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REVIEW ARTICLE

The use of the water treadmill for the rehabilitation of musculoskeletal injuries in the sport horse

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Abstract

In recent years, exercise on a water treadmill has come to have great relevance in rehabilitation and training centres for sport horses. Its use exploits certain physical properties of water, related to the fundamental principles of hydrodynamics, such as buoyancy, viscosity, hydrostatic pressure, and water temperature. These properties together with deliberate specification of the depth of the water and the velocity of the treadmill provide a combination of parameters that can be varied according to the purpose of the rehabilitation or training programme, the disease to rehabilitate, or the healing phase. In the current article, kinematic adaptations to exercise on a water treadmill and the direct application of such exercise to the rehabilitation of superficial and deep digital flexor tendon and accessory ligament injuries and back and joint diseases are described.

Keywords: horse, exercise, rehabilitation, training, water.

Introduction

Exercise in water is a therapeutic option for the management of musculoskeletal disorders in human beings. It may be pursued not only to improve the primary injury but also to reduce the harmful locomotor compensatory changes derived from the primary alteration. In human patients, exercise in water is an effective therapeutic strategy to increase the range of joint motion (ROM), re-educate normal locomotion patterns, improve muscle function, and reduce secondary atrophy and limit proprioceptive deficits (31). These effects derive from various physical properties of water, such as buoyancy, hydrostatic pressure, and viscosity, which combined with changes in water temperature, osmolarity and depth, and changes in velocity of movement, define several therapeutic combinations that can be integrated into a musculoskeletal rehabilitation plan. Exercise in water represents a versatile treatment modality, capable of inducing a wide variety of therapeutic responses. It is an effective method for the management of the sensory and motor alterations associated with primary and secondary musculoskeletal injuries in order to achieve a complete functional restoration of performance.

Types of horse exercise in water

The best-known modalities of exercise in water in the horse are swimming pools (complete flotation) and water treadmills (WT, semiflotation). The physiological adaptations to these types of exercise are different. Thomas *et al.* (35) described heart rates (HR) between 150 and 200 beats/min and blood lactate (LA) concentrations up to 10 mmol/l in horses after a tethered swimming exercise. Mean HRs of 70–80 beats/min (60–106 beats/min range) and blood LA concentrations of 0.96–1.1 mmol/l (1–2 mmol/l range) have been found in horses exercised at different depths on a WT for a 20 min duration session (23). Therefore, swimming appears to induce greater cardiovascular and metabolic stress than exercise on a WT at a walk. Greco-Otto *et al.* (10) documented that horses exercised on a WT at different depths work at exercise intensities of 27.7–32.7% of their maximal HR, reflecting its aerobic nature.

Marked locomotor differences exist between swimming and exercise on a WT. Greater electromyographic activity of the *brachiocephalicus* muscle has been found during exercise in water than during terrestrial locomotion, probably due to the action of pulling the forelimb forward against water resistance. The electromyographic activity of this muscle was greater in swimming than on a WT (36). An interesting finding of this research was that during swimming horses often stopped movement of the forelimbs, showing only movement of the hindlimbs. This fact is important from a rehabilitation point of view because it is not possible to cease movement of the forelimb during land or WT locomotion. Greater electromyographic activity was detected on the *extensor digitorum communis* on a WT at a walk, probably because of the need to protract the limb against water resistance (36).

Horses are not natural swimmers. They use their forelimbs to maintain balance and hindlimbs for propulsion. Extreme ROM though the hip, stifle, and hock joints are observed in horses during swimming. Moreover, horses adopt a lordotic posture with cervical thoracolumbar and pelvic extension, and as a result, different authors recommend caution using swimming in horses with thoracolumbar, sacroiliac, hip, stifle, or hock injuries (2, 14). A summary of the physiological adaptations to the two main types of exercise in water (swimming and WT exercise) are shown in Table 1.

Physical properties of water

The most important properties in training and rehabilitation are buoyancy, viscosity (which determines the drag force), and hydrostatic pressure. In hydrotherapy, buoyancy is defined as a vertical force opposing the force of gravity. It acts by reducing the axial forces on the limbs, and it also depends on the velocity of movement and the depth of water. A three- to fivefold decrease in vertical ground reaction forces (vGRF) has been detected in human beings walking immersed in 1.3 m of water compared with the forces imparted by walking out of water (33). Levine *et al*. (17) found in dogs that vGRF decreased proportionally to increasing depth of water. Similar studies have not been conducted in the horse. However, it has been indirectly estimated that immersion in salt water reduces the effective weight of the animal by 10% with water at the level of the elbow, 30%–60% with water at the level of the scapulohumeral joint and 75% with water at the level of the coxal tuberosity (15, 16, 20). The ability to control the reduction of the load on the axial skeleton on a WT is of great benefit in the prescription of therapeutic exercise. By monitoring the depth at which functional movements occur, the effect of gravity can be progressively increased in order to achieve an incrementally greater load and a gradual strengthening of tendons, ligaments, bones, and joints.

Water is more viscous than air, which implies that the resistance to displacement in this medium is significantly higher than that encountered in terrestrial locomotion. The viscosity determines the drag force, which increases with the velocity. A considerable increase in total muscle power expended with increasing depth of water has been described by the authors in previous works, the increase probably being a consequence of the greater drag force (23, 24, 34). This muscle power decreased at the same depth of water when the velocity was reduced (23). Our results have two main implications for rehabilitation. Firstly, injured horses might have remained untrained for prolonged periods and their fitness level may be deficient. The authors have observed that neither HR nor blood LA concentrations appear to be reliable indicators of fatigue during this type of exercise. The buoyancy counteracting body weight results in decreasing HR at greater water depths in humans. The hydrostatic pressure promotes venous return, which increases stroke volume and consequently, HR does not increase and may even decrease at greater water depths in humans on a WT (19). The same appears to happen in the horse. In our experience, although monitoring HR and blood LA concentrations is highly recommended, we consider it advisable to also modulate the velocity of the WT and measure plasma/serum creatine kinase activity to detect muscle injury. We have found significant increases in this enzyme's activity during a training programme in sedentary horses, probably reflecting muscle damage (observational study; unpublished data). Secondly, the drag force of the movement in water is important for animals with chronic low severity lameness and muscle atrophy.

Table 1. Summary of the main physiological adaptations to swimming exercise (full flotation) and exercise on a water treadmill (semiflotation) in the horse. Values are presented as maximum and minimum means reported in the literature

Parameters	Swimming	Water treadmill without water	Water treadmill
Velocity, m/s	1.08–1.15	1.11–1.67	
VO_2, ml/kg/min	Not measured	8.93–9.57	10.44–16.7
RR, breaths/min	25.0–30.0	37.6–39.7	33.5–51.9
Vt, L	Not measured	3.8–3.9	4.2–6.0
VE, L/min	Not measured	152.1–158.3	169.3–242.2
HR, beats/min	182–190	49–76	60–97
LA, mmol/l	2.3–2.8	0.7–1.4	0.7–2.0

(VO_2 – oxygen uptake; RR – respiratory rate; Vt – tidal volume; VE – minute ventilation; HR – heart rate; LA – blood lactate) (according to references 10, 12, 18, and 23)

Table 2. Physical properties of water useful for rehabilitation and training purposes and therapeutic effects (according to references 16 and 31, with modifications)

Physical property	Therapeutic effects
Buoyancy	Reduction of the axial forces supported by joints and surrounding soft tissues Reduction of cardiovascular effort (lesser HR increase than during on-land exercise)
Viscosity. and drag force	Improvement of the range of motion Increase in muscle strength and power Increase in neuromotor control
Hydrostatic pressure	Reduction of oedema and inflammation Promotion of lymphatic return, increasing stroke volume Increases in blood flow to the muscles, and in diffusion of metabolic waste products from muscles to blood Reduction of pain Increase in the range of motion Muscle strengthening
Temperature (cold)	Reduction of blood flow Control of oedema, inflammation and pain Reduction of fatigue

The greater muscle power associated with exercise on a WT can be used for muscle building before initiating more intense land training. The drag force leads to greater muscle activation, improves strength and motor control, and promotes joint stability, as confirmed by electromyography in human patients with knee osteoarthritis (30).

Hydrostatic pressure produces circumferential compression on the limbs, promoting venous return and lymphatic drainage. Both facts decrease oedema and inflammation of the soft tissues, resulting in a larger ROM and a decrease in pain (13). Another positive effect of the hydrostatic pressure is the stimulation of the sensitive nerves of the skin and the joint mechanoreceptors. This stimulation results in an improvement in proprioceptive neuromuscular function, protecting joint structures from an excessive or abnormal load (15). The main therapeutic effects of several physical properties of water are listed in Table 2.

Currently, there are no specific WT exercise protocols designed for each musculoskeletal disorder, except for protocols recommended by the manufacturers. The regime recommended for bowed tendon rehabilitation by one manufacturer has been described (3). Other protocols have been reported for moderate tendinitis (1) and induced midcarpal joint osteoarthritis (15, 16). Despite the paucity of scientific information about how to use the WT for rehabilitation of locomotor injuries in the horse, this type of exercise can be integrated into a rehabilitation plan if we know the kinematic adaptations.

Rehabilitation of tendon and ligament injuries

The depth of water significantly influences stride frequency (SF) and length (SL), the duration of the stance and swing phases, and the protraction and retraction of the limbs. Exercise on a WT with water depth at the level of the stifle leads to a longer SL and a reduced SF compared to exercise at lesser water depths (21, 23, 24, 34). We have investigated changes in the locomotor pattern during a session of WT exercise at different depths using a triaxial accelerometer placed in two different locations: at the level of the sternum (more representative of changes of the centre of gravity and of forelimb activity) and at the dorsal midline at the level of the sacrum (more representative of the accelerometric pattern of the hindlimbs). When the accelerometer was fixed at the sacrum a reduction in SF and, consequently, an increase in SL was found with water at the level of the fetlock and carpus compared to baseline conditions (without water). However, when the accelerometer was fixed at the sternum, these changes were not observed until the water reached the level of the carpus (34). It appears that the behaviour of the forelimbs differs from that of the hindlimbs in regard to changes in SF and SL at the same depth. These differences were attributed to the different functions of the fore- and hindlimbs.

Rehabilitation of the superficial digital flexor tendon and the suspensory ligament

The drag force is believed to reduce the protraction of the forelimbs proportionally to the depth of water, while the protraction of the hindlimbs does not reduce and may even increase (26). In terrestrial locomotion, the protraction of the distal part of the limbs is mainly passive due to the release of the elastic energy stored in the superficial digital flexor tendon (SDFT) and to a lesser degree in the suspensory ligament (SuspL) (11). The greater activation of the brachiocephalic muscle during exercise on a WT could alter the normal pendulum of the limb. For that reason, the use of a WT in cases of acute SDFT lesions is not currently recommended (1, 26, 27).

In subacute and chronic tendinitis, WT exercise is recommended after taking two factors into consideration. Firstly, the greatest strain in the SDFT and its accessory ligament (SDFT-AL) occur during the stance phase (8). As the load supported by the limb decreases proportionally to the depth of the water as a consequence of buoyancy, it appears advisable to start with deep water and progressively reduce the depth. Secondly, the function of the SDFT depends not only on the passive tension the SDFT-AL, but also on the active contraction of the muscle belly (11). For this reason, it is important to avoid muscle fatigue. The results of a recent study (9) showed that SDF muscle manifests significant fatigue in response to treadmill exercise, with muscle LA concentrations two to three times greater than at rest. These data are relevant since the SDT muscle has a high proportion of slow-contraction fibres and a very low percentage of fast-contraction type IIX fibres (3). All of this might indicate that the SDT muscle belly can be fatigued quickly. This possibility should be considered when rehabilitating injuries of the SDFT, since fatigue at the musculotendinous junction can aggravate the pre-existing injury.

Treadmill locomotion (land treadmill and WT) is characterised by an increase in the retraction of the limb because the foot is drawn caudally by the moving belt during the stance phase (4). Increased retraction has been also documented in the hindlimb on a WT and this retraction increased with water depth (25, 27). Increased retraction could be counterproductive in the rehabilitation of certain conditions such as proximal SuspL desmitis in the hindlimbs. Furthermore, exercise on a WT with the water at the level of the hock results in a significant increase in flexion in the distal joints of the limb, and does even more so with the water at the level of the stifle (21). For both reasons, proximal suspensory desmitis in the hindlimbs can be aggravated. However, water at a greater depth (at the level of stifle or deeper), together with a reduction in the velocity of the WT might reduce the load on the SuspL during the stance phase. In addition, exercise on a WT will increase the drag on the hindlimbs potentially increasing muscle development. The relatively firm surface of the belt would favour the energy return to the limb. If the horse is able to advance the limb sufficiently in deep water, there might be a rationale for using the WT to limit the load on the SuspL while redeveloping hindlimb musculature at the same time. The velocity should be reduced because the drag force causes comfortable speed on the WT to be about half that on a land treadmill or on the ground.

The weight of the rider influences the kinematics of the limbs, increasing the relative duration of the stance phase, the maximum extension and the ROM of the fetlock, affecting mainly to the forelimbs (6). Therefore, exercise on a WT (or on a land treadmill) would be recommended before starting riding exercise in horses with fetlock, SDFT, and SuspL injuries.

Rehabilitation of the deep digital flexor tendon and its accessory ligament

During the last part of the stance phase, there is an active contraction of the muscle belly of the deep digital flexor muscle, and the accessory ligament of the deep digital flexor tendon (AL-DDFT) has a prominent role in elevating the fetlock. In this part of the stance phase, the DDFT and the AL-DDFT are maximally stretched, the latter coming under more tension (8). The increased contraction during the stance phase on a WT and/or a land treadmill can therefore be assumed to result in increased tension in both anatomical structures (4). For this reason, the use of treadmills is not recommended in these injuries. We have observed that horses with chronic DDFT injuries do not improve on a land treadmill. In contrast, exercise on a WT led to a reduction of the size of the injured region (measured with a Gulick tape), probably because of the effect of the hydrostatic pressure, which reduces oedema and inflammation (observational studies).

Nankervis *et al.* (26) suggested that horses with certain anatomical conformations, such as hyperextension of the carpus or very straight hindlimbs, show a more marked increase in retraction during exercise on a WT, although the authors based this finding on observational studies. Until we have more information concerning this hypothesis, this type of exercise should be used with caution in horses with these conformations.

Rehabilitation of back injuries

Exercise on a WT is being incorporated into the rehabilitation of horses with loss of performance and back stiffness, although its effectiveness has not yet been proven. In addition, it appears that each horse with a back injury can adopt different kinematic strategies in order to adapt to the depth of water according to its conformation (22, 25). The kinematics of the back during exercise on a WT is modified by the position of the head and neck and by the kinematic changes of the limbs. Exercise on a WT significantly alters the ROM of the back, although the effects on flexion and extension depend on the depth of the water and the anatomical region (22, 25).

In shallow water, the horse keeps the head and the neck relatively low, and consequently, a slight cranial thoracic flexion occurs up to T13 (25). However, when the water depth increases, the horse tends to raise its head in order to avoid contact with the water, achieving greater cervical and cranial thoracic extension. The theory of the bow and string explains the kinematics of the equine back. Due to the greater protraction of the hindlimbs and the increased flexion of their distal joints at greater depth, a tension effect would be induced in the arch through the traction of the retractor muscles of the hindlimbs and the epaxial musculature. The consequence would be an increase in ROM at the level of L3 due to an increase in flexion. ROM in T18 shows an intermediate pattern between the extension of T13 and the flexion of L3 (25).

Although the WT could be beneficial for the rehabilitation of back injuries, therapy should proceed with caution in injuries more cranial than T13 with deep water, due to the cranial thoracic extension, a movement that would not be advisable for the rehabilitation of these injuries (for example, disorders of the spinous processes). In fact, the recommended exercise for the *longissimus dorsi* muscle consists of increasing flexion, not extension (5, 7).

Rehabilitation of joint injuries

Due to the significant increase in ROM in the distal joints of the limb (21), exercise on a WT is not indicated in acute inflammatory joint disorders. However, in chronic osteoarthritis, the benefits of this type of exercise have been demonstrated (15, 16). These benefits consisted in improvement in postural control, increase in ROM, reduction of the compensatory biomechanical alterations secondary to the primary joint injury, greater activity of the stabilising muscles, and histological changes compatible with a decrease in inflammation and fibrosis in the synovial membrane (15, 16).

Postural control depends to a great extent on the joint mechanoreceptors, which have been found to be altered in osteoarthritic joints. These mechanoreceptors act as proprioceptors and as modifiers of muscle activity. In human patients with hip and knee osteoarthritis, a reduction in balance and postural stability has been reported (28). Several factors lead to postural instability in these patients. There is an alteration in the joint afferent information, due to the involvement of the mechanoreceptors reducing the activation of the γ-neurons, modifying the sensitivity of muscle spindles, and leading to proprioceptive deficits. Furthermore, there is a reduction in strength and a delayed activation of the musculature that stabilises the joint. Joint pain, chronic inflammation, and structural damage act on the interneurons of the ventral horn of the spinal cord, inhibiting the activity of the muscles that support the affected joint and resulting in arthrogenic muscle inhibition (32).

In a study of horses with induced midcarpal joint osteoarthritis, exercised on a WT for eight weeks beginning 15 days after injury, and with the water depth at the level of the chest (a theoretical 60% reduction of body weight), King *et al.* (15) found increased postural stability under different conditions (standing with narrow base, eyes blindfolded). In contrast, in these horses subjected to the same exercise on a land treadmill, the improvement of postural stability was only observed in a normal square position (15). Postural stability improvement was defined as a decrease in the variation of the centre or pressure in craniocaudal and mediolateral axes. In the same study, an increase in the passive ROM of the affected joint was detected from the first week of exercise on the WT, and at the end of the research the ROM of the affected joint had fully recovered. Exercise on a WT has been shown to result in a significant increase in ROM over WT exercise without water in all the distal joints, affecting mainly the flexion and to a lesser extent, the extension. The most evident increase in the ROM of the metacarpophalangeal and metatarsophalangeal joints happened with the water at the level of these joints or at the hock. The larger ROM of the carpus was achieved with the water at the level of the hock and the larger ROM in the hock with the water at the level of the stifle (21). The combined results of all these studies (15, 16, 21) provided scientific evidence to inform the selection of the water depth with the purpose of improving ROM in a particular joint.

In lame horses, there is a redistribution of the load supported by the affected limb towards the other limbs. In forelimb injuries, the distribution happens towards the contralateral forelimb if the lameness has low to moderate severity and towards the three remaining limbs if it has greater severity (37). The reduced load on the affected limb and the consequent decrease in the peak vGRF lead to a reduction of the duration of the stance phase. In an attempt to maintain propulsion, the relative duration of the stance phase in relation to the total duration of the stride increases (37). In horses with forelimb osteoarthritis, it has been described that the distribution of the load and the peak vGRF were more symmetrical between affected and unaffected forelimbs after WT exercise compared to exercise on a land treadmill (16). This is a very interesting result because compensatory maladaptive changes often persist for a long time after lameness resolution. Therefore, the WT appears to have higher potential for re-education of the locomotor patterns after lameness compared to land treadmill or hand-walking exercise.

Exercise on a WT caused the flexor muscles of the affected joint to recover their functional symmetry with the sound forelimb in both timing and intensity of the electromyographic activation, reflecting an overall improvement in their functionality, which was not observed when animals were exercised on a land treadmill (16).

Up to now, the research carried out on horses with osteoarthritis has seemed to emphasise that exercise on a WT is a useful strategy to improve the functionality of the musculature of the affected limb, resulting in joint stabilisation and increased ROM. These results are very promising in sport horses because they can limit the need for administration of both systemic anti-inflammatory drugs and intra-articular drugs in the long-term management of chronic osteoarthritis.

Monitoring the progression of a rehabilitation programme

It is highly recommended to monitor the progression of each patient undergoing rehabilitation as accurately as possible. Habitual techniques used by clinicians and researchers in field and hospital settings include ultrasonography and other methods to study symmetry (accelerometry, inertial sensors, force, and pressure platforms). Other field techniques are goniometry to measure joint angles, Gulick tape to record the size of the injured area and algometry to establish the nociceptive mechanical threshold. These last techniques have enough repeatability when performed by the same clinician to monitor the evolution of patients through the rehabilitation plan (2, 29).

In summary, the use of exercise on a WT with comprehensive control of the velocity and the depth of water should be taken into consideration in the design of a rehabilitation plan for a sport horse. It is mainly apt for subacute and chronic tendon and ligament injuries, and in chronic osteoarthritis. Furthermore, exercise in water appears to be of greater benefit than land exercise in chronic osteoarthritis. Because of these findings, the interactions derived from exercise on a WT and other types of therapy (manual therapies, electrophysical methods, other types of therapeutic exercise, and orthobiological techniques) deserve future investigation.

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