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The effect of water height on stride frequency, stride length and heart rate during water treadmill exercise

R. SCOTT, **K. NANKERVIS***, **C. STRINGER**, **K. WESTCOTT** and **D. MARLIN**

The Equine Therapy Centre, Hartpury College, Gloucester, UK.

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Summary

Reasons for performing study: **Water treadmill exercise is often incorporated into rehabilitation programmes for horses yet little is known about the biomechanical and physiological responses to water walking.**

Objectives: **To establish whether stride frequency (SF) reached steady state as a result of 6 introductory water treadmill sessions and then to investigate the effect of increasing water height on SF, stride length (SL) and heart rate (HR).**

Methods: **Nine horses with no previous experience of water treadmills completed 6 sessions of walking for between 15 and 30 min. Each horse was fitted with a leg mounted accelerometer to measure SF. The effect of session on SF was tested using univariate ANOVA. Eight horses completed 3 further sessions at each of the following water heights; proximal interphalangeal joint (PIP), carpus and ulna. SF, SL and HR at each water height were compared to a control (hoof height) using univariate ANOVA.**

Results: **When SF during introductory sessions 4–6 were compared, there was no significant effect of session on SF ($P>0.05$). In the second part of the experiment, SF was 0.57 ± 0.03 strides/s at control, 0.54 ± 0.03 strides/s at the PIP joint, 0.51 ± 0.02 strides/s at the carpus and 0.52 ± 0.03 strides/s at the ulna. Stride frequency at carpal and ulna height was significantly lower than at control ($P<0.05$). Stride length was 1.53 ± 0.09 m for control, 1.63 ± 0.10 m at the PIP joint, 1.71 ± 0.08 m at the carpus and 1.68 ± 0.10 m at the ulna. Stride length at carpal and ulna height was significantly greater than control ($P<0.05$). There was no significant difference between HR during control and any other water height ($P>0.05$).**

Conclusion: **Horses reached steady state gait within the first 6 sessions of water treadmill exercise. Walking in water at the level of the carpus or ulna resulted in a lower SF compared to walking in water at hoof height.**

Introduction

Water treadmills are now widely used in rehabilitation centres and professional training establishments worldwide. Relatively little is known about the kinematics of movement in water and therefore exercise programmes used to date have a limited evidence base. The measurement of biomechanical variables during exercise in water treadmills does present some methodological challenges due to the design of water treadmills (usually either sunken into a pit or in a chamber which precludes measurement using video) and the availability of equipment which is suitable for use underwater. Previous work studying heart rates and blood lactate levels post water treadmill exercise shows that it is predominantly an aerobic activity (Voss *et al*. 2002; Lindner *et al*. 2003) with heart rates of up to 120 beats/min during trotting in high water and blood lactates of approximately 1.0 mmol/l (Voss *et al*. 2002). Unlike swimming, where heart rates in excess of 200 beats/min have been reported (Misumi *et al*. 1994) water treadmill exercise is unlikely to provide a useful substitute for canter or gallop work within a training programme. Water treadmill exercise may, however, be a useful substitute for ridden exercise in sport horses (dressage and showjumpers) and for horses undergoing rehabilitation for injuries such as tendinitis, desmitis and treatment of back pain/dysfunction. Water treadmill exercise may provide a more appropriate alternative to swimming as a nonridden form of exercise for sport horses as the horse works in a similar gait and posture to overland ridden exercise but with a reduction in concussive forces experienced by the distal limb joints.

As water treadmill exercise appears to be a lower intensity activity than swimming, it is more suitable for horses in the early stages of a controlled exercise programme. Despite the fact that heart rate is a less reliable indicator of work done when the horse is partially submerged (Nankervis *et al*. 2009a) it can be used to compare workloads of horses provided the temperature of water used is the same in all cases and the horse has had a suitable period of habituation to water treadmill exercise. Nankervis and Williams (2006) suggested a minimum of 2 × 15 min acclimating runs in order to reach a threshold steady state heart rate as calculated using the method of Buchner *et al*. (1994). Water provides buoyancy and will assist the horse in lifting the limb in the vertical plane, but presents a greater resistance to movement in the sagittal plane when compared to walking on a normal treadmill belt. Tokuriki *et al*. (1999) showed that the intensity of EMG activity within the *extensor digitorum communis* was higher during walk on a water treadmill than during either walk overland or trot on a water treadmill. The authors concluded that walking in water may provide more intensive training for some forelimb muscles than trotting on the water treadmill.

*Corresponding author email: kathryn.nankervis@hartpury.ac.uk.
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The aim of this study was firstly to determine whether stride frequency (SF) reached steady state as a result of 6 introductory water treadmill sessions and secondly to establish the effect of water height on SF, stride length (SL) and heart rate (HR) in horses accustomed to water walking.

Materials and methods

Part 1 of the experiment was the measurement of stride frequency in 9 horses throughout their first 6 sessions of water treadmill walking. Five geldings and 4 mares (5 Thoroughbred crosses and 4 Warmbloods) were used for Part 1; age 7.9 ± 1.9 years (mean ± s.d.); bodyweight (bwt) 560.2 ± 53.8 kg; height at withers 166.5 ± 4.2 cm. Eight of these 9 horses (4 geldings and 4 mares) were then used for Part 2; age 8.0 ± 2.0 years; bwt 563.4 ± 56.6 kg and height at withers 167 ± 4.2 cm. All horses were in full work (at least 1 h of exercise a day 5 times a week to include schooling and/or jumping) and were considered sound by their owners.

For Part 1 of the study, each horse carried out one exercise session of between 15 and 30 min per day on an Aquafit water treadmill[1] over 6 consecutive days. Horses were fitted with a leg mounted accelerometer[2] sealed in a watertight pack[3] and fitted to a brushing boot on the left forelimb. The speed of the belt was 0.9 m/s and water temperature 14°C throughout the study period. None of the horses used had previous experience of water treadmill exercise and were sedated for the first session (as per standard practice within our Centre in order to increase safety) using i.v. romifidine at a dose of 20–30 µg/kg bwt. Horses were exercised in a bridle with a rein held by a handler either side of the treadmill. The heart rate monitor electrodes were positioned on the sternum and behind the scapula on the left hand side of the horse with both the transmitter and receiver secured to a leather roller. Heart rate data were recorded every 5 s during exercise using a Polar S810i[4] heart rate monitor and downloaded to a P.C using Polar HorseTrainer[4] software.

Over the course of the first 6 sessions, the water height was progressively increased, with all horses introduced to walking in water up to ulna height by the end of the fourth session. The Pegasus accelerometer has a sampling frequency of 102.4 Hz with SF calculated as a rolling 5 s average. Data obtained using this equipment had been validated previously by direct comparison to data obtained using a 3D motion capture system (Nankervis *et al*. 2009b). The last 60 s of data at each water height were used to calculate a mean SF for each individual horse for sessions 1–6 and also a group mean. The mean and standard deviation of SF for each horse within each session was calculated. A univariate ANOVA was used to determine whether there was a significant effect of session on SF between sessions 4–6 in order to establish if steady state gait had been reached.

Eight horses then completed 3 further sessions in a randomised design at each of the following water heights; proximal interphalangeal (PIP) joint, carpus and ulna over 3 separate days. The speed of the belt was 0.9 m/s during each session. At the start of each session the water was pumped to ulna height for 5 min to act as a warm-up, before being lowered to the designated test height for a further 5 min and then dropped down to below the coronary band (hoof height) for a further 5 min. Data collected during this final 5 min served as a control, yielding a control for each test height. The water was never dropped below the level of the treadmill belt (i.e. run completely dry) in order to allow smooth running of the belt. The last 60 s of data (i.e. SF and HR) for the designated test height was used for analysis and compared against the last 60 s of the data at control. Stride length for each water height was calculated using the following equation; belt speed × (1/SF). SF and HR at each water height were compared using univariate ANOVA. P values less than 0.05 were considered to be significant.

Results

Part 1: During the first 6 sessions group mean SF varied between 0.49 strides/s and 0.59 strides/s. (Fig 1). There was no significant effect of session on SF between sessions 4–6 (P>0.05). Part 2: Mean SF was 0.57 ± 0.03 strides/s for the control, 0.54 ± 0.03 strides/s at the PIP joint, 0.51 ± 0.02 strides/s at the carpus and 0.52 ± 0.03 strides/s at the ulna (Fig 2). Stride frequency at carpal and ulna height was significantly greater (P<0.05) than control, but there was no significant difference in SF between PIP joint and control (P>0.05). Stride length was 1.53 ± 0.09 m for control, 1.63 ± 0.10 m at the PIP joint, 1.71 ± 0.08 m at the carpus and 1.68 ± 0.10 m at the ulna. SL was significantly greater (P<0.05) at the carpus and ulna than at control, but there was no significant difference in SL between PIP joint and control.

Group mean HR was 62.0 ± 10.2 beats/min during control, 61.1 ± 8.3 beats/min at PIP joint height, 60.6 ± 6.7 beats/min at carpal height and 64.7 ± 8.0 beats/min at ulna height. There was no significant difference between HR during control and any other water height (P>0.05).

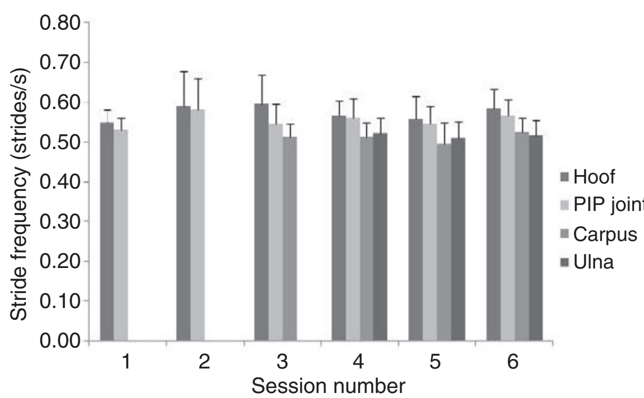

Fig 1: Mean ± s.d. of SF at each water height during the course of the first 6 water treadmill sessions (n = 9).

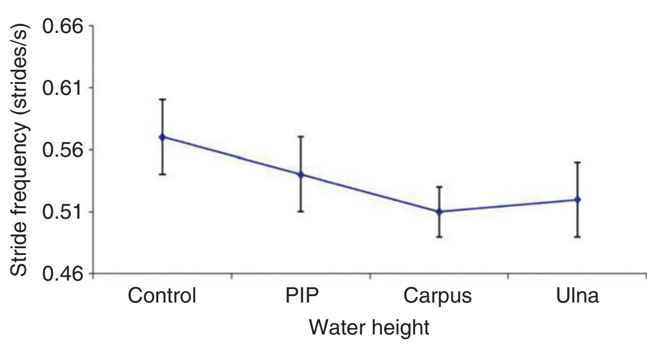

Fig 2: Mean ± s.d. stride frequency (strides/s) during water treadmill walking (n = 8).

Discussion

The walk speed used during this study was typical of that used for water treadmill walking but is slower than a typical walk overland or on an ordinary treadmill belt. Stride frequency during session 2 was higher than in session 1 (when horses were sedated). Stride frequency at hoof, PIP joint and carpal height were lower in session 4 than in session 2. Buchner *et al*. (1994) found that SF decreased throughout the course of the first 10, 5 min walking sessions on a normal treadmill and concluded therefore that habituation was still incomplete. As there was no significant effect of session (P>0.05) on SF between sessions 4–6, it appeared that steady state gait had been reached within the course of the introductory sessions. Buchner *et al*. (1994) suggested that higher velocities were more constraining (trot variables stabilised before walk variables) and in the current study, higher water appears to be more constraining than lower water, as the SF in carpal and ulna height water shows relatively less change with session number than SF at hoof and PIP joint height. In Part 2, walking in water at any level between the PIP joint and the ulna brought about a decrease in SF and an increase in SL compared to the control. Horses select a lower SF and greater SL in carpal and ulna height water than at lower water heights. Water provides buoyancy and so water should assist the limb being lifted vertically. Water provides a resistance to movement of the limb in the sagittal plane; so an increase in height of the flight arc may also minimise the resistance experienced in swinging the limb back and forth. When moving in water between carpal and ulna height, the horse may find it easier to adopt a rounder flight arc by increasing flexion of the hip, stifle and hock joints. Water treadmill exercise may increase activity of muscles which flex the hip (e.g. *superficial gluteal, tensor fasciae latae*, flex the stifle (e.g. caudal *biceps femoris*) and protract the hindlimb (e.g. *tensor fasciae latae* and *iliopsoas*). Any difference in muscle recruitment patterns between overland, dry treadmill and water treadmill walking would need to be investigated using electromyography. Unfortunately, one of the muscles of particular interest, the *iliopsoas* is relatively inaccessible and, therefore, difficult to study. Perhaps any significant effects of water treadmill exercise on this muscle could only be inferred by repeated *per rectum* palpation of this muscle over the course of a longer term period of water treadmill exercise. Anecdotally, one of the concerns of water treadmill exercise has been that forelimb musculature may become overdeveloped as the horse has to work harder in water to advance the forelimb. Indeed, Tokuriki *et al*. (1999) found that EMG activity in the *extensor digitorum communis* was greater during walking on the water treadmill than overland when horses walked at a speed of 1.34 m/s; considerably faster than in the present study. In the author's experience, water walking at >1.0 m/s results in larger head and neck displacement, and an extended thoracolumbar posture whilst walking at or around 1.0 m/s enables the horse to maintain a similar posture to overland exercise with a lower head and neck carriage and a flexed thoracolumbar spine.

Heart rate was not measured during Part 1, but was expected to have reached steady state by Part 2 based on evidence obtained in a previous study (Nankervis and Williams 2006). Heart rates obtained in the current study were similar to those seen previously during walk on a water treadmill (Voss *et al*. 2002; Nankervis and Williams 2006; Nankervis *et al*. 2009a). No significant difference was seen in heart rate at any water height compared to control which also echoes the findings of Voss *et al*. (2002). As the heart rate did not alter significantly between control height water and carpal or ulna height water, the change in stride kinematics is not accompanied by an increase in workload. The alteration in gait pattern seen between hoof and carpal height water may allow the horse to accommodate the increased water resistance without a concomitant increase in workload. Range of movement within the hindlimb can be increased by adding weight to the distal limb although this is accompanied by a disproportionate increase in metabolic effort (Wickler *et al*. 2004).

This study shows that water treadmill walking in carpal or ulna height water results in a lower SF and a higher SL than walking in water at hoof or PIP joint height. Water treadmill walking could be used to encourage hind limb flexion as part of a rehabilitation programme without increasing the workload of the horse.

Conflicts of interest

None declared.

Manufacturers' addresses

[1]Aqua-Fit, Gesteut Nehmten, Germany.
[2]European Technology for Business Ltd, Codicote, Herts. UK.
[3]AquaPac International Limited, London. UK.
[4]Polar Electro (UK) Ltd, Warwick, UK.

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