HUMAN MOVEMENT
2016, vol. 17 (2), 112–118

# THE INFLUENCE OF ENERGY BOOST AND SPRINGBLADE FOOTWEAR ON THE KINETICS AND KINEMATICS OF RUNNING

doi: 10.1515/humo-2016-0010

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ABSTRACT

**Purpose.** The aim of the current study was to comparatively examine the effects of energy return, spring and conventional footwear on the kinetics and kinematics of running. **Methods.** Twelve male runners ran over an embedded force platform at 4.0 m · s$^{-1}$ in the three footwear conditions. Lower limb kinematics were collected using an 8 camera motion capture system and tibial accelerations were obtained using an accelerometer. Differences in kinetic and kinematic parameters between footwear were examined using one-way repeated measures ANOVA. **Results.** The results showed that there were no significant differences in kinetic parameters between footwear. However, it was shown that that spring footwear were associated with significantly greater angles of peak eversion (–12.49°) and tibial internal rotation (13.09°) in comparison to the conventional footwear (eversion = –10.52° & tibial internal rotation = 10.84°). **Conclusions.** Therefore, the findings from the current investigation indicate that spring footwear may place runners at increased risk from chronic injury related to excessive ankle eversion/tibial internal rotation.

**Key words:** footwear, biomechanics, running

## Introduction

Recreational distance running is known to mediate a number of physiological benefits [1]. However, despite this, runners are also known to be highly susceptible to chronic injuries [2], with an incidence rate of around 70% over the course of one year [3]. A number of intrinsic and extrinsic risk factors have been associated with the aetiology of running injuries, such as mileage, previous injury, number of years of training, training characteristics, running mechanics, surface and footwear [4]. The most common chronic injuries associated with distance running are iliotibial band syndrome, tibial stress fractures, patellofemoral pain, Achilles tendinitis, and plantar fasciitis [4].

A large range of preventative/treatment modalities have therefore been explored, such as modifications to training schedules [*5–7],* stretching regimens [8–10], warm ups/cool downs [11], external supports [12], orthoses [13, 14] and footwear [15] in an attempt to mitigate the high risk of injury in runners. A key preventative modality is to select running shoes with appropriate mechanical midsole characteristics, which can influence the biomechanical mechanisms linked to the aetiology of injury. The properties of running shoe midsoles have therefore been proposed as a mechanism by which chronic injuries can be managed [16].

Energy return has become a contemporary topic in footwear biomechanics literature [17–19]. The first energy return footwear utilized a thermoplastic polyurethane midsole which is designed to reduce energy loss in comparison to traditional ethylene-vinyl acetate footwear midsoles. There has been only one study which has examined biomechanics of running in these footwear. Sinclair et al. [17] investigated the effects of conventional and energy return footwear on the kinetics and kinematics of running. Their results showed that the conventional running footwear with an ethylene-vinyl acetate footwear midsole were associated with significantly reduced tibial accelerations and peak eversion angles in comparison to energy return. In addition, a further footwear design has also been introduced, which also claims to increase energy return via 16 curved springs designed to store and release energy. Currently, there is no published information regarding the biomechanics of the spring footwear. However, given the high incidence of chronic pathologies in runners and the popularity of these new footwear models, research of this nature would be of both practical and clinical significance.

Therefore, the aim of the current study was to comparatively examine the effects of energy return, spring and conventional footwear on the kinetics and kinematics of running. Given the high rate of chronic pathologies in runners, a study of this nature may give key information to runners and clinicians with regards to the selection of footwear for the reduction of injury.

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## Material and methods

### Participants

Twelve male participants volunteered to take part in the current investigation. The mean ± SD characteristics of the participants were; age 23.59 ± 2.00 years, height 177.05 ± 4.58 cm and body mass 77.54 ± 5.47 kg. All were free from musculoskeletal pathology at the time of data collection and provided written informed consent. The procedure utilized for this investigation was approved by the University ethical committee in accordance with the principles outlined in the Declaration of Helsinki.

### Procedure

The runners completed five successful trials in which they ran through a 22 m walkway at an average velocity of 4.0 $m \cdot s^{-1}$ in each of the three running shoe conditions. The participants struck a piezoelectric force platform (Kistler Instruments) embedded into the middle of the laboratory with their right foot [20]. The force platform data was collected with a frequency of 1000 Hz. Running velocity was controlled using timing gates (SmartSpeed Ltd UK) and a maximum deviation of 5% from the predetermined velocity was allowed. Three-dimensional (3D) kinematic information from the stance phase of the running cycle were obtained using an eight-camera motion capture system (Qualisys Medical AB, Goteburg, Sweden) with a capture frequency of 250 Hz. To prevent any sequence effects, the order in which participants performed in each footwear condition was counterbalanced. Each footwear condition had four participants who received it first, second and last. The stance phase was delineated as the duration over which > 20 N of vertical force was applied to the force platform.

To quantify lower extremity joint kinematics in all three planes of rotation, the calibrated anatomical systems technique was utilized [21]. Retroreflective markers (19 mm) were positioned unilaterally allowing the right foot, shank and thigh to be defined. The foot was defined via the 1$^{st}$ and 5th metatarsal heads, medial and lateral malleoli and tracked using the calcaneus, 1$^{st}$ metatarsal and 5$^{th}$ metatarsal heads. The shank was defined via the medial and lateral malleoli and medial and lateral femoral epicondyles and tracked using a cluster positioned onto the shank. The thigh was defined via the medial and lateral femoral epicondyles and the hip joint centre and tracked using a cluster positioned onto the thigh. To define the pelvis additional markers were positioned onto the anterior (ASIS) and posterior (PSIS) superior iliac spines, and this segment was tracked using the same markers. The hip joint centre was determined using a regression equation that uses the positions of the ASIS markers [22]. The centers of the ankle and knee joints were delineated as the mid-point between the malleoli and femoral epicondyle markers [23, 24]. Static calibration trials were obtained allowing for the anatomical markers to be referenced in relation to the tracking markers/ clusters. The Z (transverse) axis was oriented vertically from the distal segment end to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior to anterior. Finally, the X (sagittal) axis orientation was determined using the right hand rule and was oriented from medial to lateral.

To quantify tibial accelerations an accelerometer (Biometrics ACL 300, Gwent UK), sampling at 1000 Hz was utilized. The accelerometer was attached onto a piece of lightweight carbon-fibre material using the protocol outlined by Sinclair et al. [25], and strapped securely to the distal anterio-medial aspect of the tibia in alignment with its longitudinal axis 0.08 m above the medial malleolus [26].

### Footwear

The footwear used during this study consisted of conventional footwear (New Balance 1260 v2), energy return (Adidas energy boost) and spring (Adidas springblade drive 2) footwear, (shoe size 8–10 in UK men's sizes).

### Processing

Trials were processed in Qualisys Track Manager in order to identify anatomical and tracking markers, then exported as C3D files. Kinematic parameters were quantified using Visual 3-D (C-Motion Inc, Gaithersburg, USA) after marker data was smoothed using a low-pass Butterworth 4$^{th}$ order zero-lag filter at a cut off frequency of 12 Hz. Kinematics of the hip, knee, ankle and tibial segment were quantified using an XYZ cardan sequence of rotations (where X is flexion-extension; Y is ab-adduction and Z is internal-external rotation). 3D kinematic measures from the hip, knee, ankle and tibia which were extracted for statistical analysis were 1) angle at footstrike, 2) angle at toe-off, 3) peak angle during stance and 4) relative range of motion (ROM) from footstrike to peak angle.

From the force platform vertical force parameters of impact peak, time to impact peak, average loading rate and instantaneous loading rate were calculated. The impact peak was taken as the vertical ground reaction force peak that occurred early in the stance phase. The average loading rate was calculated by dividing the impact peak by the duration over which the impact peak occurred whereas instantaneous loading rate was calculated as the maximum increase between adjacent data points [16]. The acceleration signal was filtered with a 60Hz low-pass Butterworth 4$^{th}$ order zero-lag filter. Peak tibial acceleration was defined as the highest positive acceleration peak measured during the stance phase. Tibial acceleration slope was quantified by dividing the peak tibial acceleration magnitude by the duration over which the acceleration occurred, whereas tibial acceleration instantaneous loading rate was calculated as the maximum increase in tibial acceleration between adjacent data points [16].

All of the aforementioned kinetic and kinematic parameters were extracted from each of the five trials and the data was then averaged within subjects for statistical analysis. Hip, knee and ankle joint kinematic curves were time normalized to stance and were ensemble averaged across subjects for graphical purposes.

Statistical analysis

Means and standard deviations were calculated for each outcome measure for all footwear conditions. Differences in kinetic and kinematic parameters between footwear were examined using one-way repeated measures ANOVAs, with significance accepted at the $p < 0.05$ level. Effect sizes were calculated using partial eta$^2$ ($p\eta^2$), with $p\eta^2 = 0.2$ considered small, $p\eta^2 = 0.5$ considered medium and $p\eta^2 = 0.8$ considered large. Post-hoc pairwise comparisons were conducted on all significant main effects. The data was screened for normality using a Shapiro–Wilk which confirmed that the normality assumption was met. All statistical actions were conducted using SPSS v22.0 (SPSS Inc., Chicago, USA).

## Results

Kinetics

Table 1 presents the kinetic parameters obtained as a function of the different experimental footwear.

The results show that there were no differences ($p > 0.05$) between footwear were found for any of the kinetic parameters.

Kinematics

Tables 2–5 and figures 1–2 presents the 3D kinematic parameters obtained as a function of the different experimental footwear.

Table 1. Kinetic and tibial acceleration parameters as a function of footwear

| | Conventional | | Energy return | | Spring | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Impact peak (N/kg) | 17.58 | 6.10 | 17.86 | 6.28 | 18.32 | 6.16 |
| Time to impact peak (s) | 0.03 | 0.01 | 0.03 | 0.01 | 0.03 | 0.01 |
| Load rate (N/kg/s) | 678.23 | 74.04 | 653.63 | 91.27 | 669.36 | 133.84 |
| Instantaneous load rate (N/kg/s) | 1102.82 | 196.37 | 1287.51 | 373.67 | 1438.55 | 435.65 |
| Peak tibial acceleration (g) | 6.60 | 2.47 | 7.03 | 2.79 | 7.53 | 2.75 |
| Time to peak tibial acceleration (s) | 0.05 | 0.03 | 0.04 | 0.03 | 0.05 | 0.03 |
| Tibial acceleration slope (g/s) | 242.28 | 145.69 | 225.71 | 112.99 | 241.17 | 154.88 |
| Tibial acceleration instantaneous slope (g/s) | 709.67 | 353.88 | 659.42 | 290.16 | 720.26 | 298.88 |

Table 2. Hip joint kinematic parameters as a function of footwear

| | Conventional | | Energy return | | Spring | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Sagittal plane (+ = flexion & – = extension) | | | | | | |
| Angle at footstrike | 23.79 | 7.67 | 27.02 | 10.07 | 24.03 | 6.43 |
| Angle at toe-off | –17.40 | 9.25 | –15.24 | 11.11 | –17.21 | 8.95 |
| Peak angle | 24.95 | 6.80 | 27.41 | 9.94 | 24.78 | 6.56 |
| ROM | 1.16 | 2.26 | 0.39 | 0.77 | 0.76 | 0.76 |
| Coronal plane (+ = adduction & – = abduction) | | | | | | |
| Angle at footstrike | 0.78 | 3.62 | 1.00 | 2.39 | 1.65 | 4.56 |
| Angle at toe-off | –3.88 | 5.25 | –4.08 | 4.15 | –4.01 | 4.68 |
| Peak angle | 7.31 | 4.36 | 7.14 | 3.42 | 7.61 | 3.33 |
| ROM | 6.53 | 2.46 | 6.14 | 1.68 | 5.96 | 3.17 |
| Transverse plane (+ = internal & – = external) | | | | | | |
| Angle at footstrike | –11.40 | 6.55 | –12.52 | 7.90 | –12.76 | 8.29 |
| Angle at toe-off | –9.89 | 9.78 | –8.80 | 9.87 | –8.58 | 10.73 |
| Peak angle | –18.16 | 6.77 | –17.88 | 7.00 | –17.63 | 7.20 |
| ROM | 6.76 | 5.86 | 5.36 | 4.33 | 4.86 | 3.59 |

Table 3. Knee joint kinematic parameters as a function of footwear

| | Conventional | | Energy return | | Spring | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Sagittal plane (+ = flexion & – = extension) | | | | | | |
| Angle at footstrike | 9.81 | 8.76 | 10.04 | 9.57 | 9.57 | 7.43 |
| Angle at toe-off | 14.05 | 8.02 | 12.91 | 4.69 | 12.93 | 4.06 |
| Peak angle | 37.98 | 5.27 | 35.56 | 5.05 | 36.22 | 2.98 |
| ROM | 28.17 | 8.24 | 25.52 | 6.18 | 26.65 | 6.80 |
| Coronal plane (+ = adduction & – = abduction) | | | | | | |
| Angle at footstrike | –0.61 | 7.16 | –0.25 | 6.60 | –0.68 | 7.14 |
| Angle at toe-off | –3.26 | 4.08 | –2.52 | 4.12 | –3.02 | 4.17 |
| Peak angle | –7.77 | 7.32 | –6.87 | 7.43 | –7.03 | 7.15 |
| ROM | 7.16 | 3.68 | 6.62 | 2.82 | 6.35 | 3.28 |
| Transverse plane (+ = internal & – = external) | | | | | | |
| Angle at footstrike | –2.13 | 6.37 | –0.86 | 6.52 | –0.58 | 7.24 |
| Angle at toe-off | –1.72 | 6.05 | –1.74 | 4.78 | –1.22 | 6.18 |
| Peak angle | 11.05 | 5.76 | 11.36 | 6.28 | 10.76 | 6.25 |
| ROM | 13.17 | 6.24 | 12.23 | 4.81 | 11.34 | 6.42 |

Table 4. Ankle joint kinematic parameters as a function of footwear

| | Conventional | | Energy return | | Spring | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Sagittal plane (+ = dorsiflexion & – = plantarflexion) | | | | | | |
| Angle at footstrike | 4.75 | 12.26 | 3.48 | 10.87 | 4.03 | 12.13 |
| Angle at toe-off | –23.70 | 5.42 | –20.91 | 6.60 | –19.79 | 6.59 |
| Peak angle | 19.29 | 5.39 | 18.56 | 4.32 | 21.55 | 5.19 |
| ROM | 14.53 | 7.91 | 15.08 | 7.63 | 17.52 | 7.55 |
| Coronal plane (+ = inversion & – = eversion) | | | | | | |
| Angle at footstrike | 0.75 | 4.99 | 0.29 | 5.64 | –1.08 | 4.93 |
| Angle at toe-off | 3.75 | 4.76 | 1.63 | 4.78 | 0.84 | 5.28 |
| Peak angle | –10.52 | 7.01 | –11.17 | 6.58 | –12.49 | 6.92 |
| ROM | 11.27 | 3.80 | 11.46 | 3.92 | 11.41 | 3.92 |
| Transverse plane (+ = external & – = internal) | | | | | | |
| Angle at footstrike | –10.83 | 5.14 | –10.72 | 5.35 | –12.64 | 5.62 |
| Angle at toe-off | –5.60 | 6.83 | –6.41 | 7.24 | –8.57 | 6.08 |
| Peak angle | –0.95 | 3.97 | –0.38 | 4.50 | –1.85 | 4.31 |
| ROM | 9.88 | 2.54 | 10.34 | 1.78 | 10.79 | 2.91 |

Table 5. Tibial internal rotation parameters as a function of footwear

| | Conventional | | Energy return | | Spring | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Transverse plane (+ = internal & – = external) | | | | | | |
| Angle at footstrike | 3.29 | 7.18 | 3.82 | 7.12 | 5.84 | 6.74 |
| Angle at toe-off | 1.87 | 7.86 | 3.50 | 7.90 | 5.56 | 7.57 |
| Peak angle | 10.84 | 7.16 | 11.27 | 7.19 | 13.09 | 6.85 |
| ROM | 7.55 | 2.98 | 7.44 | 3.49 | 7.24 | 3.41 |

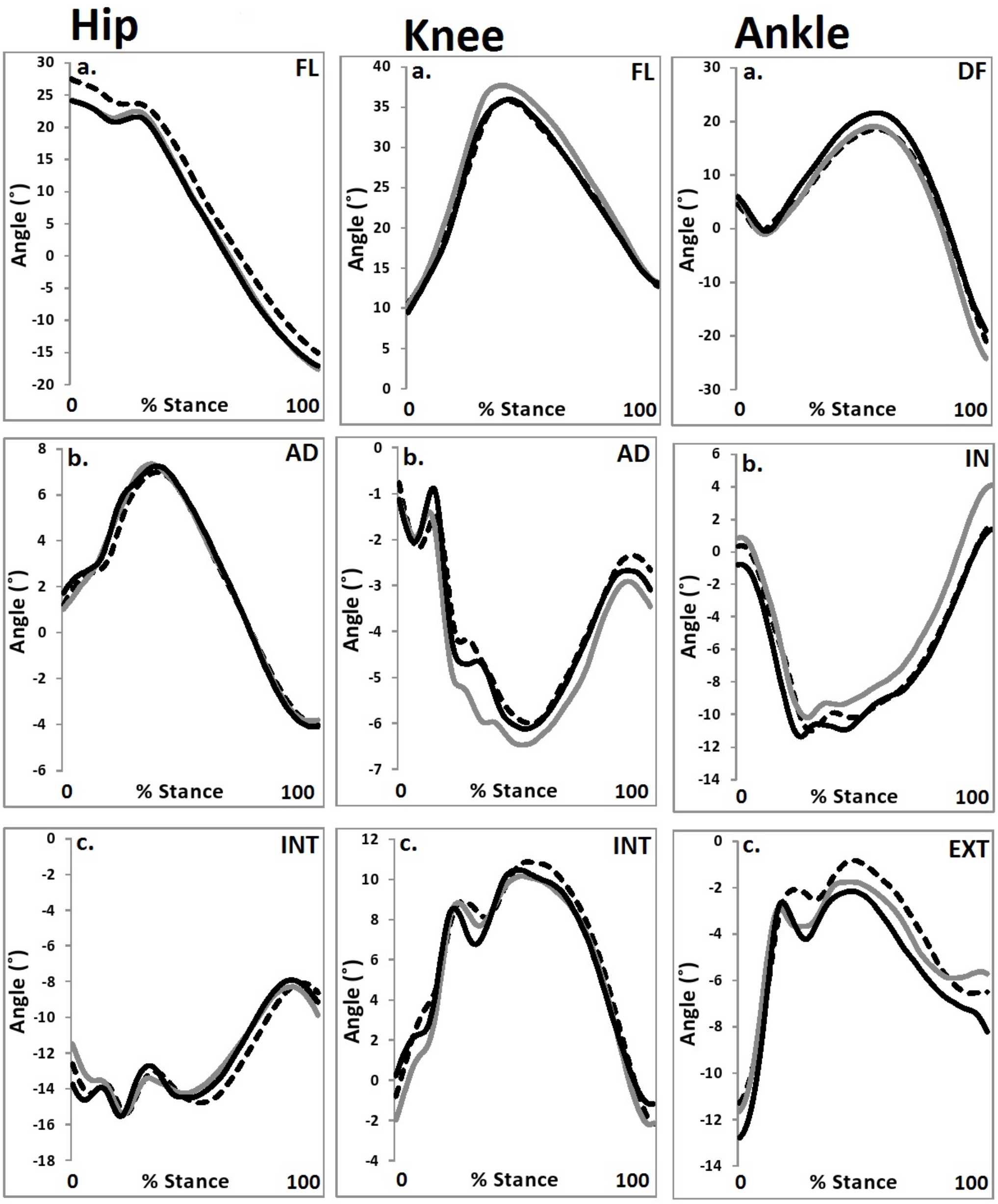


Figure 1. Lower extremity kinematic parameters in the a sagittal, b. coronal and c. transverse planes (grey = conventional, black = spring, dash = energy return), (FL = flexion, DF = dorsiflexion, AD = adduction, IN = inversion, INT = internal, EXT = external)

*Hip*

No differences ($p > 0.05$) in hip joint kinematics were found between footwear.

*Knee*

No differences ($p > 0.05$) in knee joint kinematics were found between footwear.

*Ankle*

In the coronal plane a main effect ($p < 0.05$, $p\eta^2 = 0.45$) was shown for the angle at footstrike. Post-hoc analysis revealed that the eversion was significantly greater in the spring footwear compared to the conventional and energy return conditions. A main effect ($p < 0.05$, $p\eta^2 = 0.71$) was also shown for the angle at toe-off. Post-hoc analysis revealed that the inversion was significantly reduced in the spring footwear compared to the conventional condition. Finally a main effect ($p < 0.05$, $p\eta^2 = 0.41$) was found for the angle of peak eversion. Post-hoc analysis revealed that the angle of eversion was significantly greater in the spring footwear compared to the conventional condition.

*Tibia*

A main effect ($p < 0.05$, $p\eta^2 = 0.36$) was shown for the angle at footstrike. Post-hoc analysis revealed that the internal rotation was significantly greater in the spring

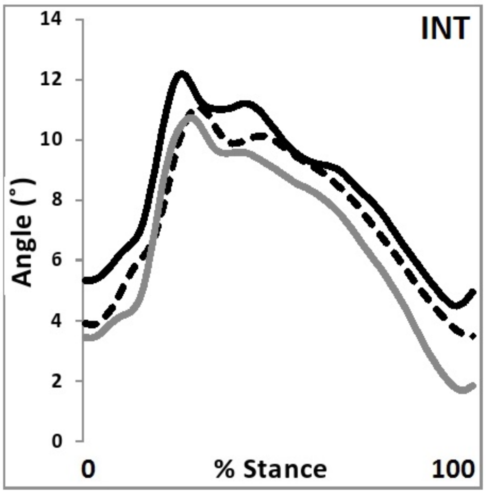

Figure 2. Tibial internal rotation kinematics (grey = conventional, black = spring, dash = energy return), (INT = internal)

footwear compared to the conventional and energy return conditions. A main effect ($p < 0.05$, $p\eta^2 = 0.54$) was also shown for the angle at toe-off. Post-hoc analysis revealed that internal rotation was significantly greater in the spring footwear compared to the conventional condition. Finally a main effect ($p < 0.05$, $p\eta^2 = 0.45$) was found for the angle of peak internal rotation. Post-hoc analysis revealed that the angle of peak internal rotation was significantly greater in the spring footwear compared to the conventional condition.

## Discussion

The aim of this work was to determine the influence of energy return, spring and conventional running footwear on the kinetics and kinematics of running. To the authors knowledge, this study represents the first to comparatively examine the biomechanical effects of running in energy return and spring footwear.

The first key observation from the current investigation is that no significant differences in impact kinetics were shown between any of the experimental footwear. This finding is interesting in light of the vastly different midsole characteristics between the three footwear conditions and shows that different materials can have the same impact attenuating properties. This finding disagrees with the findings of Sinclair et al. [5] who demonstrated that conventional running shoes were associated with reduced tibial accelerations compared to energy return footwear. Therefore, importantly based on the findings from this study, it appears that the experimental footwear used in this research does not appear to affect runner's susceptibility to impact related chronic disorders.

That the peak angle of eversion and tibial internal rotation were significantly greater in spring footwear compared to conventional running shoes is also an important observation. It is proposed that this finding relates to the lack of medial support in the spring footwear in relation to the conventional running shoes, meaning that their mechanical characteristics are unable to physically restrain the coronal plane motion of the ankle and associated inward rotation of the tibia. This observation may have clinical significance as increased eversion and tibial internal rotation parameters have been linked to the aetiology of chronic injuries [27]. Therefore the current investigation indicates that spring footwear may place runners at increased risk from chronic injuries in comparison to conventional running shoes.

A potential drawback of this study is that it investigated only the kinetics and 3D kinematics of running. This procedure represents a useful practice when investigating the effects of different footwear on running biomechanics. However the mechanical characteristics of the energy return and spring footwear are designed specifically to increase energy return from the midsole and reduce the metabolic requirements of running. Therefore in addition to the current work, future research should seek to determine whether these footwear can influence the metabolic cost of running.

## Conclusions

In conclusion, the present investigation adds to the current knowledge by providing a comprehensive evaluation of both kinetic and kinematic parameters when running in energy return, conventional and spring footwear. Firstly, the current study demonstrated that despite the infinitely different midsole characteristics of the three footwear conditions and the manufacturers claims, there were no differences in impact attenuation. Secondly, the current study showed that the peak angles of eversion and tibial internal rotation were significantly larger in spring in comparison to conventional footwear. Therefore the findings from the current investigation indicate that spring footwear may place runners at increased risk from chronic injury related to excessive ankle eversion/ tibial internal rotation.

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Paper received by the Editor: March 15, 2016
Paper accepted for publication: May 17, 2016

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