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Original article

Muscle activity and kinematics of forefoot and rearfoot strike runners

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Abstract

Background: Forefoot strike (FFS) and rearfoot strike (RFS) runners differ in their kinematics, force loading rates, and joint loading patterns, but the timing of their muscle activation is less clear.
Methods: Forty recreational and highly trained runners ran at four speeds barefoot and shod on a motorized treadmill. “Barefoot” runners wore thin, five-toed socks and shod runners wore neutral running shoes. Subjects were instructed to run comfortably at each speed with no instructions about foot strike patterns.
Results: Eleven runners landed with an FFS when barefoot and shod and eleven runners landed with an RFS when barefoot and shod. The 18 remaining runners shifted from an FFS when barefoot to an RFS when shod (shifters). Shod shifters ran with a lower stride frequency and greater stride length than all other runners. All FFS runners landed with more plantarflexed ankles and more vertical lower legs at the beginning of stance compared to RFS runners. FFS runners activated their plantarflexor muscles 11% earlier and 10% longer than RFS runners.
Conclusion: This earlier and longer relative activation of the plantarflexors likely enhances the capacity for the passive structures of the foot and ankle to store elastic energy, and may also enhance the performance of the active muscle by increasing the storage of elastic strain energy in the cross-bridges and activated titin.

Keywords: Barefoot; Forefoot strike; Gastrocnemius; Muscle activity; Rearfoot strike; Running

1. Introduction

In modern times, runners usually land on their heels using cushioned running shoes to absorb the impact.[1–3] The differences in foot position during landing are used to classify various running styles; “toe-heel-toe” running or forefoot strike (FFS), “flat-footed” running with a midfoot strike (MFS), or “heel-toe” running with a rearfoot strike (RFS).[4–6] The majority of habitual barefoot runners FFS or MFS, while the majority of habitual shod runners RFS.[5–9] Due to the lower occurrence of both FFS and MFS runners (5%–25%), they are often grouped together as an FFS running style, where the point of impact of the foot occurs anterior to the ankle joint.[5,7,8] These FFS and MFS running styles will result in similar dorsiflexion torques about the ankle and presumably similar muscle activation patterns to absorb that impact.

FFS runners experience no impact peak and lower loading rates of the ground reaction force compared to RFS runners.[3,5,10–12] Despite the higher load rate and magnitude of the impact peak during RFS running, RFS runners are more prevalent in modern times due to the development of the running shoe with a cushioned heel.[1] Before the cushioned heel in running shoes, humans ran without this protection and likely ran more often on the balls of their feet reducing the

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landing impact[5,11–14] and enhancing the storage and release of energy by the elastic structures in the leg and foot.[3,9,13,15]

Although most runners have a habitually preferred style, they can generally convert from an RFS style to an FFS style or *vice versa*, when requested.[9,15–17] For example, some habitually shod RFS runners can readily convert to an FFS style when running barefoot to reduce the pressure on their heels using similar kinematics and mechanics as habitual FFS runners.[12,17–19]

General gait kinematics (stride length and stride frequency) have been well studied when examining FFS and RFS running. FFS runners run with shorter stride lengths, higher stride frequencies, and shorter contact times with the ground.[11,16,20] FFS runners flex their knees more at strike, shortening their stride.[5,16,19] Bending the knees shortens the stride length during FFS running, which correspondingly increases the stride frequency.[2] Additionally a higher stride frequency means each stride takes less time resulting in shorter contact times with the ground.[11] Shorter stride lengths during FFS running also allow the runners to land with a more plantarflexed ankle and flatter foot to allow for the toe-heel-toe running style.[3,11–14,19]

Although the kinematics and landing forces have been well studied, the muscle activation patterns of barefoot or FFS running have been less commonly examined.[19,20] Habitual RFS runners activate their calf muscles differently in amplitude between barefoot and shod running.[20] For example, the pre-activation amplitude of the medial and lateral gastrocnemius muscles (MG and LG) are 24% and 14% greater, respectively, when barefoot compared to the shod condition using an RFS style.[20] The EMG amplitude of the gastrocnemius jumps to 400%–450% for the pre-activation, increases by only 28% during the stance phase, and are similar during the take-off phase during FFS running compared to that of RFS running.[19] The pre-activation of the plantarflexor muscles before landing would increase tension in the Achilles tendon allowing absorption of the impact of landing.[2,19,21] Furthermore, the activation of the plantarflexor muscles will stretch the tendons in the shank and foot, allowing for enhanced storage of energy in these elastic structures.[9,20] Instead of muscle activation amplitude, the current study focuses on the timing of the plantarflexor activation during FFS and RFS running.

We hypothesize that consistent FFS runners will activate their gastrocnemii muscles earlier than consistent RFS runners in order to stiffen the ankle,[12,16] resist the ground reaction forces acting to dorsiflex the ankle,[13,19,22] and lessen the internal ankle forces.[18] We also hypothesize that runners who switch between FFS and RFS styles depending on their footwear condition will change their muscle activity patterns as they switch between running styles to accommodate the different stride and joint kinematics during FFS *vs.* RFS running.[3,12,13,16,18,19] The current study aims to determine the muscle activity and stride patterns used to compensate for the different impact forces of barefoot and shod running, allowing insight into how FFS and RFS running styles influence the activity patterns of the gastrocnemii muscles and joint kinematics.

2. Materials and methods

2.1. Subjects

Forty runners (20 males and 20 females, ages 18–56, mean age = 29.0 ± 11.9 years) were recruited from Harvey Mudd College and the surrounding community. The subjects measured 1.72 ± 0.10 m in height and 65.15 ± 10.74 kg in weight. Of the 40 subjects, 21 were recreational runners who ran at least 8 miles per week for more than 1 year, while 19 subjects trained regularly and ran competitively, including ultramarathons. Four subjects self-reported using minimal running shoes, two subjects self-reported using Vibram Five-Finger shoes, and all other subjects used typical running shoes. The subjects were instructed to run comfortably at all speeds, with no instructions to use or convert to any particular foot strike pattern. All experiments were performed with Institutional Review Board approval from Harvey Mudd College and the Claremont Graduate University.

2.2. Running regimen

Subjects ran on a motorized treadmill at 2.5, 2.8, 3.2, and 3.5 m/s while wearing five-toed lightweight toesocks (45 g; Injinji, San Diego, CA, USA), which we considered to simulate being “barefoot”, and in a neutral running shoe (Asics GEL-Cumulus).[5,9,23] Subjects wore thin toesocks during the “barefoot” condition to hold in place and protect the pressure sensors as well as to prevent injury to the runners from the textured treadmill belt (see Section 2.3; Fig. 1). Since running in unloaded diving socks and Vibram FiveFinger shoes adequately imitate the mechanics and energetics of running barefoot, wearing lightweight five-toed socks should also adequately mimic barefoot running even though the sensory feedback may differ slightly.[9,11,13] The order of speeds while barefoot or shod was randomized. Each subject first ran at a self-selected comfortable speed for 2 min. Then, the subjects ran for 1 min to become adjusted to the new speed before a 30-s data collection period.

2.3. Gait kinematics

The timing of the stride cycles was determined from plantar pressures measured on the bottom of the foot. These plantar pressure forces were collected at 4000 Hz with a wireless data logger and four circular, 0.5″-diameter force sensing resistors placed below the metatarsal heads of the 1st, 4th, and 5th toes and the heel pad (Fig. 1; Myomonitor IV; Delsys Inc., Natick, MA, USA; Interlink Electronics, Camarillo, CA, USA).[24] The pressure sensor system allowed for immediate collection and processing of 20–30 sequential steps.[11,20] The pressure sensors were protected and held in place by five-toed socks (Injinji). Plantar pressure recordings were used to determine the average stride frequency, which in combination with running speed, further provided average stride length. The fraction of the stride period, where plantar pressure was measurable, underestimated the stance phase, because the