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Effects of energy boost and springblade footwear on knee and ankle loads in recreational runners

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The aim of the current investigation was to comparatively examine the effects of conventional, energy boost and spring footwear on the loads experienced by the patellofemoral joint and Achilles tendon during running. Ten male runners underwent 3D running analysis at 4.0 m/s. Patellofemoral joint and Achilles tendon loads were quantified using a musculoskeletal modelling approach and contrasted between footwear using one-way repeated measures ANOVA. The results showed that peak patellofemoral force and pressure were significantly greater in conventional (force = 31.72 N/kg & pressure = 10.05 MPa) footwear in relation to energy boost (27.80 N/kg & pressure = 9.02 MPa). In addition peak Achilles tendon force was shown to be significantly greater in conventional (54.98 N/kg) compared to springblade (49.92 N/kg) footwear. On the basis that peak patellofemoral and Achilles tendon forces were significantly greater when running in conventional footwear, the findings from the current investigation indicate that utilization of conventional running footwear may place runners at increased risk from knee and ankle pathologies in comparison to energy boost and springblade shoe conditions.

Key words: springblade footwear, knee loads, ankle loads, running

Recreational runners are renowned for their susceptibility to chronic injuries; as many as 80 % of all who participate in running activities will suffer from a chronic pathology over the course of one year [1]. The structures of the knee and ankle joints are the most common injury sites and have been shown to be associated with one-fifth of running-related injuries [1].

Given their high susceptibility to injuries, runners and clinicians/ researchers have investigated a number of different strategies which aim to attenuate the risk of injury. One such strategy is to select running footwear with appropriate mechanical characteristics; the properties of athletic footwear have been linked to the prevention of running injuries and improvement of performance and have thus been extensively investigated in biomechanical/ clinical literature.

In recent years the concept of energy return has been of interest to the footwear biomechanics community. The first footwear to incorporate the energy return principle into their design were the energy boost concept designed by Adidas. These footwear utilize an expanded thermoplastic polyurethane midsole designed to be more compliant and associated with reduced energy loss in comparison to traditional footwear midsoles. There has been only limited published research which has investigated the biomechanics of the energy boost footwear. Sinclair et al [2] examined the kinetics and kinematics of running in conventional and energy return footwear. Their findings showed that the energy boost shoes were associated with significantly increased tibial accelerations and peak eversion angles. Both Woborets et al [3] and Sinclair et al [4] showed that energy boost footwear were able to improve treadmill running economy in comparison to conventional running shoes.

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In addition Sinclair et al [5] demonstrated that the energy boost footwear improved running economy and reduced the bodies' reliance on carbohydrate as a fuel source compared to minimalist footwear. In addition to the energy boost footwear a further footwear design the springblade has been introduced by Adidas which also aims to improve energy return through 16 curved blades designed to compress and release energy with each footstrike. There has yet to be any published research concerning the biomechanics of the springblade footwear, nor has there been any investigations examining knee and ankle loading in energy return footwear. Given the high incidence of knee and ankle 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 investigation was to comparatively examine the effects of conventional, energy boost and spring footwear on the loads experienced by the patellofemoral joint and Achilles tendon during running. Given the high incidence of knee and ankle pathologies in runners, a study of this nature may provide important clinical information to runners regarding the selection of appropriate footwear.

Methods

Participants

Ten 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 of Central Lancashire, 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/s in each running shoe condition. The participants struck an embedded piezoelectric force platform (Kistler Instruments) with their right foot [6]. The force platform 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 pre-determined velocity was allowed. 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. The order in which participants performed in each footwear condition was counterbalanced. The stance phase was delineated as the duration over which > 20 N of vertical force was applied to the force platform.

Lower extremity segments were modelled in 6 degrees of freedom using the calibrated anatomical systems technique [7]. To define the segment co-ordinate axes of the foot, shank and thigh, retroreflective markers were placed bilaterally onto 1st metatarsal, 5th metatarsal, calcaneus, medial and lateral malleoli, medial and lateral epicondyles of the femur. To define the pelvis segment further markers were posited onto the anterior (ASIS) and posterior (PSIS) superior iliac spines. Carbon fiber tracking clusters were positioned onto the shank and thigh segments. The foot was tracked using the 1st metatarsal, 5th metatarsal and calcaneus markers and the pelvis using the ASIS and PSIS markers. The centers of the ankle and knee joints were delineated as the mid-point between the malleoli and femoral epicondyle markers [8,9], whereas the hip joint centre was obtained using the positions of the ASIS markers [10]. Static calibration trials were obtained allowing for the anatomical markers to be referenced in relation to the tracking markers/ clusters.

Footwear

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

Processing

Patellofemoral pressure (MPa) was calculated as a function of the patellofemoral contact force divided

Dynamic trials were digitized using Qualisys Track Manager in order to identify anatomical and tracking markers then exported as C3D files to Visual 3D (C-Motion, Germantown, MD, USA). Ground reaction force and kinematic data were smoothed using cut-off frequencies of 25 and 12 Hz with a low-pass Butterworth 4th order zero lag filter. 3D kinematics of the knee and ankle were calculated using an XYZ cardan sequence of rotations (where X = sagittal plane; Y = coronal plane and Z = transverse plane). Kinematic curves were normalized to 100% of the stance phase then processed trials were averaged. Joint kinetics were computed using Newton-Euler inverse-dynamics. To quantify net joint moment anthropometric data, ground reaction forces and angular kinematics were used.

A previously utilized musculoskeletal model was used to determine patellofemoral contact force and pressure [11]. This method has been successfully utilized to resolve differences in patellofemoral contact force and pressure when wearing different footwear [12-14]. Patellofemoral joint contact force (N/kg) during running was then estimated as a function of knee flexion angle (*Kfa*) and knee extensor moment (ME) according to the biomechanical model described by Ho et al [15]. Firstly, the moment arm of the quadriceps muscle (mq) was calculated as a function of knee flexion angle using non-linear equation, which is based on cadaveric information presented by van Eijden et al [16]:

$$mq = 0.00008\,Kfa^3 - 0.013\,Kfa^2 + 0.28\,Kfa + 0.046$$

Quadriceps force (QF) was then calculated using the below formula:

$$QF = ME / mq$$

PTF was estimated using the QF and a constant (K):

$$PTF = QF\ K$$

The constant was described in relation to the *fa* using a curve fitting technique based on the non-linear equation described by Eijden et al [16]:

$$K = (0.462 + 0.00147\,Kfa^2 - 0.0000384\,fa^2) / (1 - 0.0162\,Kfa + 0.000155\,Kfa^2 - 0.000000698\,Kfa^3)$$

by the patellofemoral contact area. The contact area was described in accordance with the Ho et al [15] recommendations by fitting a second-order polynomial curve to the data of Powers et al [17] who documented patellofemoral contact areas at varying levels of knee flexion.

$$\text{Patellofemoral pressure} = \text{patellofemoral contact force} / \text{contact area}$$

Achilles tendon force (N/kg) was determined using a previously utilized musculoskeletal model. This model has been used previously to resolve differences in Achilles tendon force between footwear [14,18]. Achilles tendon force was quantified as the plantarflexion moment (MPF) divided by the estimated Achilles tendon moment arm (mat). The moment arm was quantified as a function of the ankle sagittal plane angle (*ak*) using the procedure described by Self and Paine [19]:

$$\text{Achilles tendon force} = MPF / mat$$

$$mat = -0.5910 + 0.08297\,ak - 0.0002606\,ak^2$$

Average patellofemoral contact force and Achilles tendon load rate were quantified as the peak patellofemoral contact force / Achilles tendon force divided by the time over which the peak force occurred. Instantaneous patellofemoral/ Achilles tendon load rate were also determined as the peak increase in patellofemoral contact force/ Achilles tendon force between adjacent data points. In addition to this we also calculated the total patellofemoral contact force/ Achilles tendon force impulse (N/kg·s) during running by multiplying the patellofemoral contact force/ Achilles tendon force estimated during the stance phase by the stance time.

Analyses

Means and standard deviations were calculated for each outcome measure for all footwear conditions. Differences in Achilles tendon force and patellofemoral contact force parameters between footwear were examined using one-way repeated measures ANOVAs, with significance accepted at the $P \leq 0.05$ level. Effect sizes were calculated using partial eta^2 ($p\eta^2$). 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

Tables 1-2 and Figure 1 present the knee and ankle loads during the stance phase of running, as a function of the different experimental footwear. The results indicate that footwear significantly influenced both knee and ankle kinetic parameters.

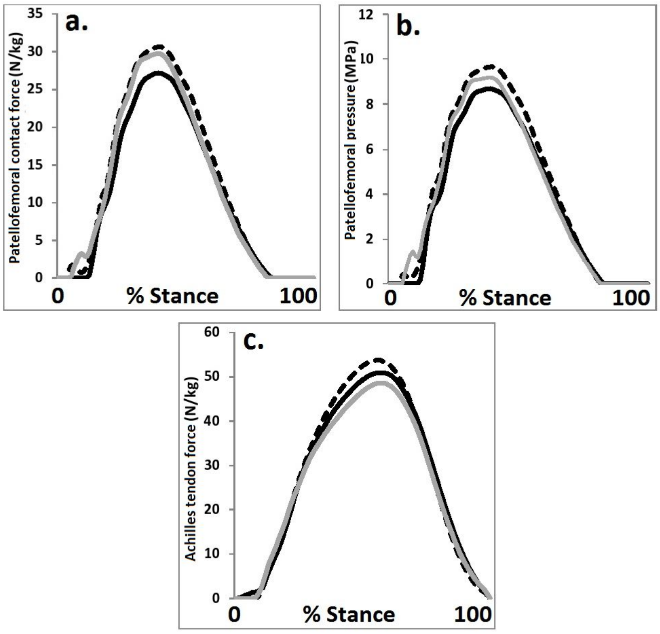

Figure 1 Knee and ankle loads as a function of footwear; a. = Patellofemoral contact force, b. = Patellofemoral pressure, c. = Achilles tendon force (black = energy boost, grey = springblade, dash = conventional).

	Conventional		Energy return		Spring	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Peak patellofemoral contact force (N/kg)	31.72	6.37	27.80	5.70	30.17	4.73
Time to patellofemoral contact force (s)	0.09	0.01	0.08	0.01	0.08	0.01
Patellofemoral load rate (N/kg/s)	372.34	53.13	334.11	60.83	356.99	34.94
Patellofemoral instantaneous load rate (N/kg/s)	1470.35	561.44	1435.06	529.05	1532.02	372.51
patellofemoral contact force impulse (N/kg·s)	2.84	0.90	2.26	0.68	2.58	0.82
Patellofemoral pressure (MPa)	10.05	1.87	9.02	1.71	9.70	1.38

Table 1 Knee loads as a function of footwear.

	Conventional		Energy return		Spring	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Peak Achilles tendon force (N/kg)	54.98	7.73	52.40	8.50	49.92	7.21
Time to Achilles tendon force (s)	0.13	0.02	0.13	0.02	0.13	0.01
Achilles tendon load rate (N/kg/s)	449.21	110.49	436.33	138.79	381.65	88.49
Achilles tendon instantaneous load rate (N/kg/s)	1316.78	387.07	1114.70	342.44	1377.57	570.81
Achilles tendon force impulse (N/kg·s)	6.23	1.26	5.82	1.22	5.88	1.06

Table 2 Ankle loads as a function of footwear.

Knee loads
A main effect (P<0.05, p η^2=0.32) was found for peak patellofemoral contact force. Post-hoc analyses indicated that peak patellofemoral contact force was significantly greater in conventional footwear compared to energy boost (Table 1; Figure 1a). A main effect (P<0.05, p η^2=0.29) was similarly for peak patellofemoral pressure. Post-hoc analyses indicated that peak patellofemoral pressure was significantly greater in conventional footwear compared to energy boost (Table 1; Figure 1b). There was also a main effect for (P<0.05, p η^2=0.33) patellofemoral load rate. Post-hoc analyses indicated that peak patellofemoral load rate was significantly greater in conventional footwear compared to energy boost (Table 1). A main effect (P<0.05, p η^2=0.31) was shown for patellofemoral impulse. Post-hoc analyses indicated that patellofemoral impulse was significantly greater in conventional footwear compared to energy boost (Table 1).

Ankle loads
A main effect (P<0.05, p η^2=0.30) was found for peak Achilles tendon force. Post-hoc analyses indicated that peak Achilles tendon force was significantly greater in conventional footwear compared to springblade (Table 2; Figure 1c).

Discussion

The aim of the current investigation was to comparatively examine the effects of conventional, energy boost and spring footwear on the loads experienced by the patellofemoral joint and Achilles tendon during running. To the authors knowledge this represents the first investigation to comparatively investigate knee and ankle loads when running in energy boost and spring footwear.

The first key finding from the current study is that patellofemoral contact force and contact pressure were shown to be significantly greater in the conventional footwear in relation to the energy boost condition. This finding is in agreement with the findings of Sinclair, [14] and Bonacci et al [12] who confirmed that different footwear can significantly influence patellofemoral loading magnitude**.** This observation may be important clinically with regards to the aetiology of patellofemoral disorders in runners. Patellofemoral pain syndrome is is considered to be caused by repeated high loads that are imposed too frequently to the patellofemoral joint itself [15]. Therefore the findings this study indicate that the energy boost footwear may be the most efficacious for runners who are susceptible to patellofemoral joint conditions.

A potential limitation of previous research investigating the effects of different running footwear on the forces experienced by the musculoskeletal system when running is that only the peak forces experienced per step have been reported. Therefore the potential effects that alterations in stance time/ stride frequency may have on the summative loads experienced by the body are not accounted for. The findings from the current investigation can be further contextualized by examining the patellofemoral impulse associated with each footwear. The findings for patellofemoral impulse mirror those in relation to peak patellofemoral force in that energy boost footwear significantly reduced impulse, giving further support to the earlier proposition that these footwear may be able reduce the likelihood of experiencing patellofemoral pain symptoms in runners.

A further important finding from the current study is that Achilles tendon load was shown to be significantly larger in the conventional footwear in comparison to the springblade shoes. This observation similarly concurs with the findings of Sinclair, [14] who showed that different footwear significantly influenced Achilles tendon force. This observation may also be relevant clinically with regards to the aetiology of Achilles tendon pathologies in runners. The aetiology of Achilles tendinosis relates to repeated high loads applied too frequently to the tendon itself without sufficient rest [20]. Loads exceeding the tendons physiological threshold mediate collagen degradation which ultimately leads to injury [21]. Therefore the findings from the current investigation indicate that the springblade footwear may be most appropriate for runners who are susceptible to Achilles tendon pathologies.

In conclusion, although energy return footwear have been investigated extensively in biomechanics research, the current knowledge regarding the effects of energy boost and springblade footwear on patellofemoral contact and Achilles tendon forces is limited. The present investigation therefore adds to the current knowledge by providing a comprehensive evaluation of patellofemoral and Achilles tendon force parameters when running energy boost, springblade and conventional footwear. On the basis that patellofemoral and Achilles tendon force were significantly greater when running in conventional footwear, the findings from the current investigation indicate that utilization of conventional running footwear may place runners at increased risk from knee and ankle pathologies in comparison to energy boost and springblade shoe conditions.

References

1. van Gent R, Siem DD, van Middelkoop M, van Os TA, Bierma-Zeinstra SS, Koes, BB. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. British Journal of Sports Medicine 2007: 41: 469-480. (PubMed)
2. Sinclair J, Franks C, Goodwin JF, Naemi R, Chockalingam, N. Influence of footwear designed to boost energy return on the kinetics and kinematics of running compared to conventional running shoes. Comparative Exercise Physiology 2014; 10: 199-206. (Link)
3. Worobets J, Wannop JW, Tomaras E, Stefanyshyn D. Softer and more resilient running shoe cushioning properties enhance running economy. Footwear Science 2014; 6: 147-153. (Link)
4. Sinclair J, Mcgrath R, Brook O, Taylor PJ, Dillon S. Influence of footwear designed to boost energy return on running economy in comparison to a conventional running shoe. Journal of Sports Sciences, 2016; 34: 1094-1098. (PubMed)
5. Sinclair J, Shore H., Dillon S. The effect of minimalist, maximalist and energy return footwear of equal mass on running economy and substrate utilization. Comparative Exercise Physiology (In press, 2016).
6. Sinclair J, Hobbs SJ, Taylor PJ, Currigan G, Greenhalgh A. The Influence of Different Force and Pressure Measuring Transducers on Lower Extremity Kinematics Measured During Running. Journal of Applied Biomechanics 2014 30: 166–172. (PubMed)
7. Cappozzo A, Catani F, Leardini A, Benedeti MG, Della CU. Position and orientation in space of bones during movement: Anatomical frame definition and determination. Clinical Biomechanics 1995; 10: 171-178. (PubMed)
8. Graydon, R, Fewtrell, D, Atkins, S, Sinclair, J. The test-retest reliability of different ankle joint center location techniques. Foot Ankle Online J. 2015; 8: 1-11. doi: 10.3827/faoj.2015.0801.0011
9. Sinclair, J, Hebron, J, Taylor, PJ. The Test-retest Reliability of Knee Joint Center Location Techniques. Journal of Applied Biomechanics 2015; 31: 117-121. doi: 10.1123/jab.2013-0312
10. Sinclair, J, Taylor, PJ, Currigan, G, Hobbs, SJ. The test-retest reliability of three different hip joint centre location techniques. Movement & Sport Sciences. 2014; 83: 31-39. doi: (Link)
11. Ward SR, Powers CM. The influence of patella alta on patellofemoral joint stress during normal and fast walking. Clinical Biomechanics 2004; 19: 1040–1047. (PubMed)
12. Bonacci J, Vicenzino B, Spratford W, Collins P. Take your shoes off to reduce patellofemoral joint stress during running. British Journal of Sports Medicine, (In press). (Link)
13. Kulmala JP, Avela J, Pasanen K, Parkkari J. Forefoot strikers exhibit lower running-induced knee loading than rearfoot strikers. Medicine & Science in Sports & Exercise 2013; 45: 2306-2313. (PubMed)
14. Sinclair J. Effects of barefoot and barefoot inspired footwear on knee and ankle loading during running. Clinical Biomechanics 2014; 29: 395-399. (PubMed)
15. Ho, KY, Blanchette MG, Powers CM. The influence of heel height on patellofemoral joint kinetics during walking. Gait & Posture 2012; 36: 271-275. (PubMed)
16. van Eijden TM, Kouwenhoven E, Verburg J, Weijs WA. A mathematical model of the patellofemoral joint. Journal of Biomechanics 1986; 19: 219–229, 1986. (PubMed)
17. Powers CM, Lilley JC, Lee TQ. The effects of axial and multiplane loading of the extensor mechanism on the patellofemoral joint. Clinical Biomechanics 1998; 13: 616–624. (PubMed)
18. Sinclair, J, Taylor, PJ, Atkins, S. Influence of running shoes and cross-trainers on Achilles tendon forces during running compared with military boots. Journal of the Royal Army Medical Corps 2015; 161: 140-143. (PubMed)
19. Self, BP, Paine, D. Ankle biomechanics during four landing techniques. Medicine & Science in Sports & Exercise 2001; 33: 1338–1344.
20. Selvanetti, ACM, Puddu, G. Overuse tendon injuries: basic science and classification. Operative Techniques in Sports Medicine 1997; 5: 110–17. (Link)
21. Kirkendall, DT, Garrett W.E. Function and biomechanics of tendons. Scandinavian. Journal of Medicine & Science in Sports 1997; 7: 62–66. (PubMed)