Short Communication

Kinematic and kinetic comparison of barefoot and shod running in mid/forefoot and rearfoot strike runners

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ABSTRACT

Barefoot running has been associated with decreased stride length and switching from a rearfoot strike (RFS) pattern to a mid/forefoot strike (M/FFS) pattern. However, some individuals naturally contact the ground on their mid/forefoot, even when wearing cushioned running shoes. The purpose of this study was to determine if the mechanics of barefoot running by natural shod RFS runners differed from natural shod M/FFS runners. Twenty habitually shod runners (ten natural M/FFS and ten natural RFS) participated in this study. Three-dimensional motion analysis and ground reaction force data were captured as subjects ran at their preferred running speed in both barefoot and shod conditions. M/FFS experienced only a decrease in stride length when switching from shod to barefoot running. Whereas, when switching from shod to barefoot running, RFS individuals experienced a decrease in stride length, switched to a plantarflexed position at ground contact and saw reduced impact peak magnitudes. These results suggest that when barefoot, the RFS group ran similar to the M/FFS group running barefoot or shod.

1. Introduction

Barefoot running has received considerable attention in the scientific literature as of late [1]. Much of the interest has been driven by media claims of potential performance benefits and reduced injury risk. Barefoot running results in gait alterations that may lead to these proposed benefits. Gait alterations associated with barefoot running include decreased stride length [2–4] and switching from a rearfoot strike (RFS) pattern when shod to a mid/forefoot strike (M/FFS) pattern when running barefoot [2,3,5]. However, it is estimated that 72–89% of individuals are RFS runners, while the remainder M/FFS even when wearing cushioned running shoes [5,6]. The purpose of this study was to determine if the mechanics of barefoot running by natural shod RFS runners differed from natural shod M/FFS runners.

2. Material and methods

Ten healthy, injury free, natural M/FFS individuals [5 men, 5 women; age: 28 ± 5.9 years; height: 1.71 ± 0.08 m; mass: 70.8 ± 10.3 kg] and RFS individuals [5 men, 5 women; age: 29 ± 6.0 years; height: 1.70 ± 0.09 m; mass: 65.3 ± 8.6 kg] volunteered for this study. Foot strike was verified by motion analysis, with M/FFS defined as a foot strike angle $<0°$ and RFS defined as a foot strike angle $>0°$ [7]. The University of Idaho's Institutional Review Board approved this study.

2.1. Protocol

Three-dimensional motion analysis and ground reaction force (GRF) data were captured as subjects ran over a 15 m runway with an embedded force plate (AMTI, Waterton, MA). Subjects ran with their preferred running gait (i.e., self-selected stride length and velocity) in both barefoot (BF) and shod (SHOD) conditions. To

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familiarize to each condition subjects ran for 10 min prior to data collection. Ten strides from ten separate trials, in which the subject contacted the force plate, were used to calculate participant mean data for each condition. Trials in which velocity or stride length differed by >5% were excluded.

2.2. Kinematics and kinetics

Sixteen retro-reflective markers were affixed to anatomical landmarks according to Kadaba et al. [8]. Three-dimensional marker positions were captured at 250 Hz via a Vicon MX system (Vicon, Oxford Metrics, UK). Marker trajectory data were filtered using a Woltring filter with predicted mean square error of 4 mm^2. The three orthogonal components of the GRF were recorded at 1000 Hz in synchrony with motion data. Force data were low-pass filtered at 30 Hz using a second-order Butterworth filter before being combined with motion data. Stride length was measured as the horizontal distance between ipsilateral heel marker minima. Impact peak magnitude was measured as the first observable peak in the vertical GRF (vGRF). If the impact peak was absent, no value was recorded.

2.3. Statistics

Two-sample Hotelling tests were used to compare spatio-temporal variables and lower extremity kinematics at ground contact between M/FFS and RFS groups in the BF and SHOD conditions (dependent variables: stride length, velocity; 3D ankle, knee and hip joint angles). One-sample Hotelling tests were used to compare peak kinematics (dependent variables: 3D ankle, knee and hip joint angles) and peak kinetics (dependent variables: 3D GRFs and impact peak magnitude) between the BF and SHOD conditions for the M/FFS and RFS groups. For significant multivariate results ($p < 0.05$), t-tests were performed to find which variable(s) made the significant difference ($p < 0.05$).

3. Results

The M/FFS and RFS groups both showed a significant decrease in stride length when switching from shod to barefoot running. The RFS group had an 8.0% reduction in stride length ($p = 0.008$), and the M/FFS group experienced a 6.3% decrease ($p < 0.001$) (Table 1). There were no significant differences between RFS and M/FFS groups in stride length ($p = 0.177$) or velocity ($p = 0.160$) (Table 1).

3.1. Kinematics at ground contact

Lower extremity kinematics at ground contact differed significantly between M/FFS and RFS groups in the SHOD condition ($p = 0.0002$). RFS runners switched from a dorsiflexed position when SHOD [9.8 (5.1)°] to a plantarflexed position at ground contact when BF [−3.3 (8.7)°] ($p < 0.0001$) (Fig. 1). M/FFS individuals maintained a plantarflexed position when switching from SHOD to BF running [SHOD: −4.1 (6.3)°, BF: −5.3 (4.6)°] (Fig. 1). The M/FFS group had greater knee internal rotation at ground contact in the BF and SHOD conditions [SHOD: −13.8 (7.0)°, BF: −14.4 (5.9)°] than the RFS group [SHOD: −22.5 (8.9)°, BF: −20.2 (13.9)°] ($p = 0.026$) (Table 1).
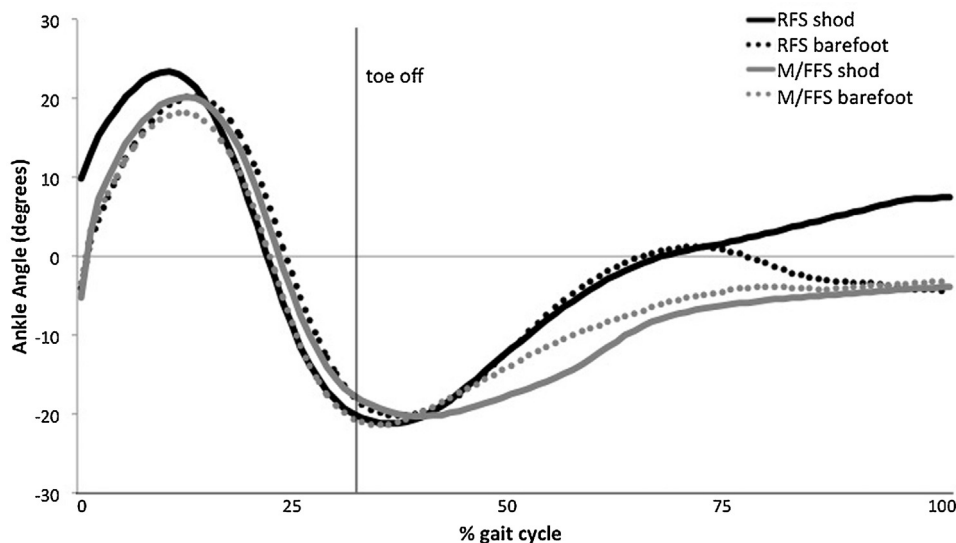
3.2. Peak values

The RFS runners showed a significant difference in peak kinetics between SHOD and BF running ($p = 0.0008$). The RFS SHOD and RFS BF conditions differed significantly in terms of vGRF ($p = 0.006$) and medio-lateral GRF (mlGRF) ($p = 0.008$) (Table 1). Impact peak magnitude in the RFS SHOD condition was significantly greater than the RFS BF ($p = 0.045$) and M/FFS SHOD ($p = 0.041$) conditions (Table 1). In the M/FFS group, there were no significant differences in peak kinetics between SHOD and BF conditions (Table 1). Peak kinematics did not differ significantly between any conditions.

4. Discussion

The only difference when from switching from shod to barefoot running in M/FFS subjects was a decrease in stride length. Alternatively, RFS individuals experienced gait changes commonly associated with barefoot running [1]; including decreased stride length, a plantarflexed position at ground contact and reduced impact peak magnitude. These changes reflect that when running barefoot, the RFS group ran similar to the M/FFS group.

The primary kinematic difference between SHOD M/FFS and RFS runners was ankle position at ground contact. RFS individuals contacted the ground with the ankle dorsiflexed, which requires the tibialis anterior to decelerate plantar flexion and has been associated with increased lower leg anterior compartment pressures [9]. Alternatively, the plantarflexed position adopted by M/FFS runners requires the triceps surae to slow dorsiflexion and has been associated with higher achilles tendon strain and plantar flexor moments [10,11].

Despite the fact that subjects ran at their preferred velocity in all conditions, velocity differences between conditions were non-significant. It is unlikely that the small magnitude differences in velocity affected kinematics or kinetics [12]. In the present study,

Table 1
Kinematic and kinetic data.

	RFS		M/FFS	
	SHOD	BF	SHOD	BF
Stride length/leg length	**2.53 (0.27)**[#]	**2.34 (0.24)**[#]	**2.62 (0.23)**[#]	**2.46 (0.24)**[#]
Velocity (m/s)	3.13 (0.30)	3.01 (0.28)	3.35 (0.56)	3.19 (0.54)
Lower extremity kinematics at ground contact				
Ankle dorsiflexion (°)	**9.8 (5.1)**[*,#]	**−3.3 (8.7)**[#]	**−5.3 (4.6)**[*]	−4.1 (6.3)
Ankle adduction (°)	−1.9 (3.6)	1.9 (7.3)	−0.6 (3.4)	0.8 (2.4)
Ankle internal rotation (°)	8.05 (12.0)	4.2 (16.3)	0.5 (13.6)	−3.3 (11.3)
Knee flexion (°)	11.8 (7.9)	13.9 (8.8)	14.3 (4.7)	13.9 (6.9)
Knee varus (°)	−1.6 (7.4)	2.9 (8.1)	2.2 (5.9)	3.7 (5.6)
Knee internal rotation (°)	**−22.5 (8.9)**[*]	**−20.2 (13.9)**[*]	**−13.8 (7.0)**[*]	**−14.4 (5.9)**[*]
Hip flexion (°)	38.1 (7.5)	35.4 (8.5)	34.8 (8.1)	33.6 (7.7)
Hip adduction (°)	7.5 (4.0)	4.8 (5.3)	7.6 (3.8)	6.3 (3.7)
Hip internal rotation (°)	12.2 (8.6)	13.5 (10.2)	13.8 (19.3)	12.9 (18.2)
Peak kinetics				
Peak vGRF (BW)	**2.44 (0.33)**[#]	**2.21 (0.49)**[#]	2.46 (0.42)	2.48 (.42)
Peak positive apGRF (BW)	0.24 (0.06)	0.24 (0.12)	0.29 (0.05)	0.26 (0.10)
Peak mlGRF (BW)	**0.12 (0.06)**[#]	**0.09 (0.05)**[#]	0.17 (0.07)	0.12 (0.06)
Impact peak (BW)	**1.77 (0.20)**[*,#]	**1.52 (0.17)**[#]	**1.51 (0.26)**[*]	1.52 (0.10)

Data are mean (standard deviation). Significant results are shown in bold.
[*] Significant difference between M/FFS and RFS for a given shoe condition (BF or SHOD) ($p < 0.05$).
[#] Significant difference between BF and SHOD for a given foot strike (M/FFS or RFS) pattern ($p < 0.05$).

Fig. 1. Ensemble average sagittal plane ankle angle for a complete step. M/FFS (gray) and RFS (black) running in the SHOD (solid) and BF (dashed) conditions. There was a significant interaction of foot strike and shoe condition at ground contact (i.e., 0%).

both M/FFS and RFS runners reduced stride length when barefoot. Reduced stride length is commonly associated with barefoot running and it has been proposed that this is due to shoes limiting proprioception by blocking stimulation of the foot's mechanoreceptors [13,14]. It is possible that improved proprioception when barefoot triggers the plantarflexed position at ground contact in RFS runners.

Similar to previous studies, we found lower impact peak magnitudes in SHOD M/FFS runners than in SHOD RFS runners [3,5]. It has been proposed that M/FFS runners absorb impact through compression of the arch of the foot, eccentric contraction of the triceps surae, and achilles tendon stretch [5]. Alternatively, in RFS running impact absorption is limited to the heel pad and shoe, leading to higher impact peak magnitudes [15]. In the present study, RFS runners adopted a plantarflexed position at ground contact when barefoot, leading to impact peak magnitudes similar to the M/FFS group. Conversely, there was no difference in impact peak magnitude when M/FFS runners ran barefoot. These results indicate that RFS runners adopt a M/FFS pattern when running barefoot in an attempt to reduce impact peak magnitudes and loading rates.

The results presented here show that natural RFS runners run similar to natural shod M/FFS runners when running barefoot. The results of this study indicate the importance of considering foot strike when evaluating the effects of barefoot and shod running.

Conflict of interest

None of the authors report a conflict of interest.

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