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Loading rate increases during barefoot running in habitually shod runners: Individual responses to an unfamiliar condition

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ABSTRACT

The purpose of this study was to examine the effect of barefoot running on initial loading rate (LR), lower extremity joint kinematics and kinetics, and neuromuscular control in habitually shod runners with an emphasis on the individual response to this unfamiliar condition.

Kinematics and ground reaction force data were collected from 51 habitually shod runners during overground running in a barefoot and shod condition. Joint kinetics and stiffness were calculated with inverse dynamics. Inter-individual initial LR variability was explored by separating individuals by a barefoot/shod ratio to determine acute responders/non-responders.

Mean initial LR was 54.1% greater in the barefoot when compared to the shod condition. Differences between acute responders/non-responders were found at peak and initial contact sagittal ankle angle and at initial ground contact. Correlations were found between barefoot sagittal ankle angle at initial ground contact and barefoot initial LR.

A large variability in biomechanical responses to an acute exposure to barefoot running was found. A large intra-individual variability was found in initial LR but not ankle plantar–dorsiflexion between footwear conditions. A majority of habitually shod runners do not exhibit previously reported benefits in terms of reduced initial LRs when barefoot. Lastly, runners who increased LR when barefoot reduced LRs when wearing shoes to levels similar seen in habitually barefoot runners who do adopt a forefoot-landing pattern, despite increased dorsiflexion.

1. Introduction

Barefoot running (BR) is promoted as a means to reduce the incidence of running related injury [1,2], particularly in the lay media, despite research that is in its infancy. Whether BR is an effective method of reducing injury risk and improving performance is equivocal. Currently, behaviour is driven by anecdotal evidence and testimonies of influential people, sufficient to drive a burgeoning industry.

A conclusive study, particularly a prospective injury study [3], is yet to appear. However, given the complexity of injury aetiology [4] combined with a poorly understood individual variability in response to BR [2], it may be unrealistic to expect this definitive study. Another approach could be to evaluate the individual responses in the acute biomechanical changes occurring between shod and BR. Thus, future findings can be explained as a function of predicting which runners might respond positively or negatively to the various footwear conditions.

Previous research has focused on factors hypothesized to be associated with running injuries [4–6], assessing differences between shod and BR that may predict injury risk. Early BR research focused on initial loading rate (LR) as factor previously associated with some typical running injuries [7]. This was found to be reduced in habitual barefoot runners who land on their forefoot [2,8]. Thus, it became core to the advocacy of BR and was proposed as a means to reduce this purported injurious factor.

Importantly, this purported benefit does not exist for all runners when barefoot, though this was not acknowledged in that

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study [2,9]. That is, the proposed favourable reduction in LR when barefoot was present only in those runners who assumed a forefoot landing [2], and who may thus be considered acute 'responders'. Conversely, those continuing to heelstrike (may be considered acute 'non-responders'), experienced barefoot LRs greater than double that of shod [2,10]. Recently, higher LRs in minimalist shoes when compared to traditional running shoes have also been reported and numerous other studies have linked heelstriking and injury risk as a result of higher LR [11,12].

The implication of these findings is important for potential adoption of BR, because they suggest the need for individualized recommendations. However, recommendations cannot be comprehensive until the acute and longitudinal biomechanical response to BR is better understood. This will remain true even after prospective studies to examine injury risk have been conducted, since any differences in injury outcomes in those studies may be explained by inter- and intra-individual differences in neuromuscular and biomechanical variables, which remain equivocal.

Accordingly, the present study aimed to examine the effect of acute exposure to BR on initial LRs, lower extremity joint biomechanics in habitually shod runners. We hypothesized that habitually shod runners would present with greater LRs when running barefoot ("acute non-responders") in those who continued to land in ankle dorsiflexion. Further we aim to identify biomechanical changes that were associated with this increase. We also hypothesized that shoes would reduce LRs in these "acute non-responders", irrespective of footstrike.

2. Methods

2.1. Participants

Fifty-one habitually shod (traditional cushioned shoes) male runners volunteered to participate in this study. Participants were able to run 10 km in <50 min and were injury free for six months prior to the study. Participants provided written informed consent and were fully aware of the benefits and potential risks associated with the study. The study was granted ethical approval by the Human Research Ethics Committee of the study institution.

2.2. Experimental conditions

Biomechanical testing was conducted under two different conditions. (1) Barefoot and (2) in the running shoe in which they were currently completing the most training mileage. All shod midsoles comprised of traditional ethylene vinyl acetate (EVA) cushioned shoes and were not controlled for mileage, shore count or heel–toe drop except in the case of a marketed minimalist shoe. The runners were afforded a familiarization (two lengths of the running track) in condition before performing the running trials.

2.3. Instrumentation

Running trials were conducted on a 40 m indoor synthetic running track. Three-dimensional marker trajectories were captured using an 8-camera VICON MX motion analysis system (Oxford Metrics Ltd, Oxford, UK), sampling at 250 Hz. Ground reaction force (GRF) data were collected using a 900 mm × 600 mm force platform (AMTI, Watertown, MA, USA), sampling at 2000 Hz. Sixteen Reflective markers were attached according to the lower body PlugInGait model.

2.4. Procedures

Participants completed 6 clean overground running trials in each footwear condition in a randomized order, with no instruction to running style. The speed of overground running trials was set based on the participant's current 10 km performance pace (within a month). Trials were accepted if the velocity was within ±5% of the target speed. During these runs, synchronized collection of marker motion and force platform measurements were obtained, a successful trial was defined as one within the specified velocity range, where all markers were in view of the cameras and there was no visual evidence of force platform targeting.

Marker trajectory and force platform data were filtered using a low-pass fourth-order Butterworth filter with a cut-off frequency at 20 and 100 Hz respectively. For each trial, one complete stance phase of the gait cycle was analyzed. Three-dimensional lower extremity joint angles and net resultant joint moments using a Newton–Euler inverse dynamics approach were calculated [15]. Three-dimensional joint moments were expressed as external moments normalized to body mass (Nm/kg).

2.5. Data analysis

The data for each participant's right limb were averaged over 6 trials for each condition. Sagittal, and frontal plane ankle and knee angles (degrees) and moments (Nm/kg) are reported. Specifically, discrete variables at initial ground contact, maxima during stance were extracted. Further, peak vertical ground reaction force (vGRF in body weight (BW) units) and initial vertical LR (BW/s) was quantified between 200 N and 90% of the first impact peak of the vGRF [2,16]. When no distinct first impact peak was present, the same parameters were measured using the average percentage of stance ±1 standard deviation as determined for each condition in trials with an initial impact peak [2]. Sagittal plane joint stiffness for the ankle joint was calculated as the angular distance from initial touchdown to the maximum dorsiflexion angle during stance, as was the magnitude of the moment at the same points. A linear fit of the slope of the torque-angle profile produced the magnitude of the ankle stiffness [17]. Knee joint stiffness was calculated similarly.

Intra-individual variability to each condition was assessed by comparing the standard deviation of the six trials collected from each runner's initial loading rate and sagittal ankle flexion angle at initial ground contact. Exploration into the acute ability to present lower initial LRs when barefoot compared to shod were conducted. For ease of comparison, where the average individual's shod LR was greater than the barefoot LR, were categorized as SHOD > BF and the vice versa is expressed as BF > SHOD. Two groups resulted from this separation of LR and as defined above with subsequent sub-analysis of associated biomechanical and neuromuscular variables between the two groups.

2.6. Statistical analysis

Data were screened for normality of distribution and homogeneity of variances using a Shapiro–Wilk's Normality Test. Differences between the two groups were compared using *t*-tests or non-parametric Wilcoxon signed-rank test. The false discovery procedure was used to account for multiple comparisons set at 0.01. This practical method overcomes some of the pitfalls associated with other common techniques (Bonferroni, Newman–Keuls and least square difference). Only significant variables are reported post-adjustments with the original *p*-value. Two-way ANOVA (condition × LR response group) was used for differences between acute non- and responders. Pearson and Spearman's Rho correlations were used to determine relationships between variables of interest. Original statistical significance was set at $p < 0.05$. Data are presented as means ± standard deviations unless stated otherwise.