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Biomechanics of slow running and walking with a rocker shoe

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ABSTRACT

Evidence suggests a link between the loading of the Achilles tendon and the magnitude of the ankle internal plantar flexion moment during late stance of gait, which is clinically relevant in the management of Achilles tendinopathy. Some studies showed that rocker shoes can reduce the ankle internal plantar flexion moment. However, the existing evidence is not conclusive and focused on walking and scarce in running. Sixteen healthy runners participated in this study. Lower extremity kinetics, kinematics and electromyographic (EMG) signals of triceps surae and tibialis anterior were quantified for two types of shoes during running and walking. The peak ankle plantar flexion moment was reduced significantly in late stance of running (0.27 Nm/kg; $p < 0.001$) and walking (0.24 Nm/kg; $p < 0.001$) with the rocker shoe compared to standard shoe. The ankle power generation and plantar flexion moment impulse were also reduced significantly when running and walking with the rocker shoe ($p < 0.001$). No significant changes in the knee and hip moments were found in running and walking. A significant delay of the EMG peak, approximately 2% ($p < 0.001$), was present in the triceps surae when walking with rocker shoes. There were no significant changes in the EMG peak amplitude of triceps surae in running and walking. The peak amplitude of tibialis anterior was significantly increased (64.7 μV, $p < 0.001$) when walking with rocker shoes. The findings show that rocker shoes reduce the ankle plantar flexion moment during the late stance phase of running and walking in healthy people.

1. Introduction

Achilles tendinopathy is common in both the general and athletic population [1,2]. A possible explanation for this problem is that the Achilles tendon is subject to repetitive high magnitude of loads during locomotion, making it highly vulnerable to overuse tendinopathy [3].

Load management, in order to control the pain and allow tendon adaptation, plays a central role in the treatment of (Achilles) tendinopathy [4].

It has been shown that loading of the Achilles tendon is related to the magnitude of the ankle "internal plantar flexion moment" (PFM) [5]. For the sake of simplicity, if we assume terminal stance of gait as a static condition (Fig. 1), the external dorsiflexion moment (ground reaction force × external moment arm) is equal to PFM (muscle force × internal moment arm). Footwear modifications such as rocker profiles (rocker shoes) affect the joint moments [6]. Biomechanically, rocker shoes with the apex proximal to metatarsophalangeal joint (Fig. 2A) cause a decrease in external dorsiflexion moment arm of the ground reaction force around the ankle joint [7]. This alteration reduces the external dorsiflexion moment, and consequently results in smaller PFM around the ankle, which is mainly generated by the triceps surae (attached to the Achilles tendon) [7]. In both running and walking as dynamic situations, the same effect (reduction in PFM during terminal stance) should be expected when using the rocker shoe. Although theoretically plausible, the body of evidence for such an effect is not sufficient to make concrete conclusions, especially considering running.

In the only published study so far in slow running, the ankle PFM during terminal stance was reported to be lower for a rocker shoe (Masai Barefoot Technology, MBT®) compared to standard running shoes [8]. In walking, some studies found significant reduction in ankle PFM during terminal stance for rocker shoes compared to standard shoes [9–12], other studies found no significant differences or, at the most, small changes which were not considered clinically significant [13,14].

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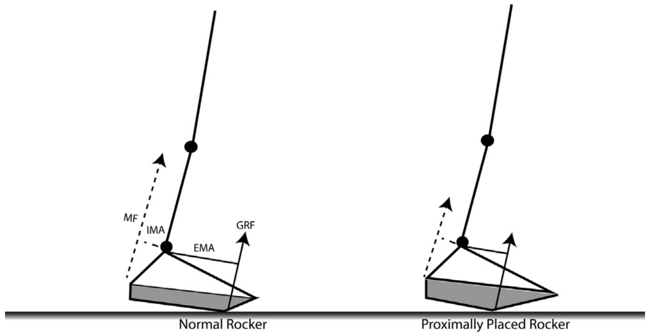

Fig. 1. The effect of proximally placed rocker profile on external and internal moments around the ankle joint during terminal stance of gait. GRF = ground reaction force; EMA = external moment arm; MF = muscle force generated by triceps surae; IMA = internal moment arm.

The aim of this study was to further investigate the biomechanics of a custom-made special rocker shoe design (proximally placed stiffened rocker profile) in both slow running and walking, with special attention to the ankle joint moments.

Firstly, we hypothesized that this type of rocker shoe would significantly reduce the ankle PFM during terminal stance. Secondly, we hypothesized that the knee and hip joint moments would increase to compensate for changes in the ankle joint moment.

The primary outcome was the peak PFM during terminal stance of slow running (shortly referred to as running) and walking. The secondary outcome measures included ankle PFM impulse, ankle power, ankle angles, knee and hip joint moments, and EMG (timing and amplitude) of the main ankle plantar- and dorsiflexors.

Fig. 2. (A) Shoe with a proximally placed rocker profile and (B) standard shoe. The black arrow indicates the apex (rolling point) of the shoe.

2. Methods

2.1. Participants

For the current study we considered 10% reduction in ankle PFM as a clinically significant change for both walking and slow running. In walking this percentage change results in an amount of reduction of about 0.1 Nm/kg when using the data of Riley et al. [15]. For slow running no studies have been reported on normative data for ankle kinetics, but we expected that the relative standard deviation would not be substantially larger than in walking. Based on the power analysis, [16] a minimum of 13 subjects was necessary to provide a statistical power of 80% to detect 0.1 Nm/kg decrease in peak PFM.

To be included, runners needed to be healthy with no injury in the back, trunk or lower extremities in the 12 months preceding the study and running at least twice a week for 5 km each time. A convenience sample of 16 heel-toe runners (8 females and 8 males) in the age of 20–50 years was recruited. The demographic information (mean ± standard deviation) was as follows: age = 29 ± 9 years, height = 177.1 ± 9.3 cm, weight = 69.8 ± 11 kg, body-mass index = 22.1 ± 2 kg/m2 and shoe size = 41 ± 2. The experimental protocol was approved by the local Medical Ethical Committee and each subject read and signed a consent form.

2.2. Shoe condition

Twenty two pairs of standard running shoes in 11 European sizes (36 to 46) were purchased for this study. Eleven pairs remained in their original state for the baseline measurements (standard shoe, Fig. 2B). The others were modified with a stiffened rocker profile (rocker shoe, Fig. 2A) by a certified orthopedic shoe technician. The apex (rolling point) of the rocker shoes and baseline shoes were at 53% (proximal to metatarsal region) [17] and 65% of the shoe length from the heel respectively. The rocker profile thickness was 2.2 ± 0.1 cm at the apex and under the heel. Due to extra weight of rocker profiles, a pair of modified shoes was heavier than a pair of baseline shoes (depending on shoe sizes, the mass of the baseline shoes was on average 467 ± 87 g, and the mass of the rocker shoes was on average 805 ± 157 g).

2.3. Study design

The design used in this study was similar to a cross-over design. Participants were asked to run slowly and walk with both the rocker shoe and the standard shoe overground in the 10-m long gait lab. For each subject all testing procedures were completed in one session consisting of two parts. Half of the participants started with the standard shoe in the first part and continued with the rocker shoe, while for the other participants this order was reversed. The order of running and walking changed with subjects within each part, and were balanced across the order in shoes. The patients were randomly assigned to one of the eight combinations in order of shoes and tasks

2.4. Experimental protocol

After receiving the shoes with an appropriate size, each subject was given approximately 15 min to walk and run to get used to the first pair of shoes (either standard or rocker). Additional familiarization was permitted, if desirable.

Subsequently, sixteen reflective markers were placed bilaterally on the following anatomical landmarks (lower body Plug-in-Gait