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Original article

Can minimal running shoes imitate barefoot heel-toe running patterns? A comparison of lower leg kinematics

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Abstract

Background: Numerous studies about the interaction between footwear (and barefoot) and kinematic and kinetic outcomes have been published over the last few years. Recent studies however lead to the conclusion that the assumed interactions depend mainly on the subjects' experience of barefoot (BF) walking/running, the preferred running strike pattern, the speed, the hardness of the surface, the thickness of the midsole material, and the runners' level of ability. The aim of the present study was to investigate lower leg kinematics of BF running and running in minimal running shoes (MRS) to assess comparability of BF kinematics in both conditions. To systematically compare both conditions we monitored the influencing variables described above in our measurement setup. We hypothesized that running in MRS does not alter lower leg kinematics compared to BF running.
Methods: Thirty-seven subjects, injury-free and active in sports, ran BF on an EVA foam runway, and also ran shod wearing Nike Free 3.0 on a tartan indoor track. Lower-leg 3D kinematics was measured to quantify rearfoot and ankle movements. Skin markers were used in both shod and BF running.
Results: All runners revealed rearfoot strike pattern when running barefoot. Differences between BF and MRS running occurred particularly during the initial stance phase of running, both in the sagittal and the frontal planes. BF running revealed a flatter foot placement, a more plantar flexed ankle joint and less inverted rearfoot at touchdown compared to MRS running.
Conclusion: BF running does not change the landing automatically to forefoot running, especially after a systematic exclusion of surface and other influencing factors. The Nike Free 3.0 mimics some BF features. Nevertheless, changes in design of the Nike Free should be considered in order to mimic BF movement even more closely.
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Keywords: 3D-kinematics; Ankle; Barefoot; Minimal running shoes; Rearfoot; Running

1. Introduction

Advantages and disadvantages of barefoot (BF) running have been of major interest for numerous years, scientifically as well as in the running population. As a consequence of this, there have been numerous concepts and products on the market that mimic specific aspects of BF movement, shape, or feeling, "suggesting that some of the perceived advantages of barefoot running are transferred into a shod condition".[1] Scientifically, publications and discussions about advantages and disadvantages of BF running increased tremendously after a publication by Lieberman et al.[2] in *Nature*.

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Numerous studies about the interaction between shod and BF kinematic and kinetic outcomes have been published over the last few years and described by Nigg[1] and Nigg and Enders.[3] Most of these studies were based on the comparison of running in traditional running shoes (TRS) and BF running. Recent studies however lead to the conclusion that the assumed interactions depend mainly on the subjects' experience with BF walking/running,[2,4–8] the preferred running strike pattern,[9,10] the speed,[11] the hardness of the surface,[12] the thickness of the midsole material,[13] and the runners' level.[10] A few studies[4–7] have already included minimal running shoes (MRS) into their setup.

To systematically analyze suggested "barefoot features" in given MRS and compare with the BF situation, it is necessary to take the above-mentioned criteria into account. Therefore, studies should monitor the subjects' experience in BF walking/running (unexperienced or experienced), the preferred running strike pattern (rearfoot, midfoot, forefoot), the running speed (typical running speed, depending on runners' level and gender), the hardness of surface (hardness of BF running surface comparable to midsole hardness of MRS), the thickness of midsole material (one thickness) and the subject's athletic level (recreational, elite). Further, skin mounted markers should be used[14] as shoe-mounted markers are not adequate to assess the in-shoe foot motion, and consequently overestimate its real motion. Although these results have been shown for TRS with stiff heel counters, the flexible heel counter of MRS might have an even greater influence on the resultant rearfoot and ankle kinematics.

The aim of the present study was to investigate lower leg kinematics of BF running and running in MRS (Nike Free 3.0; Nike Inc., Beaverton, OR, USA) to assess comparability of BF kinematics in both conditions. Furthermore, we aimed to find out if foot strike characteristics remained the same after monitoring the influencing variables described above in our measurement setup. We hypothesized that running in MRS does not alter lower leg kinematics compared to BF running and that foot strike pattern remained the same in both conditions.

2. Materials and methods

2.1. Subjects

Overall, 37 subjects were included in the study (Table 1). All subjects were rearfoot strikers (visually inspected beforehand while running in their own TRS), free of any injury for at least 6 months prior to the study, recreational athletes (different sports) and aged between 18 and 55 years. None of the subjects had a history of or experience with BF running. The study complies with the Declaration of Helsinki, and all subjects signed a written consent form prior to the testing procedures.

2.2. Experimental setup

Three-dimensional kinematics was recorded with a six-camera infrared system (ViconPeak, MCam, M1; Oxford, UK) at a sampling frequency of 250 Hz. All runners ran BF on a 20-m EVA foam runway (shore hardness approx. 40), and shod wearing Nike Free 3.0 (shore hardness approx. 40) on a 20-m tartan indoor track. The height of the foam runway was 10 mm, comparable to the midsole/outsole heel height of MRS. The order of running conditions was randomized. Prior to the recorded measurements, sufficient time was allowed for the subjects to familiarize themselves with the laboratory setup and to get used to the running speed and surface to enable an individual running style. All subjects ran with a controlled running speed of 11 km/h monitored using a photoelectric barrier, and a running speed between 10.5 km/h and 11.5 km/h was accepted. The test speed of 11 km/h was chosen as this is an average running speed in recreational athletes, both for men and women. Touch-down was visually inspected to find out if subjects landed on the rearfoot or on the mid/forefoot.

Eighteen markers were placed on each subject according to the recommendations of the International Society of Biomechanics,[15] marking both shanks (medial and lateral tibia plateau, tibial tuberosity, medial tibial crest, lateral and medial malleoli), the foot (lateral, medial, and posterior calcaneus), and the hallux. Rearfoot markers were screwed to a short thread (∼1 cm) and screw sockets were attached to customized flexible plastic disks placed on the calcaneus to ensure their visibility and identical placement for both BF and shod conditions (Fig. 1) and to ensure a good fit of the markers with respect to the foot. Joint excursions were quantified by calculating Cardan angles according to Söderkvist and Wedin[16] with the foot segment rotating with respect to the shank segment (ankle dorsiflexion/plantarflexion, rearfoot inversion/eversion), or with respect to the global coordinate system (tibial rotation, sagittal ankle, and frontal rearfoot motion). Further, the first rotation was computed around the sagittal axis (dorsiflexion/plantarflexion), the second rotation around the frontal axis (inversion/eversion) and finally, the third rotation was computed around the transversal axis (external/internal rotation). For

Table 1
Overview of all subjects included in the study (mean ± SD).

Subject	*n*	Age (year)	BMI (kg/m^2)	Weight (kg)	Height (cm)	Running (h/week)	Exercising (h/week)
All	37	30 ± 9	22 ± 2	67 ± 12	175 ± 9	1 ± 2	5 ± 4
Male	14	26 ± 5	24 ± 2	78 ± 11	181 ± 7	1 ± 2	5 ± 4
Female	23	32 ± 11	21 ± 2	61 ± 6	170 ± 7	1 ± 1	6 ± 4

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