

Kinematics and neuromuscular recruitment during vertical treadmill exercise

JORDAN, Alastair, BARNES, Andrew <<http://orcid.org/0000-0001-8262-5132>>, CLAXTON, David, PURVIS, Alison <<http://orcid.org/0000-0002-3581-4990>> and FYSH, Mary

Available from Sheffield Hallam University Research Archive (SHURA) at:

<https://shura.shu.ac.uk/16211/>

This document is the Published Version [VoR]

Citation:

JORDAN, Alastair, BARNES, Andrew, CLAXTON, David, PURVIS, Alison and FYSH, Mary (2017). Kinematics and neuromuscular recruitment during vertical treadmill exercise. *Journal of Exercise Rehabilitation*, 13 (3), 307-314. [Article]

Copyright and re-use policy

See <http://shura.shu.ac.uk/information.html>

Kinematics and neuromuscular recruitment during vertical treadmill exercise

Alastair R. Jordan^{1,*}, Andrew Barnes², David Claxton², Alison Purvis², Mary Fysh²

¹School of Sport, York St. John's University, Lord Mayor's Walk, York, UK

²Academy of Sport and Physical Activity, Sheffield Hallam University, Sheffield, UK

The vertical treadmill (VertiRun) is an unresearched, partial weight-bearing exercise mode for lower limb rehabilitation. The user undertakes a "running-like" action whilst body weight is supported by a bench and the limb is drawn downwards against overhanging resistance cables on a vertically hung nonmotorised treadmill. This study sought to describe the kinematics and neuromuscular recruitment during VertiRun exercise in the supine, 40°, and 70° postures. Twenty-one healthy male participants (age, 25 ± 7 years; stature, 1.79 ± 0.07 m; body mass, 77.7 ± 8.8 kg) volunteered for sagittal plane kinematic analysis of the ankle, knee and hip and electromyography of lower limb musculature in all three postures. Results indicated similar kinematic and neuromuscular profiles in the 40° and 70° postures which differed from the supine. Regardless of posture, a basic movement pattern was observed where the hamstrings and gastrocnemius muscles were active to extend the hip, flex the knee,

plantarflex the ankle and draw the leg down the treadmill belt in the contact phase. The rectus femoris and tibialis anterior were active to flex the hip and knee, and dorsiflex the ankle to draw the leg upwards during the swing phase. The vasti muscles were not active during VertiRun exercise. The VertiRun demonstrated similar kinematic and neuromuscular patterns to overground gait, allows workload progression based on effort and posture changes, and is a low-impact exercise mode that could maintain physical fitness without loading injured tissues. This study suggests that the VertiRun could supplement rehabilitation programmes for lower-limb injuries.


Keywords: Rehabilitation, Electromyography, Low-impact exercise, VertiRun, Vertical treadmill, Biomechanics

INTRODUCTION

Partial weight-bearing exercise modes such as cycling, anti-gravity treadmills, recumbent stepping, and hydrotherapy have been implemented in the early stages of rehabilitation programmes in athletes with a range of lower extremity injuries (Kern-Steiner et al., 1999; Kim et al., 2010; Reiser et al., 2004). Partial weight-bearing exercise modes reduce the gravitational mechanical load on injured tissues (Billinger et al., 2008; Hass et al., 2001) and allow progressive loading of the injured limbs to facilitate healing and the transition to full weight-bearing exercise (Grabowski, 2010; Kern-Steiner et al., 1999). Limitations with current partial weight-bearing exercise modes include cost, inability of injured athletes to perform the cyclic motions, or pedal against a constant resistance, and offer a limited range of motion

in which movement patterns are restricted by pedals (Billinger et al., 2008; Stoloff et al., 2007; Trumbower and Faghri, 2005). For example, cycling and recumbent stepping demonstrate a limited range of motion at the hip and a lack of hip extension which are essential for maintaining muscle function, joint mobility and return to full weight-bearing ambulation (Huang and Ferris, 2004; Stoloff et al., 2007).

The vertical treadmill (VertiRun, Sheffield, UK) is a novel partial weight-bearing exercise mode in which the user engages in an unrestricted "running like" exercise. The VertiRun consists of a vertically hung nonmotorised treadmill, an adjustable bench mechanism and overhanging resistance cables (Fig. 1). The body posture and position of the user with respect to the treadmill belt can be manipulated by adjusting the back rest and the fore and aft setting of the bench mechanism. The overhanging cables are teth-

*Corresponding author: Alastair R. Jordan  <http://orcid.org/0000-0002-7669-4753>
School of Sport, York St. John's University, Lord Mayor's Walk, York, YO31 7EX, United Kingdom
Tel: +44-19-0487-6125, Fax: +44-19-0487-6500, E-mail: a.jordan1@yorksj.ac.uk
Received: January 30, 2017 / Accepted: June 11, 2017

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.



Fig. 1. The VertiRun (Sheffield, UK) being used in the supine posture.

ered to the ankle and offer resistance to the musculature of the posterior chain (20 N on the uptake of tension up to 70 N as the leg descends to the lowest point of the treadmill). Therefore, the magnitude of the resistance is dependent on the leg length and the lower limb range of motion of the user.

The VertiRun could be an effective rehabilitation tool as it demonstrates some important characteristics that are essential for a return to full weight-bearing exercise. Firstly, it is a low-impact exercise mode in which body weight is supported, therefore athletes with lower limb injuries can exercise to maintain cardiovascular fitness without excessive mechanical loading and subsequent exacerbation of injuries. Pilot data from our laboratory suggests that the VertiRun reduces the loading on the lower limbs compared to conventional horizontal treadmill gait (46% reduction in tibial shock) whilst exercising at the same rate of perceived exertion (categorised as 'hard' exercise [Borg, 1998]). The VertiRun also offers a variable resistance, open kinetic chain exercise in which the athlete is able to exercise within a range of motion and at an intensity that their particular injury will allow. The VertiRun engages users in rhythmic motions and might activate common neuromuscular pathways to overground gait which have been identified as essential components of rehabilitation apparatus for a return to full weight-bearing exercise (Hass et al., 2001; Stoloff et al., 2007). Furthermore, the VertiRun has an adjustable back rest that permits alterations to the posture of the user (ranging from supine [0°] to 70° in 10° increments). Posture-related changes in the neuromuscular recruitment and the kinematic profiles have been reported in other forms of partial weight-bearing exercise due to differences in the relative geometry of body segments (Egaña et al., 2010; Reiser et al., 2004; Tachi et al., 2004).

Egaña et al. (2010) reported greater neuromuscular activation in the rectus femoris, vastus lateralis, biceps femoris and gluteus maximus during high intensity cycling in the supine posture compared with upright cycling. Furthermore, Tachi et al. (2004) observed greater neuromuscular activity of the tibialis anterior when the leg was above the level of the heart when compared with below. Therefore, it is hypothesised that by altering the posture of the VertiRun user, rehabilitation professionals could target or preclude specific musculature and kinematic patterns depending on the individuals' stage of rehabilitation. To date, there is a lack of research on the VertiRun with respect to the kinematics, neuromuscular recruitment and efficacy of VertiRun for rehabilitation to substantiate these potential benefits, therefore professionals lack the knowledge to recommend appropriate rehabilitation programmes using the VertiRun. Prior to substantiating the efficacy of VertiRun for rehabilitation of lower-limb injuries, it is prudent to firstly identify the kinematics and neuromuscular recruitment patterns of VertiRun exercise in different postures. Therefore, the aim of this study was to determine the kinematics and neuromuscular recruitment patterns during moderate intensity VertiRun exercise in three different postures.

MATERIALS AND METHODS

Participants

After institutional ethics approval, 21 male participants (age, 25 ± 7 years; stature, 1.79 ± 0.07 m; body mass, 77.7 ± 8.8 kg) were recruited for the study. All participants were healthy, physically active and injury-free at the time of testing.

Procedure

All participants were habituated to VertiRun exercise in different configurations and intensities of exercise over two 30-min sessions on separate days. VertiRun exercise was completed with the treadmill oriented vertically and the back rest angle at 0°, 40°, and 70°. In accordance with the manufacturer instructions, the fore and aft bench settings were adjusted for each participant to ensure the knee was flexed by 20° when the foot was flat against the treadmill belt and aligned vertically with the greater trochanter.

After a 5-min warm-up on the VertiRun, retro-reflective markers were placed on the right leg of each participant to define a four segment kinematic model (pelvis, thigh, shank, foot). Markers were placed at the posterior superior iliac spine, greater trochanter, femoral epicondyle and lateral malleolus. At the foot, markers were placed on the participant's own sports footwear overlying the

posterior aspect of the calcaneus and the distal head of the 5th metatarsal. Electromyographic (EMG) active surface electrodes (Delsys Inc., Natick, MA, USA) were adhered to the skin of the right leg in accordance with SENIAM guidelines on electrode preparation and positioning (Hermens et al., 2000) overlying the vastus lateralis, vastus medialis, rectus femoris, biceps femoris, semitendinosus, tibialis anterior, medial gastrocnemius, and lateral gastrocnemius. Participants exercised on the VertiRun at an intensity that was perceived to replicate their overground jogging velocity (described to participants as the pace when going for a casual jog for one hour) for 5 min. The treadmill speed was recorded (PowerLab 8.0M, ADInstruments Ltd., Oxford, UK) and rate of perceived exertion (Borg, 1998) taken after each bout of exercise. Kinematic marker data were recorded for 1 min once a consistent speed was achieved (mean \pm 0.5 km/hr) using an eight-camera optical motion analysis system sampling at 200 Hz (Motion Analysis Corp., Santa Rosa, CA, USA). EMG data were synchronised with the kinematic data using an eight-channel system (Delsys Bagnoli 8-channel EMG system, Delsys Inc., Natick, MA, USA) sampling at 1,000 Hz with signal preamplification (\times 1,000) at the electrodes.

Data analysis

Raw coordinate data were filtered using a zero-lag fourth order low-pass Butterworth filter (8-Hz cutoff). Foot contacts on the VertiRun treadmill were established when the horizontal acceleration of the calcaneus or 5th metatarsal marker (whichever occurred first) was zero. Toe-off was identified by the minimum horizontal velocity of the 5th metatarsal marker during the contact phase (Fellin et al., 2010). Two-dimensional sagittal plane angles of the hip, knee and ankle were computed, cropped and normalised to 100% gait cycle (0% indicates initial foot contact and 100% indicates the next contact of the same foot). Kinematic variables of interest were peak angles and range of motion at the hip, knee and ankle during the gait cycle. Temporal variables of interest were

treadmill belt speed, cadence, stride length, stride time, and contact time (relative to gait cycle [%]). Stride length was calculated by dividing treadmill belt speed by cadence. Raw EMG data were subjected to a low-pass (500 Hz) and a high-pass filter (10 Hz), and root-mean-squared (Clancy et al., 2002). All EMG data were cropped and normalised to 100% of the gait cycle. The timing of muscle activation and deactivation was established when the EMG signal rose two standard deviations above and below the mean resting signal, respectively. Dependent variables of interest were subject to a within subjects repeated measures analysis of variance with Bonferroni pairwise comparisons. Effect sizes were calculated and regarded as large (0.5), medium (0.3) or small (0.1) in accordance with Cohen *d* classifications (Cohen, 1992).

RESULTS

Temporal spatial parameters

Temporal spatial parameters are presented in Table 1. There was a significant main effect for speed between postures where participants moved the treadmill belt faster in the 40° ($P=0.009$, $d=0.63$) and 70° ($P<0.001$, $d=0.71$) compared to the supine posture. Stride length differed between postures, however a significant increase in stride length was only observed between supine and 70° posture ($P=0.005$, $d=0.49$). Cadence differed between postures with a lower cadence observed in the supine posture when compared with 40° ($P=0.003$, $d=0.63$) and 70° ($P=0.004$, $d=0.62$). Similarly, gait cycle time differed between postures with a greater contact time in the supine posture than the 40° ($P=0.012$, $d=0.59$) and 70° ($P=0.012$, $d=0.59$) postures. No differences were observed between 40° and 70° in any temporal spatial parameters.

Kinematics

Kinematic profiles of the ankle, knee and hip are presented in Fig. 2. At the ankle, peak dorsiflexion observed during the con-

Table 1. Statistics of temporal spatial parameters during VertiRun exercise in the supine, 40°, and 70° postures

Variable	0°	40°	70°	<i>F</i>	<i>P</i> -value
Speed (m/sec)	1.50 \pm 0.30 ^{*,†}	1.70 \pm 0.33	1.73 \pm 0.33	12.92	<0.001
Stride length (m)	1.46 \pm 0.19 [†]	1.52 \pm 0.23	1.56 \pm 0.24	4.30	0.012
Cadence (step/min)	123.36 \pm 15.73 ^{*,†}	134.32 \pm 18.75	132.79 \pm 14.82	10.12	<0.001
Cycle time (sec)	0.99 \pm 0.12 ^{*,†}	0.91 \pm 0.14	0.92 \pm 0.12	8.40	0.001
Contact phase (% gait cycle)	39.8 \pm 5.3	37.7 \pm 5.8	38.6 \pm 6.2	3.94	0.208

Values are presented as mean \pm standard deviation.

F and *P*-values represent main effect for posture.

*Difference between supine and 40°. †Difference between supine and 70°.

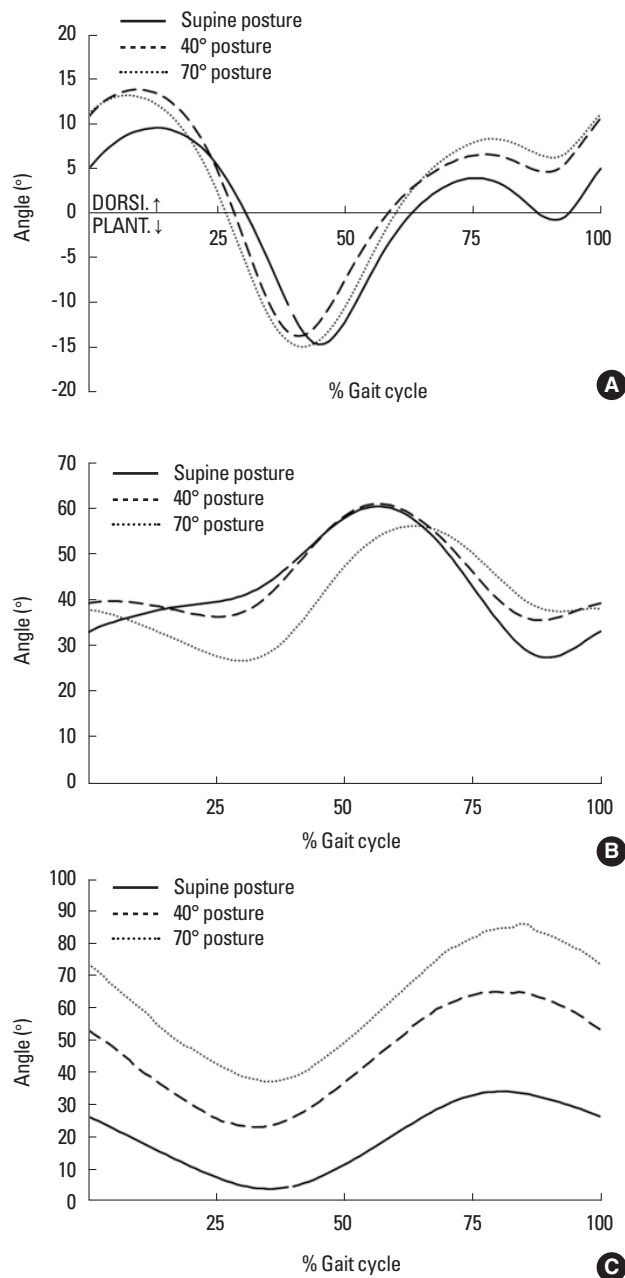


Fig. 2. Mean sagittal ankle (A), knee (B), and hip angles (C) during VertiRun (Sheffield, UK) exercise.

tact phase showed significant differences across postures ($F[2, 19] = 9.96, P < 0.001$) with less dorsiflexion in the supine than 40° ($P = 0.003, d = 0.58$) and 70° ($P = 0.014, d = 0.41$), however no differences in peak plantarflexion were observed in early swing phase ($F[2, 19] = 2.49, P = 0.096$). Ankle range of motion differed between postures ($F[2, 19] = 14.31, P < 0.001$) and was reduced in the supine posture compared to the 40° ($P = 0.008, d = 0.69$) and

70° ($P < 0.001, d = 0.89$) postures. At the knee, peak flexion observed during swing phase differed between postures ($F[2, 19] = 13.22, P < 0.001$) with a greater peak flexion in the supine and 40° ($P = 0.033, d = 0.12$) posture when compared with the 70° posture ($P = 0.001, d = 0.43$). There was no difference in the minimum flexion at the knee or range of motion between postures ($F[1.003, 19] = 1.19, P = 0.316$ and $F[2, 19] = 1.34, P = 0.274$, respectively). There was a significant difference in peak hip flexion observed in the contact phase ($F[2, 19] = 517.63, P < 0.001$), peak hip extension in swing phase ($F[2, 19] = 145.89, P < 0.001$) and range of motion ($F[2, 19] = 27.22, P < 0.001$). Peak hip flexion, extension and range of motion differed between all postures ($P < 0.001$), all with large effect sizes ($d = 0.95-2.49$).

Neuromuscular recruitment

Fig. 3. demonstrates the neuromuscular recruitment patterns during VertiRun exercise in the supine, 40° and 70° postures.

The rectus femoris activation during contact differed between postures ($F[2, 19] = 8.87, P = 0.001$) where activation occurred later in the supine when compared with the 40° ($P = 0.003, d = 0.88$) and 70° postures ($P = 0.007, d = 0.70$). Deactivation of biceps femoris late in the contact phase differed between postures ($F[2, 19] = 17.64, P < 0.001$) with a later deactivation in the supine posture compared with the 40° ($P < 0.001, d = 1.02$) and 70° postures ($P < 0.001, d = 1.14$). Semitendinosus activation during late swing phase differed between postures ($F[2, 19] = 7.69, P = 0.001$) with a later activation in the supine posture than 40° ($P = 0.019, d = 0.73$) and 70° ($P = 0.004, d = 0.87$) postures. Furthermore, deactivation of the semitendinosus in the contact phase differed between postures ($F[2, 19] = 27.39, P < 0.001$) and deactivated earlier in the supine posture than the 40° ($P < 0.001, d = 1.20$) and 70° posture ($P < 0.001, d = 1.38$). There were no differences between postures in the activity of the lateral or medial gastrocnemius. The tibialis anterior was active, throughout the whole gait cycle whereas the vastus lateralis and vastus medialis were inactive.

DISCUSSION

The aim of this study was to identify the kinematics and neuromuscular recruitment during moderate intensity VertiRun exercise in three different postures. Key findings of this study indicated that temporal, kinematic and neuromuscular recruitment differed in the supine posture when compared with 40° and 70° postures, most with large effect sizes. The 40° and 70° inclined pos-

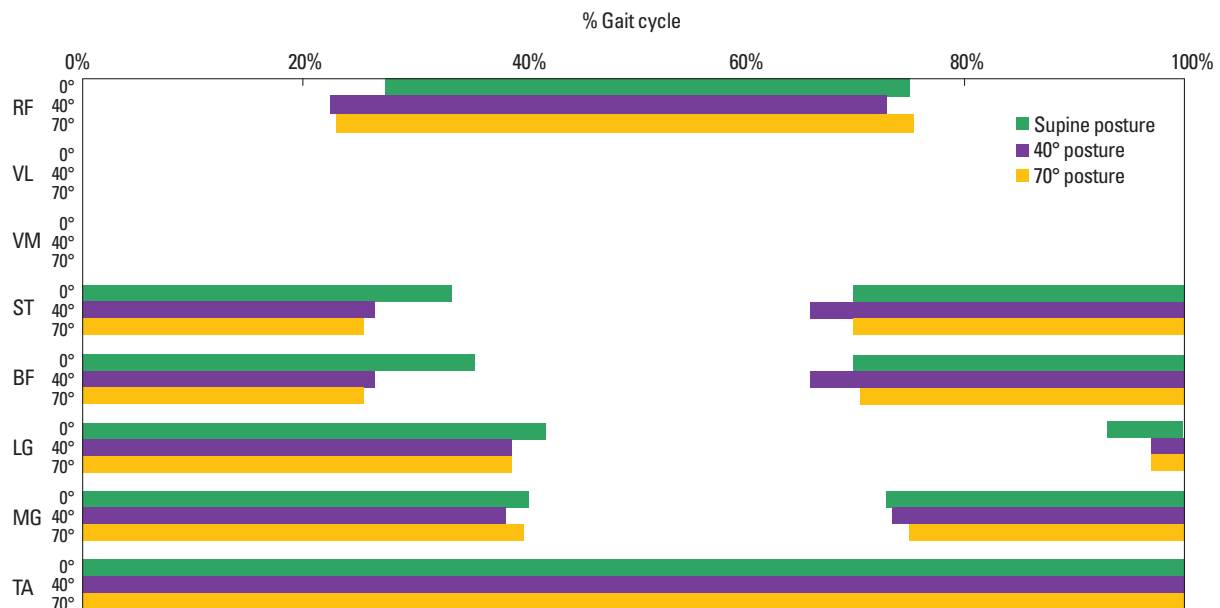


Fig. 3. Mean recruitment of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), biceps femoris (BF), lateral gastrocnemius (LG), medial gastrocnemius (MG), and tibialis anterior (TA) during incremental VertiRun (Sheffield, UK) exercise. Zero percent (0%) indicates initial foot contact.

tures saw largely similar patterns, generally, with smaller effect sizes. Despite these differences in posture, a general kinematic and neuromuscular pattern was evident that describes VertiRun exercise. The musculature of the posterior chain (biceps femoris, semitendinosus, medial and lateral gastrocnemius) were active during the contact phase to extend the hip, flex the knee and plantarflex the ankle to draw the leg down the treadmill belt in opposition to the resistance cables. During the swing phase, the rectus femoris was responsible for drawing the leg upwards against gravity to return the leg to the top of the treadmill belt. Consequently, the hip flexed, the knee extended and the ankle dorsiflexed in the swing phase. The tibialis anterior was constantly active and conversely, the vasti were not active at all during VertiRun exercise. The kinematic and neuromuscular patterns displayed during VertiRun exercise show promise as mode of rehabilitation.

A key characteristic of rehabilitation apparatus is to mimic the joint actions and activate similar neuromuscular pathways as those seen in overground gait (Hass et al., 2001; Stoloff et al., 2007). The neuromuscular and kinematic patterns observed during VertiRun exercise share some similarities with over ground gait which include; a cocontraction of the tibialis anterior and gastrocnemius muscles in the early stages of the contact phase, which can be attributed to the stabilisation of the ankle joint during the absorption of body weight during overground gait (Novacheck, 1998); medial and lateral gastrocnemius activity, coupled with

hamstring activity resulting in a reduction in hip flexion and ankle plantarflexion in the latter stages of contact phase which are characteristic of propelling the lower limb into the swing phase during overground gait (Novacheck, 1998; Nymark et al., 2005); rectus femoris activity in the swing phase that flexes the hip, passively flexes the knee as the lower leg lags behind the thigh and hamstring-controlled rapid knee extension in the latter stages of the swing phase which is characteristic of adequate foot clearance and quick limb advancement during the swing phase of overground gait (Chumanov et al., 2011; Mann et al., 1986; Novacheck, 1998; Nymark et al., 2005). This similarity in neuromuscular recruitment and joint actions between VertiRun and overground gait suggest that the VertiRun might be useful in preparing athletes for a return to overground ambulation without excessive loading of injured lower limb tissues.

The VertiRun speed in the supine posture was 13%–15% slower than the inclined postures, despite the perceived effort being the same across all postures. Therefore, supine posture could be considered a more strenuous exercise than the inclined postures and offer a method of workload progression during rehabilitation. VertiRun speed in the inclined postures was faster as a result of increases in both stride length and cadence which was also reflected in a reduced gait cycle time. A shorter contact time in the inclined postures suggests that the participants were able to accelerate the treadmill belt more effectively in the inclined postures and further

supports the use of VertiRun for workload progression, a key characteristic of rehabilitation programmes (Dahan, 1997).

When comparing postures, the ankle was less dorsiflexed in the supine posture ($4.9^\circ \pm 6.58^\circ$) than the inclined postures at initial contact, however, a large standard deviation suggested that a range of different strike patterns were used by participants, including a plantarflexed ankle in some participants. Similarly, ankle angle at the initial contact differed between individuals and is associated with their preference for either a rear, mid or forefoot strike pattern in overground running (Altman and Davis, 2012). Therefore the VertiRun allows users to strike the VertiRun how they wish or within pain tolerance of an injury. In the treatment of ankle sprains and instability, early mobilisation of the ankle through partial weight-bearing exercise with a focus on dorsiflexion range of motion is beneficial to improve return to sport and prevent ankle sprain reoccurrence (Kern-Steiner et al., 1999; van der Wees et al., 2006). During VertiRun exercise, the ankle moves through a sizeable range of motion especially in the inclined postures, without weight-bearing and could be beneficial for the treatment of ankle sprains. The general motion of the hip was similar between postures, only the absolute degree of hip angle differed. Large differences in absolute hip angles were a result of the hip angle being measured as the relative angle between the thigh and pelvis and in the inclined postures the pelvis was tilted toward the thigh when compared with the supine. A limited hip extension and hip range of motion are undesirable attributes for rehabilitation of the hip, pelvis, and groin injuries because this action is significant in overground gait (Chumanov et al., 2011; Dahan, 1997; Mann and Hagy 1980; Novacheck, 1998). In the inclined postures, hip extension might have been limited by the geometry of the seat and back rest, where hip extension would require the participant to lift the pelvis out of the seat. A large standard deviation in the minimum hip flexion in the supine posture ($0.7^\circ \pm 8.3^\circ$) suggests that some participants achieved hip extension but this might have been dependent on an individual's current hip flexibility, extensor strength or posture related engagement of the stretch-shortening cycle in hip extensor muscles. Gregor et al. (2002) hypothesised that when the hip is in a more extended position, as observed in the VertiRun supine posture, the pre-stretch of the hamstrings and gluteals is reduced. To compensate for the reduced stretch-shortening, an increased muscular force is required to extend the hip against the overhanging resistance cables. This posture-related mechanical inefficiency might be a contributing factor to the slower speeds in the supine posture and emphasises the use of VertiRun as a rehabilitation tool with

workload progression capabilities.

Inactivity of the vasti could be advantageous for injuries to this specific muscle group, however inactivity of a large proportion of the quadriceps could be considered disadvantageous due to their major role in overground gait and highlights a key difference in neuromuscular activity when compared with overground gait (Hass et al., 2001; Stoloff et al., 2007). The vasti are key musculature in the occurrence of knee injuries such as patellofemoral pain syndrome, which is a common injury for sports where running is prominent (Fredericson and Yoon, 2006; van der Heijden et al., 2015). Rehabilitation of patellofemoral pain focuses on the strength of vasti activity (Heintjes et al., 2003; LaBella, 2004) and are efficacious with exercises involving both the knee and hip, rather than the knee alone (van der Heijden et al., 2015). The VertiRun does offer a partial weight-bearing, multijoint exercise where the patellofemoral stress is likely reduced, therefore injured athletes can maintain physical fitness, strengthen other musculature in the injured and contralateral limb (Heintjes et al., 2003; van der Heijden et al., 2015).

The VertiRun might be a useful in the rehabilitation of anterior cruciate ligament (ACL) injuries. Reiser et al. (2004) reported a reduced anterior displacement of the tibia relative to the femur during recumbent cycling which might reduce the load on the ACL when compared with upright cycling. Similarly, the VertiRun is a recumbent exercise with distal support from the overhanging cables rather than pedals and cyclic actions at the ankle, knee and hip that are comparable with recumbent cycling in healthy participants (Johnston et al., 2007). Therefore, VertiRun might also reduce the load on the ACL as observed in recumbent cycling (Reiser et al., 2004) and could be useful in ACL rehabilitation. Our results showed that the VertiRun exercise also unloads the vasti quadriceps, predominantly loads the hamstrings, both of which are key characteristics of the early stages of Frobell's ACL rehabilitation programme (Frobell et al., 2010). Furthermore, a focus on the hamstring activation suggests the VertiRun could facilitate the rebalance of the quadriceps/hamstring strength ratio that is a key determinant for ACL injury and reoccurrence, and for sprint performance (Askling et al., 2003; Chumanov et al., 2011). Therefore, the VertiRun might be an effective acute rehabilitation tool to rehabilitate ACL injuries and prevent the loss of strength, increase stability and range of motion at the knee and reduce the pain associated with ACL rehabilitation (Frobell et al., 2010; Shelbourne and Nitz, 1990).

There are a few limitations with the current study. The gluteals might have contributed to extend the hip extension during late

contact phase, however the gluteals were not measured in this study because of high signal noise derived from movement artefact during VertiRun exercise and the body weight of the participants pressing on the EMG cables. Further research is required to establish the role of the gluteals during VertiRun exercise and identify any potential implications for rehabilitation. This was a unilateral assessment of the right leg only due to a limited space to position the optical motion analysis cameras and impracticality of moving the VertiRun. It is possible that different kinematic and neuromuscular profiles could have been the result of some participants being assessed using their dominant limb whereas other participants used their potentially weaker, nondominant limb (Arnason et al., 2004; Fousekis et al., 2010). This study investigated VertiRun exercise at moderate intensity only, therefore the kinematics and muscle recruitment patterns could be intensity-specific and differ between high and low intensity VertiRun exercise. Egaña et al. (2010) reported posture-related deviations in muscle recruitment during high intensity cycling, but no difference during low intensity cycling (20% vs. 80% peak power output). Musculo-tendinous tissue injuries, such as achilles tendonitis and hamstring injuries are treated with eccentric strength activities (Fahlström et al., 2003; Heiderscheit et al., 2010). It is unclear whether eccentric activity occurs during VertiRun exercise because the analysis did not include joint kinetic data from inverse dynamics of forceplate data or muscle modelling techniques. We assume that eccentric activity is unlikely during VertiRun exercise due to a lack of gravity-induced loading of the lower limbs, therefore its suitability to enhance eccentric strength and rehabilitate musculo-tendinous tissue is questionable.

In conclusion, VertiRun could be an effective future rehabilitation tool as it recruits many of the major muscle groups of the lower extremity, joints exhibit sizeable ranges of motion and many kinematic and neuromuscular recruitment characteristics were similar to overground gait. VertiRun exercise is partial weight-bearing allowing athletes to exercise within pain tolerance, bilaterally and unilaterally to minimise muscle atrophy, as well as maintaining neuromuscular control and physical fitness of athletes without excessive loading of injured soft tissues. The vasti were not recruited, which could be beneficial in the early stages of rehabilitation of certain knee injuries or this may be a limiting factor and might need to be combined with other modes such as cycling (Gregersen et al., 2006) and recumbent stepping (Huang and Ferris, 2004). Key differences between VertiRun postures include a prolonged hamstring activity and slower treadmill speed in the supine posture, indicating the VertiRun as a suitable tool

for hamstring strengthening, and workload progression by altering the posture setting. Given the novelty of the exercise mode and lack of evidence to support its use, future research is required to determine the efficacy of VertiRun for the rehabilitation of specific injuries. However, early indications suggest VertiRun exercise could be used to supplement a range of rehabilitation programmes for sports or activities where overground ambulation is the mode of locomotion.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

- Altman AR, Davis IS. A kinematic method for footstrike pattern detection in barefoot and shod runners. *Gait Posture* 2012;35:298-300.
- Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med* 2004;32(1 Suppl):5S-16S.
- Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports* 2003;13:244-250.
- Billinger SA, Loudon JK, Gajewski BJ. Validity of a total body recumbent stepper exercise test to assess cardiorespiratory fitness. *J Strength Cond Res* 2008;22:1556-1562.
- Borg G. Borg's perceived exertion and pain scales. Champaign (IL): Human Kinetics; 1998.
- Chumanov ES, Heiderscheit BC, Thelen DG. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Med Sci Sports Exerc* 2011;43:525-532.
- Clancy EA, Morin EL, Merletti R. Sampling, noise-reduction and amplitude estimation issues in surface electromyography. *J Electromyogr Kinesiol* 2002;12:1-16.
- Cohen J. A power primer. *Psychol Bull* 1992;112:155-159.
- Dahan RP. Rehabilitation of muscle-tendon injuries to the hip, pelvis, and groin areas. *Sports Med Arthrosc Rev* 1997;5:326-333.
- Egaña M, Ryan K, Warmington SA, Green S. Effect of body tilt angle on fatigue and EMG activities in lower limbs during cycling. *Eur J Appl Physiol* 2010;108:649-656.
- Fahlström M, Jonsson P, Lorentzon R, Alfredson H. Chronic Achilles tendon pain treated with eccentric calf-muscle training. *Knee Surg Sports Traumatol Arthrosc* 2003;11:327-333.
- Fellin RE, Rose WC, Royer TD, Davis IS. Comparison of methods for ki-

- nematic identification of footstrike and toe-off during overground and treadmill running. *J Sci Med Sport* 2010;13:646-650.
- Fousekis K, Tsepis E, Vagenas G. Lower limb strength in professional soccer players: profile, asymmetry, and training age. *J Sports Sci Med* 2010;9:364-373.
- Fredericson M, Yoon K. Physical examination and patellofemoral pain syndrome. *Am J Phys Med Rehabil* 2006;85:234-243.
- Frobell RB, Roos EM, Roos HP, Ranstam J, Lohmander LS. A randomized trial of treatment for acute anterior cruciate ligament tears. *N Engl J Med* 2010;363:331-342.
- Grabowski AM. Metabolic and biomechanical effects of velocity and weight support using a lower-body positive pressure device during walking. *Arch Phys Med Rehabil* 2010;91:951-957.
- Gregersen CS, Hull ML, Hakansson NA. How changing the inversion/eversion foot angle affects the nondriving intersegmental knee moments and the relative activation of the vastii muscles in cycling. *J Biomech Eng* 2006;128:391-398.
- Gregor SM, Perell KL, Rushatakankovit S, Miyamoto E, Muffoletto R, Gregor RJ. Lower extremity general muscle moment patterns in healthy individuals during recumbent cycling. *Clin Biomech (Bristol, Avon)* 2002;17:123-129.
- Hass CJ, Garzarella L, de Hoyos DV, Connaughton DP, Pollock ML. Concurrent improvements in cardiorespiratory and muscle fitness in response to total body recumbent stepping in humans. *Eur J Appl Physiol* 2001;85:157-163.
- Heiderscheit BC, Sherry MA, Silder A, Chumanov ES, Thelen DG. Hamstring strain injuries: recommendations for diagnosis, rehabilitation, and injury prevention. *J Orthop Sports Phys Ther* 2010;40:67-81.
- Heintjes E, Berger MY, Bierma-Zeinstra SM, Bernsen RM, Verhaar JA, Koes BW. Exercise therapy for patellofemoral pain syndrome. *Cochrane Database Syst Rev* 2003;(4):CD003472.
- Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 2000;10:361-374.
- Huang HJ, Ferris DP. Neural coupling between upper and lower limbs during recumbent stepping. *J Appl Physiol (1985)* 2004;97:1299-1308.
- Johnston TE, Barr AE, Lee SC. Biomechanics of submaximal recumbent cycling in adolescents with and without cerebral palsy. *Phys Ther* 2007;87:572-585.
- Kern-Steiner R, Washecheck HS, Kelsey DD. Strategy of exercise prescription using an unloading technique for functional rehabilitation of an athlete with an inversion ankle sprain. *J Orthop Sports Phys Ther* 1999;29:282-287.
- Kim E, Kim T, Kang H, Lee J, Childers MK. Aquatic versus land-based exercises as early functional rehabilitation for elite athletes with acute lower extremity ligament injury: a pilot study. *PM R* 2010;2:703-712.
- LaBella C. Patellofemoral pain syndrome: evaluation and treatment. *Prim Care* 2004;31:977-1003.
- Mann RA, Hagy J. Biomechanics of walking, running, and sprinting. *Am J Sports Med* 1980;8:345-350.
- Mann RA, Moran GT, Dougherty SE. Comparative electromyography of the lower extremity in jogging, running, and sprinting. *Am J Sports Med* 1986;14:501-510.
- Novacheck TF. The biomechanics of running. *Gait Posture* 1998;7:77-95.
- Nymark JR, Balmer SJ, Melis EH, Lemaire ED, Millar S. Electromyographic and kinematic nondisabled gait differences at extremely slow overground and treadmill walking speeds. *J Rehabil Res Dev* 2005;42:523-534.
- Reiser RF 2nd, Broker JP, Peterson ML. Knee loads in the standard and recumbent cycling positions. *Biomed Sci Instrum* 2004;40:36-42.
- Shelbourne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med* 1990;18:292-299.
- Stoloff RH, Zehr EP, Ferris DP. Recumbent stepping has similar but simpler neural control compared to walking. *Exp Brain Res* 2007;178:427-438.
- Tachi M, Kouzaki M, Kanehisa H, Fukunaga T. The influence of circulatory difference on muscle oxygenation and fatigue during intermittent static dorsiflexion. *Eur J Appl Physiol* 2004;91:682-688.
- Trumbower RD, Faghri PD. Kinematic analyses of semireclined leg cycling in able-bodied and spinal cord injured individuals. *Spinal Cord* 2005;43:543-549.
- van der Heijden RA, Lankhorst NE, van Linschoten R, Bierma-Zeinstra SM, van Middelkoop M. Exercise for treating patellofemoral pain syndrome. *Cochrane Database Syst Rev* 2015;1:CD010387.
- van der Wees PJ, Lenssen AF, Hendriks EJ, Stomp DJ, Dekker J, de Bie RA. Effectiveness of exercise therapy and manual mobilisation in ankle sprain and functional instability: a systematic review. *Aust J Physiother* 2006;52:27-37.