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THE EFFECTS OF BAREFOOT AND BAREFOOT INSPIRED FOOTWEAR RUNNING ON TIBIOFEMORAL KINETICS

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ABSTRACT
Purpose. The current investigation aimed to examine the effects of running barefoot and in conventional and barefoot inspired footwear on the loads borne by the tibiofemoral joint. **Methods.** Fifteen male participants ran at 4.0 m/s over a force platform whilst running barefoot, in barefoot inspired footwear and also in conventional footwear. Lower body kinematics were collected using an eight-camera motion capture system. Peak tibiofemoral force, peak tibiofemoral stress, and tibiofemoral load rate were extracted and compared between footwear via one-way repeated measures ANOVA. **Results.** The results showed that the tibiofemoral instantaneous load rate was significantly lower in conventional footwear (106.63 BW/s) in comparison with barefoot running (173.87 BW/s), Vibram Five Fingers (160.17 BW/s), Merrell (155.32 BW/s), Inov-8 (167.79 BW/s), and Nike Free (144.72 BW/s). **Conclusions.** This indicates that running barefoot and in barefoot inspired footwear may place runners at increased risk from running-related tibiofemoral pathologies.

Key words: footwear, biomechanics, tibiofemoral, running

Introduction

Running is known to generate a vast array of physiological benefits to those who partake in this training modality [1]. Both competitive and recreational runners are however renowned for their susceptibility to overuse pathologies; as many as 80% of all runners will ultimately experience a chronic injury during one year of training/competition [2].

The knee joint has been demonstrated as being the musculoskeletal structure most susceptible to chronic pathology in runners [2]. Tibiofemoral pathologies are a common complaint in runners which may account for up to 16.8% of all knee injuries [3]. The initiation of knee osteoarthritis is mediated by mechanical stimuli [4]. The pathogenesis of tibiofemoral overuse injuries relates to the magnitude and frequency of the loads experienced by the joint during running, which represent the initiating mechanism that causes the onset of knee osteoarthritis [5, 6]. High tibiofemoral loads that are applied too frequently without sufficient rest have been shown to initiate the process of articular cartilage degradation [7, 8].

Given the extremely high incidence of chronic running pathologies, there has been extensive research into mechanisms by which these injuries may be controlled. It has been speculated that appropriate footwear is a modality by which the incidence of running injuries can be attenuated [9]. However, barefoot running has recently become the subject of increased research and commercial attention in the field of biomechanics [10]. The increased attractiveness of barefoot locomotion is borne out of the hypothesis that barefoot running may be associated with a lower prevalence of chronic running injuries [11]. Taking into account the popularity of running without shoes and propositions regarding injury prevention, barefoot inspired shoes have been developed with the goal of transferring the perceived advantages of barefoot movement into a shod condition [10].

A select number of investigations have examined the influence of running barefoot and in barefoot inspired footwear on knee joint kinetics. Bonacci et al. [12] compared the impact of barefoot and shod running on patellofemoral kinetics during the stance phase of running. Their results showed that running barefoot significantly reduced patellofemoral loading. Sinclair [13] examined the effects of barefoot and barefoot inspired footwear running on patellofemoral kinetics. The findings showed that peak patellofemoral forces were significantly reduced in running barefoot and in the least cushioned barefoot inspired footwear. Finally, Sinclair et al. [14] analysed the effects of barefoot inspired, conventional, and maximalist footwear on patellofemoral kinetics. They showed that peak patellofemoral force and patellofemoral force experienced per mile were significantly reduced in minimalist footwear. However, whilst there is information available in biomechanical literature regarding the effects of running barefoot and in barefoot inspired footwear on patellofemoral kinetics, there has yet to be any published research concerning their influence on tibiofemoral loading.

The aim of the current study was therefore to examine the effects of running barefoot, as well as in conventional and barefoot inspired footwear on the loads borne by the tibiofemoral joint. Given the high incidence of chronic tibiofemoral pathologies in runners, this study may give important information to runners regarding the selection of appropriate footwear.

Material and methods

Participants

Fifteen male participants took part in this study. The mean characteristics of the participants were: age 24.77 ± 3.04 years, height 1.78 ± 0.11 m, and body mass 75.24 ± 4.88 kg. All participants were free from lower extremity injury at the time of data collection and provided informed consent in written form. The procedure utilized for this investigation was approved by the University of Central Lancashire ethical committee.

Procedure

The participants completed five trials in which they ran through a 22-meter walkway at the average velocity of 4.0 m/s in each footwear condition. The participants struck an embedded piezoelectric force platform (Kistler Instruments) with their right (dominant) foot [15]. The force platform was collected with the frequency of 1000 Hz. The running velocity was controlled using timing gates (Smartspeed Ltd UK) and the maximum deviation of 5% from the pre-determined velocity was allowed.

Kinematic information from the stance phase of the running cycle was obtained using an eight-camera motion capture system (Qualisys Medical AB, Gothenburg, Sweden) with the 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 more than 20 N of vertical force was applied to the force platform.

Lower extremity segments were modelled in six degrees of freedom using the calibrated anatomical systems technique [16]. To define the segment co-ordinate axes of the right foot, shank and thigh, retroreflective markers were placed unilaterally onto the 1st metatarsal, 5th metatarsal, calcaneus, medial and lateral malleoli, medial and lateral epicondyles of the femur. To define the pelvis segment, further markers were positioned onto the anterior (ASIS) and posterior (PSIS) superior iliac spines. Carbon fibre 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 centres of the ankle and knee joints were delineated as the mid-point between the malleoli and femoral epicondyle markers [17, 18], whereas the hip joint centre was obtained using the positions of the ASIS markers [19]. Static calibration trials were collected in each footwear, 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.

Footwear

The shoes utilized during this study consisted of Saucony ProGrid Guide 2 (conventional), Vibram Five Fingers, Merrell Bare Access, Inov-8 Evoskin, and Nike Free 3.0. The shoes were the same for all runners; they differed in size only (sizes 8–10 in men's shoe UK sizes).

Processing

Movement trials were digitized using the Qualisys Track Manager, then exported as C3D files into Visual 3D (C-Motion, Germantown, MD, USA). Ground reaction force and kinematic data were smoothed using cut-off frequencies of 25 and 15 Hz with a low-pass Butterworth 4th order zero lag filter.

Tibiofemoral kinetics was computed using Newton-Euler inverse dynamics. To quantify joint forces, anthropometric data, ground reaction forces, and angular kinematics were applied. The net joint forces were normalized by dividing the values by each participant's bodyweight (BW). Contact stress (MPa) was calculated as a function of the contact force divided by the tibiofemoral contact area. The contact area was determined by fitting a polynomial curve to the data of Shiramizu et al. [20], which documented tibiofemoral contact areas at varying levels of knee flexion. From these data, peak tibiofemoral force and stress (defined as the greatest values of tibiofemoral force/stress during the stance phase) were extracted for statistical analysis.

In addition, tibiofemoral load rate (BW/s) was quantified as a function of the change in force from initial contact to peak force divided by the duration over which the force occurred. Tibiofemoral instantaneous load rate (BW/s) was also calculated as the maximum rate of change in tibiofemoral force during the stance phase.

Statistical analyses

Means and standard deviations of tibiofemoral kinetics were calculated for each footwear condition. Differences between footwear were examined using one-way repeated measures ANOVA, with significance accepted at the $p \leq 0.05$ level [21]. Effect sizes were calculated with partial eta squared ($p\eta^2$). Shapiro-Wilk tests were used to screen the data for normality, which confirmed that the normality assumption was not violated. All statistical analyses were conducted using SPSS v22.0 (SPSS Inc., Chicago, USA).

Results

Table 1 and Figure 1 present footwear differences in tibiofemoral kinetics.

Table 1. Tibiofemoral kinetics as a function of footwear

	Barefoot		Conventional		Vibram Five Fingers		Inov-8		Merrell		Nike Free	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Peak tibiofemoral force (BW)	2.24	0.34	2.36	0.38	2.29	0.25	2.30	0.31	2.34	0.37	2.25	0.29
Peak tibiofemoral stress (MPa)	7.92	1.33	8.30	1.24	8.12	0.96	8.09	0.99	8.28	1.39	7.89	1.28
Tibiofemoral load rate (BW/s)	42.87	36.68	32.62	5.28	30.93	6.51	40.00	19.54	37.00	10.06	37.32	20.46
Tibiofemoral instantaneous load rate (BW/s)*	173.87	75.08	106.63	24.68	160.17	58.76	167.79	68.29	155.32	46.45	144.72	39.93

* significant main effect

A significant main effect ($p < 0.05$, $p\eta^2 = 0.31$) was shown for the instantaneous load rate. *Post-hoc* pairwise comparisons proved that the instantaneous load rate was significantly lower in the conventional footwear in relation to all of the other footwear conditions. No further significant differences ($p > 0.05$) were observed.

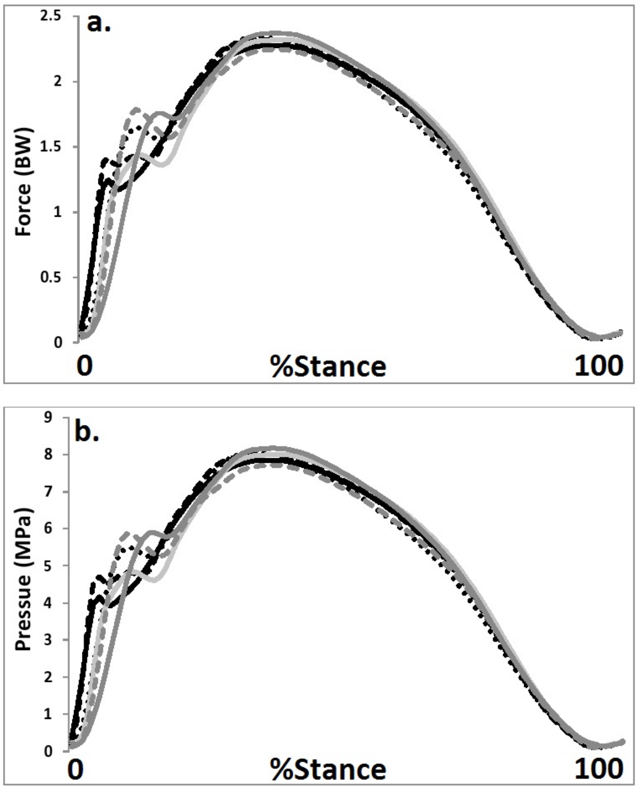

Figure 1. Tibiofemoral force (a) and stress (b) as a function of footwear (black – barefoot running, dot – Merrell, dash – Inov-8, light grey – Vibram Five Fingers, dark grey – conventional footware, dark grey dash – Nike Free)

Discussion

The aim of the current investigation was to examine the effects of running barefoot and in barefoot inspired footwear on the loads borne by the tibiofemoral joint. This represents the first study to comparatively examine the effects of barefoot and barefoot inspired footwear running on tibiofemoral kinetics.

The key observation from this work is that instantaneous tibiofemoral load rate was significantly larger in conventional footwear in relation to each of the barefoot inspired models tested as part of the study. This finding may be clinically important regarding the aetiology of chronic tibiofemoral injuries. It is widely accepted that the initiation of tibiofemoral degeneration occurs as a function of excessive tibiofemoral joint loading [5]. Therefore, given the high incidence of tibiofemoral chronic pathologies in runners [2], conventional footwear may be a potential mechanism by which runners are able to attenuate injury risk.

This finding opposes the results of previous work, which investigated the effects of barefoot inspired footwear on patellofemoral kinetics during running. Barefoot inspired footwear has habitually been shown to reduce the loads borne by the patellofemoral joint [12–14]. It can be speculated that the lack of agreement between studies relates to the distinct nature loading between the two knee joint articulations. This finding indicates that further study into the effects of tibiofemoral kinetics as well as patellofemoral kinetics is required.

The current research findings should be further appraised by taking into the account the increased step rate typically observed when running barefoot and in barefoot inspired footwear [14]. Therefore the increase in tibiofemoral loading is likely to be further accentuated, taking into account the increased number of steps required to complete a set distance when running barefoot and in barefoot inspired footwear. It can be hypothesized that the cumulative load experienced by a joint would be substantially larger when investigating tibiofemoral kinetics over a predefined distance as opposed to a single foot fall.

A potential limitation of the current work is that only habitually shod runners were examined during data collection. This may limit the generalizability of the findings as they cannot be related to those who customarily run barefoot and in barefoot inspired footwear. Previous research, investigating the effects of barefoot and barefoot inspired footwear, has shown conflicting results. Research which has examined those who habitually run barefoot or in barefoot inspired footwear has shown that these conditions serve to reduce impact loading [11, 22], whereas studies involving habitually shod runners have shown the opposite [23, 24]. Therefore it can be speculated that the results of this work may have been different had the sample habitually run barefoot or in barefoot inspired footwear. It is important for the current study to be repeated among a group of habitual barefoot runners / barefoot inspired footwear users before comprehensive assertions regarding injury predisposition can be made.

Conclusions

In conclusion, although the effects of running barefoot and in barefoot inspired footwear have been extensively studied in biomechanical literature, the current knowledge regarding the differences in tibiofemoral kinetics when running with these footwear conditions is lacking. The current investigation thus adds to the current literature base by presenting an examination of tibiofemoral kinetics when running barefoot and in barefoot inspired footwear. The findings from this study showed conventional footwear significantly reduced tibiofemoral kinetics in relation to barefoot conditions and barefoot inspired footwear. Therefore this indicates that running barefoot and in barefoot inspired footwear may place runners at increased risk from running-related tibiofemoral pathologies.

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