadmill training with water depths at the levels of the elbow and shoulder joints resulted in movement patterns that were different to water depths at the levels of the hoof, fetlock and carpal joint. LB ROM was significantly greater at water depths at the levels of the elbow and shoulder joints than at the control hoof water level ($P < 0.05$). At every other water depth, AR and PF were significantly greater than at the control hoof water level.

AR ROM increased during water treadmill training, with the greatest AR at a water depth at the level of the carpal joint. During water treadmill training, the horse presumably tries to walk in the water with the lowest expenditure of energy, as can be extrapolated from horses exercising on a regular treadmill (Hoyt and Taylor, 1981). The easiest way to walk in water at the depth of the fetlock or carpal joint is to lift both the fore and hind limbs to step over the water; to do this with the hind limbs, increased AR needs to be provided by the horse's back. At water depths at the levels of the elbow and shoulder joints, the AR decreased,

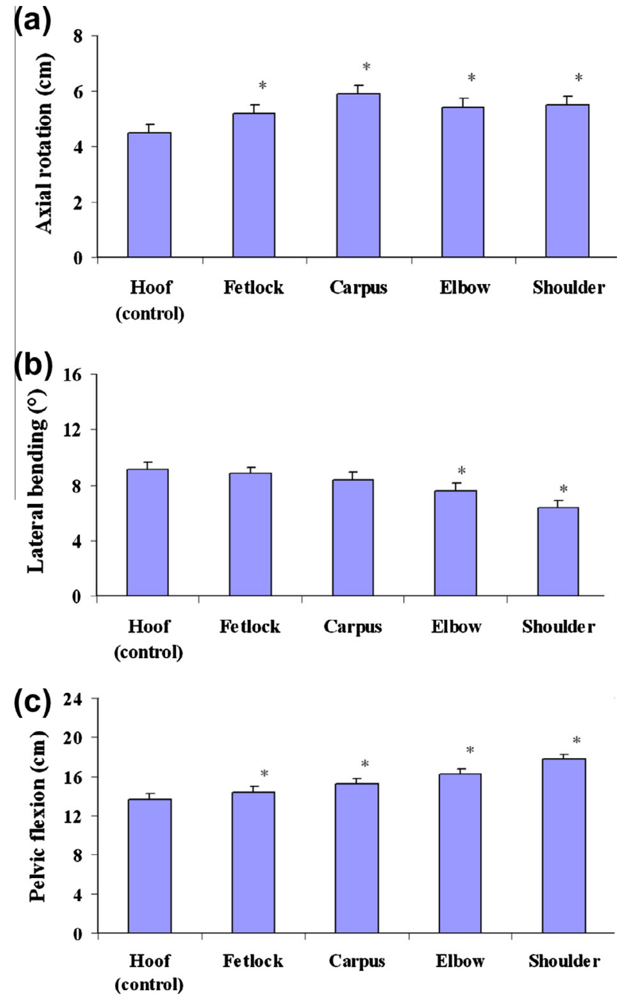

Fig. 4. Bar charts showing means (± standard errors) of (a) axial rotation (AR) range of motion (ROM) in cm, (b) lateral bending (LB) ROM in degrees (°) and (c) pelvic flexion (PF) ROM in cm for each water height (WH). Water depth 1 is at the level of the hoof, 2 at the fetlock, 3 at the carpus, 4 at the elbow and 5 at the shoulder joint. * Significantly different from control (baseline) values at hoof water level ($P < 0.05$).

because the horse was forced into another movement pattern by the resistance of the water. The water was too deep at this level for the horse to step over the surface and the movement pattern changed to increase PF and reduce LB.

In dogs, the vertical ground reaction force (GRF) decreased significantly after immersion to levels of the tarsal (9%), stifle (15%) and hip (62%) joints (Levine et al., 2010). The decrease in GRF is due to buoyancy (Monk, 2007; Levine et al., 2010). Buoyancy provides assistance in lifting a limb in the vertical plane, but water creates resistance to movement of the limb in the sagittal plane (Scott et al., 2010). In horses and dogs, buoyancy is minimal when only the distal part of the limb is immersed, whereas there is a substantial buoyancy effect when the trunk is immersed. This is why the swing phase of the limb in the sagittal plane is more difficult to implement when immersed, and swinging the limb in the usual way would use more energy than lifting the limb (Scott et al., 2010). Protraction of the hind limbs causes back flexion and hence an increase in PF (Bromiley, 2009). In dogs, contraction of the abdominal musculature also occurs at water depths at the levels of the elbow and shoulder joints due to contact with cold water (Levine et al., 2010).

Horses with longer stride lengths have greater PF ROM in the caudal saddle region at the walk (Johnston et al., 2004). Stride frequency at hoof water level is significantly higher than at carpal and elbow joint water levels (Scott et al., 2010). Stride length also increases at these water depths when compared with hoof water level when measured at a belt speed of 0.9 m/s, and it was concluded that increased PF leads to increased stride length (Scott et al., 2010). This change in stride kinematics is not accompanied by an increase in workload; the heart rate did not show a significant difference between control and test water depths (Scott et al., 2010). We used a similar speed of 0.8 m/s in the present study, which allowed all horses to walk comfortably (Peham et al., 2001).

We also found that the LB ROM of the back decreased significantly at water depths at the levels of the elbow and shoulder joints, whereas PF increased significantly. This is probably due to the increased resistance of the water, which leads to a different pattern of movement. Wennerstrand et al. (2004) found that PF and AR ROMs were smaller, and the LB was greater, in horses with back pain than in unaffected horses (Wennerstrand et al., 2004). Thus, the use of increased water depths during water treadmill training forces the horse into different movement patterns, with greater PF and lower LB.

After Bonferroni correction, there was no significant difference in the ROM of AR, LB and PF between days 1 and 10, nor between the left and right hind limbs, even though some of the horses had changed their movement pattern on subjective visual inspection at day 10. A fixed protocol may not be optimal for each horse with its individual pattern of pelvic movement. Some horses developed skin reactions, for example crusts and/or oedema, on the ventral thorax and/or limbs during the intensive water treadmill training period, although the skin was cleaned and dried after every exercise session; this might also have affected the response to water treadmill training.

Conclusions

Water treadmill training of horses with water at the level of the elbow and shoulder joints resulted in a different movement pattern compared to training with water at the level of the hoof, fetlock and carpal joint; AR and PF were increased, while LB was reduced. Water treadmill training over 10 days appears to have an effect on back motion.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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