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Original Article

Shock attenuation, spatio-temporal and physiological parameter comparisons between land treadmill and water treadmill running

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Abstract

Purpose: The purpose of this study was to compare shock attenuation, spatio-temporal and physiological parameters during water immersed (depth: anterior superior iliac spine) treadmill running (ATM) and land based treadmill running (LTM), matched for speed.
Methods: Six participants completed 15 min running under two conditions (LTM and ATM) in a randomised and balanced order, matched for speed. Synchronised tri-axial accelerometers placed at the distal tibia, lumbar region, and forehead were used to identify running dynamics and measure acceleration on impact and its attenuation. Expired respiratory gases and heart rate were sampled on a breath-by-breath basis for physiological variable collection throughout each trial.
Results: Participants experienced reduced accelerations on impact at the distal tibia ($p < 0.0001$) but not the lower back or forehead ($p = 0.1363$) during ATM compared to LTM. Consequently, large reductions ($p = 0.0001$) in shock attenuation occurred during the ATM compared to LTM. Stride frequency was greater ($p < 0.0001$) and stride length shorter ($p < 0.0001$) as a result of reduced swing time ($p < 0.0001$) for LTM, whilst ATM running increased ($p < 0.0001$) physiological demand for both heart rate and O_2 compared to LTM.
Conclusion: These findings show ATM reduces impact stress on the passive structures of the lower limbs whilst increasing physiological demand when running at matched speeds.

Keywords: Gait; Immersion; Impact; Training

1. Introduction

Land based, body supported exercise such as running is associated with repetitive strain and stress injuries to the lower extremities.[1,2] It is hypothesised that these injuries are due, at least in part, to the shockwave of energy transmitted throughout the body on impact with the ground.[2] At impact, vertical ground reaction forces of two to five times greater than body weight with rate of force development of 113 BW/s are observed.[3] Accompanying the large ground reaction forces, a shockwave of energy is transmitted through the body which must be attenuated to enable proper function of the vestibular and visual systems.[4] Typically, shock attenuation from the distal tibia to the head is reported as ~60% during running with increases of ~20% per m/s speed increment.[5] Whilst anatomical structures provide the greatest potential to attenuate shock via active eccentric muscle action, passive mechanisms such as the elasticity of bone, cartilage, synovial fluid, and soft tissue[6] have an increasing role as muscle fatigue develops.[7] Additionally, footwear choices,[8] surface characteristics such as running over uneven ground[9] or downhill,[10] and technique (incorporating proprioception, joint position and muscle tone) can be manipulated to alter individual shock attenuation profiles. However, the repetitive nature and load of such impacts, particularly during the support phase, means endurance runners are always going to be susceptible to injury of the lower extremities.[4]

Unloading forces, expressed in the scientific literature as effects on total accelerations experienced at the lower limb,[6] through the hydrostatic pressure of water immersion (Archimedes principle) have been seized upon by the sport and health industry. The reduced impact produced by hydrostatic unloading provides positive adherence to exercise programmes because it can lessen the pain or discomfort experienced[4] during running and subsequently reduce injury risk. Equally important is the finding that similar cardiovascular fitness gains

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can be obtained from aquatic exercise compared to land based activity providing physiological intensity is matched.[11]

Previously, deep water running has only been used as a means of cross-training or as a rehabilitation process.[12] However more recently, the benefits of water treadmill exercise, supplementary to normal land based training, have become apparent,[4,11] particularly, the emphasis on decreased mechanical load on the lower limbs and the diminished risk of injury. However, there are no published data quantifying the level of shock attenuation aquatic treadmill (ATM) running provides when compared to normal land based treadmill (LTM) running; or whether such training affects normal land based running spatio-temporal parameters. Understanding such an influence would provide useful information to trainers so that they might confidently prescribe supplementary ATM training without incurring additional injury risks.

Therefore, the purpose of this study was to compare shock attenuation, spatio-temporal and physiological parameters during ATM and LTM at a matched speed. We hypothesised that the hydrostatic pressure and resistance to movement during ATM would diminish the required shock attenuation between the tibia and head. This would appear as decreased acceleration magnitude and rate of acceleration development at the anterolateral aspect of the lower leg but not the forehead. Additionally, we hypothesised that stride length (swing time) would increase due to increased buoyancy effect but greater resistance at toe-off due to increased hydrostatic resistance would result in greater ground contact time.

2. Methods

2.1. Subjects

Six nationally competitive middle and long distance runners (mean ± SD; age: 29.8 ± 13.0 years, height: 169.3 ± 7.0 cm, LTM body weight: 54.6 ± 5.5 kg, BMI: 18.84 ± 0.73 kg/m^2, ATM body weight: 23.2 ± 4.9 kg), free from injury, experienced at both LTM and ATM participated in this study. All participants provided written consent in accordance with the University Human Ethics Committee approval. The research was approved by the Institutional Review Board of Massey University Human Ethics Committee: Southern A (Application 14/93).

2.2. Procedures and measurements

The experimental protocol consisted of two conditions, each performed within one session on the same day in a counter balanced order to prevent any sequence effect on the dependent variables of interest. Both conditions involved running for 15 min on an LTM (TechnoGym, Cesena, Italy) and ATM (O'Leary Engineering, Palmerston North, New Zealand). Each treadmill was calibrated to the same speed (Eq. 1) by using a magnetic switch that was triggered with each belt revolution. The depth of the LTM was set to anterior superior iliac spine level. This offered the least disturbance to arm swing whilst running and has previously been shown to balance the effects of increased resistance with increased buoyancy in terms of work done comparable to LTM.[13] Water temperature was 21°C in order to alleviate effects of thermal stress.[14]

$$\text{Treadmill speed (km/h)} = ((\text{Treadmill belt length (m)} \times \text{revs / min)}) \times 60) / 1000 \quad (1)$$

On arrival at the laboratory, participants were measured in order to determine the water depth for ATM (height from floor to anterior superior iliac spine (cm)) and weighed using hanging scales (PCE Instruments, Southampton, UK). For the water immersed body weight participants were suspended from the scales and immersed to the anterior superior iliac spine.

Following this, participants were fitted with the wireless, tri-axial accelerometers (Emerald, APDM, Portland, OR, USA). These were used to measure accelerations (reported accuracy 0.0012 m/s^2/√Hz)[15] of the distal anterolateral aspect of the right tibia, lower back (lumbar) and frontal bone of the head (forehead) at 128 Hz (Fig. 1). Specific sites were selected to minimise soft tissue oscillations during impact[6] and not interfere with gait patterns during ATM running. The accelerometers were packed tightly into a waterproof sport armband housing (h$_2$o audio, San Diego, CA, USA) and secured tightly. Additionally, participants were connected to a calibrated[16] automated portable gas analyser (K42b; Cosmed, Rome, Italy) that sampled expired air on a breath-by-breath basis, and were also fitted with a heart rate monitor strap (Polar Electro, Kempele, Finland).

All participants completed both tests in shod conditions wearing their normal running shoes. Where the ATM condition was performed first, participants used an identical (dry) model of running shoe for the LTM trial. Prior to each data collection period a familiarisation period at speeds below 2.78 m/s for 5 min was performed. Following this and immediately preceding the main trial participants ran at 2.83 m/s for 2 min. This

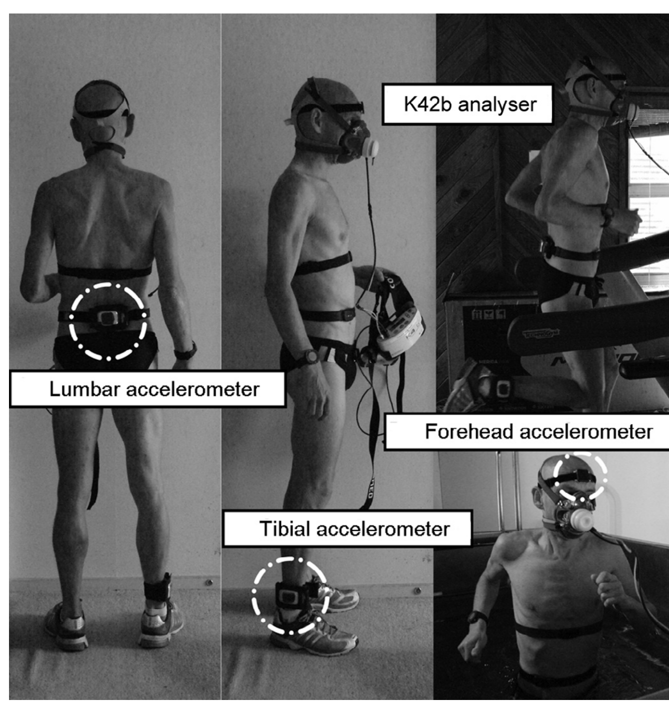

Fig. 1. Photographs depicting accelerometer locations and equipment used during the experimental protocol.

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