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Tibiocalcaneal kinematics during treadmill and overground running

by Jonathan Sinclair[1], Paul J Taylor[2]

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Epidemiological studies analyzing the prevalence of running injuries suggest that overuse injuries are a prominent complaint for both recreational and competitive runners. Excessive coronal and transverse plane motions of the ankle and tibia are linked to the development of a number of chronic injuries. This study examined differences in tibiocalcaneal kinematics between treadmill and overground running. Ten participants ran at 4.0 $m.s^{-1}$ in both treadmill and overground conditions. Tibiocalcaneal kinematics were measured using an eight-camera motion analysis system and compared using paired samples t-tests. Of the examined parameters; peak eversion, eversion velocity, tibial internal rotation and tibial internal rotation velocity were shown to be significantly greater in the treadmill condition. Therefore, it was determined treadmill runners may be at increased risk from chronic injury development.

Keywords: Biomechanics, treadmill, injury, running.

Epidemiological studies analyzing the prevalence of running injuries suggest that overuse injuries are a prominent complaint for both recreational and competitive runners [1]. Each year approximately 19.4-79.3 % of runners will experience a pathology related to running [2].

The treadmill is now recognized as a common mode of exercise, and is becoming more popular as a running modality [3]. Since the early 1980's the sport of running has changed dramatically, with a significant increase in the number of treadmill runners [4]. Runners' World suggests that 40 million people in the U.S alone run using treadmills. Traditionally, treadmills have been used in clinical and laboratory research, but are now used extensively in both fitness suites and homes.

Address correspondence to: [2]School of Psychology
University of Central Lancashire,Preston, Lancashire, PR1 2HE.
E-mail: PJTaylor@uclan.ac.uk

1 Centre for Applied Sport and Exercise Sciences, University of Central, Lancashire.

Treadmills allow ambulation at a range of velocities whilst indoors in a safe controlled environment. It is not currently known, however, whether the incidence of injuries may be affected differently between treadmill and overground running.

Lower extremity kinematic motions of excessive eversion and tibial internal rotation have been connected with various running injuries [5,6,7]. Additionally, movement coupling between the foot and shin, which causes the tibia segment to rotate internally between touchdown and midstance, has also been linked to the etiology of injury [8,9,10]. The amount of the motion transfer from ankle eversion to tibial internal rotation has been shown to differ widely among individuals [8,11]. However, given the popularity of treadmill running, surprisingly few investigations have specifically examined 3-D kinematics of the tibia and ankle during running on the treadmill in comparison to when running overground. Therefore the aim of the current investigation was to determine whether differences in tibiocalcaneal kinematics exist between treadmill and overground running.

Methods

Participants

Ten male participants (age 29.39 ± 5.17 years, height 1.81 ± 0.11m and body mass 74.19 ± 7.98kg) volunteered to take part in the current investigation. All were free from musculoskeletal pathologies at the time of data collection and provided informed consent. All runners were considered to be rearfoot strikers as they exhibited a clear first peak in their vertical ground reaction force time-curve. Ethical approval was obtained from the University Ethics Committee and the procedures outlined in the declaration of Helsinki were followed.

Procedure

All kinematic data were captured at 250 Hz via an eight-camera motion analysis system (Qualisys™ Medical AB, Goteburg, Sweden). Two identical camera systems were used to collect each mode of running. Calibration of the Qualisys™ system was performed before each data collection session.

The current investigation used the calibrated anatomical systems technique (CAST) [12]. To define the anatomical frame of the right; foot and shin retroreflective markers were positioned unilaterally to the calcaneus, 1st and 5th metatarsal heads, medial and lateral malleoli and medial and lateral epicondyle of the femur. A tracking cluster was positioned onto the shin segment. The foot segment was tracked using the calcaneus, 1st and 5th metatarsal markers respectively. A static trial was conducted with the participant in the anatomical position in order for the positions of the anatomical markers to be referenced in relation to the tracking markers/ clusters, following which those not required for tracking were removed.

In the overground condition participants completed ten running trials over a 22m walkway (Altrosports 6mm, Altro Ltd, Letchworth Garden City, Hertfordshire, UK) at 4.0m.s^{-1}±5% in the laboratory. Running velocity was monitored using infra-red timing gates (SmartSpeed Ltd UK). A successful trial was defined as one within the specified velocity range, where all tracking clusters were in view of the cameras and with no evidence of gait modification due to the experimental conditions. To collect treadmill information a Woodway™ (ELG,Weil am Rhein, Germany) high-power treadmill was used throughout. Participants were given a 5-min habitation period, in which participants ran at the determined velocity prior to the collection of kinematic data. Ten trials were also collected for treadmill kinematics. As force information was not available for each running condition, footstrike and toe-off were determined using kinematic information as in previous research [3]. The order in which participants ran in each condition was counterbalanced.

Data processing

Running data were digitized using Qualisys™ Track Manager in order to identify appropriate retroreflective markers then exported as C3D files. 3-D kinematics were quantified using Visual 3-D (C-Motion Inc, Germantown, MD, USA) after marker displacement data were smoothed using a low-pass Butterworth 4th order zero-lag filter at a cut off frequency of 15 Hz [13]. 3-D kinematics were calculated using an XYZ sequence of rotations (where X represents sagittal plane; Y represents coronal plane and Z represents transverse plane rotations) [14]. All kinematic waveforms were normalized to 100% of the stance phase then processed trials were averaged. Discrete 3-D kinematic measures from the ankle and tibia which were extracted for statistical analysis were 1) angle at footstrike, 2) angle at toe-off, 3) range of motion from footstrike to toe-off during stance, 4) peak eversion/ tibial internal rotation, 5) relative range of motion (ROM) (representing the angular displacement from footstrike to peak angle, 6) peak eversion/ tibial internal rotation velocity, 7) peak inversion/ tibial external rotation velocity, 8) eversion/ tibial internal (EV/TIR) ratio which was quantified in accordance with De Leo et al [15] as the relative eversion ROM / the relative tibial internal rotation ROM.

Statistical analysis

Means and standard deviations were calculated for each running condition. Differences in the outcome 3D kinematic parameters were examined using paired samples t-tests with significance accepted at the $p \leq 0.05$ level. Effect sizes for all significant observations were calculated using a Cohen's D statistic. The data were screened for normality using a Shapiro-Wilk test which confirmed that the normality assumption was met. All statistical analyses were conducted using SPSS 21.0 (SPSS Inc, Chicago, USA).

Results

The results indicate that while the kinematic waveforms measured during overground and treadmill running were quantitatively similar, significant differences were found to between the two running modalities. Figure 2 presents the 3-D tibiocalcaneal angular motions from the stance phase.

Tables 1 and 2 present the results of the statistical analysis conducted on the tibiocalcaneal measures.

In the coronal plane, treadmill runners were associated with significantly ($t_{(9)}$ = 5.66, p<0.05, *D*= 1.22) greater peak eversion in comparison to when running overground. In the transverse plane it was also shown that peak tibial internal rotation was significantly ($t_{(9)}$ = 5.71, p<0.05, *D*= 1.28) greater when running on the treadmill compared to when running overground. Finally, the EV/ TIR ratio was shown to be significantly higher when running on the treadmill compared to overground.

	Overground	Treadmill	
Ankle Coronal Plane			
Angle at Footstrike (°)	-2.06 ± 4.65	1.69 ± 3.89	
Angle at Toe-off (°)	-4.37 ± 3.32	0.54 ± 4.21	
Range of Motion (°)	2.24 ± 1.09	1.15 ± 0.98	
Relative range of motion (°)	10.10 ± 2.69	10.51 ± 2.97	
Peak Eversion (°)	8.20 ± 4.59	12.09 ± 4.64	*
Tibial Internal Rotation			
Angle at Footstrike (°)	2.76 ± 4.02	4.88 ± 3.96	
Angle at Toe-off (°)	3.09 ± 4.69	8.19 ± 4.13	
Range of Motion (°)	0.58 ± 2.69	3.69 ± 4.25	
Relative Range of Motion (°)	6.21 ± 1.65	7.59 ± 1.99	
Peak Tibial Internal Rotation (°)	8.89 ± 5.09	12.96 ± 4.97	*
EV/TIR ratio	1.91 ± 0.62	1.18 ± 0.46	*

Table 1 Tibiocalcaneal joint angles measured during treadmill and overground running (* = significant difference).

	Overground	Treadmill	
Ankle Coronal Plane			
Peak Eversion velocity (°/s)	144.62 ± 55.23	236.19 ± 49.63	*
Peak Inversion velocity (°/s)	-201.33 ± 51.29	-150.98 ± 43.25	
Tibial Internal Rotation			
Peak Tibial Internal Rotation velocity (°/s)	109.38 ± 47.88	165.22 ± 53.99	*
Peak Tibial External Rotation velocity (°/s)	92.13 ± 39.88	90.90 ± 40.66	

Table 2 Tibiocalcaneal angular velocities measured during treadmill and overground running (* = significant difference).

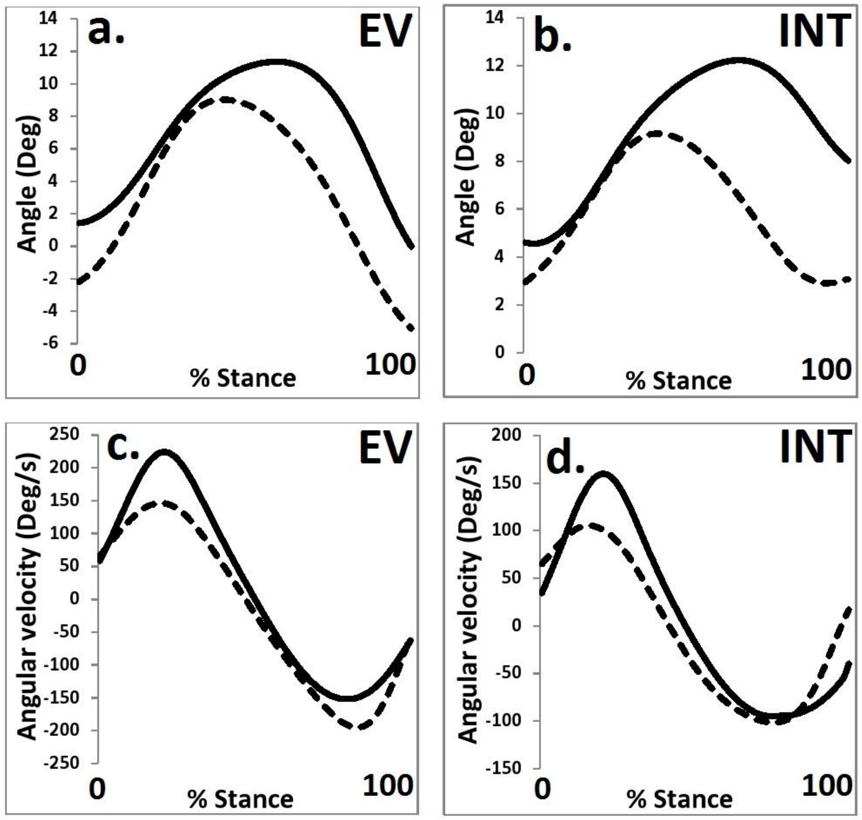

Figure 1 Tibiocalcaneal kinematics as a function of overground and treadmill conditions (Black = treadmill and Dash = overground) (a = ankle coronal plane angle, b = tibial internal rotation angle, c = ankle coronal plane velocity, d = tibial internal rotation velocity) (EV = eversion, INT = internal).

In the coronal plane, treadmill runners were associated with significantly ($t_{(9)} = 4.65$, $p<0.05$, $D= 1.06$) greater peak eversion angular velocity in comparison to when running overground. In the transverse plane it was also shown that peak tibial internal rotation angular velocity was significantly ($t_{(9)} = 4.80$, $p<0.05$, $D= 1.10$) greater when running on the treadmill compared to when running overground.

Discussion

This study aimed to determine whether differences in tibiocalcaneal kinematics exist between treadmill and overground running. This represents the first comparative investigation to consider the variations that may be present in tibiocalcaneal kinematics between these two running modalities.

The key observation from the current study is that treadmill running was associated with significantly greater eversion and tibial internal parameters in comparison to overground running. This finding may relate to the deformation characteristics of the surface during the treadmill condition and has potential clinical significance. These findings suggest that running on a treadmill may be associated with an increased risk from injury as rearfoot eversion and tibial internal rotation are implicated in the etiology of a number of overuse injuries [16,17,18,19]. Therefore treadmill runners may be at a greater risk from overuse syndromes such as tibial stress syndrome, Achilles tendinitis, patellar tendonitis, patellofemoral pain, iliotibial band syndrome and plantar fasciitis [16,17,18,19].

With respect to the potential differences in coupling between ankle and tibia it was observed that treadmill running showed a trend towards having a lower ankle eversion to tibial internal rotation ratio in comparison to overground. This suggests that differences between the two running modalities may exist in terms of the distal coupling mechanism between ankle and tibia. The EV/TIR is an important mechanism as it provides insight into where an injury is most likely to occur [8]. It is hypothesized that a greater EV/TIR ratio (i.e. relatively greater rearfoot eversion in relation to tibial internal rotation) may increase the stress placed on the foot and ankle [8,20] and are thus at greater risk for foot injuries. Conversely, those with lower EV/TIR ratios (relatively more tibial motion in relation to rearfoot eversion) are at greater risk from knee related injuries [10,20,21]. As such it appears that those who habitually run on a treadmill are susceptible to knee injuries and those who train overground may be most susceptible to foot injuries.

A limitation to the current investigation was the all-male sample. Sinclair et al [22] demonstrated that females exhibited significantly greater ankle eversion compared to age matched males. Therefore future work is required to determine the influence of different running modalities in female runners. Finally, this study quantified foot kinematics using markers positioned onto the shoe may serve as a limitation of the current analysis. There is likely to be movement of the foot within the shoe itself and thus it is questionable as to whether retro-reflective markers positioned on shoe provide comparable results to those placed on the skin of the foot [23,24]. However, as cutting holes in the experimental footwear in order to attach markers to skin compromises the structural integrity of the upper [24], it was determined that the utilization of the current technique was most appropriate.

Conclusions

In conclusion, although the mechanics of treadmill and overground running have been extensively studied, the degree in which tibiocalcaneal kinematics differs between the two modalities is limited. The present study adds to the current knowledge by providing a comprehensive evaluation of tibiocalcaneal kinematics during treadmill and overground running. Given the significant increases in eversion and tibial internal rotation observed in the treadmill condition, it was determined treadmill runners may be at increased risk from chronic injury development.

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