G Model
JSAMS-1320; No. of Pages 7
ARTICLE IN PRESS
Journal of Science and Medicine in Sport xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Biomechanics of running with rocker shoes

Sobhan Sobhani[a,b,*], Edwin R. van den Heuvel[c], Rienk Dekker[a,d], Klaas Postema[a], Bas Kluitenberg[d], Steef W. Bredeweg[d], Juha M. Hijmans[a]

[a] Department of Rehabilitation Medicine, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands
[b] Department of Physiotherapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[c] Department of Epidemiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[d] Center for Sports Medicine, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form 28 March 2016
Accepted 5 April 2016
Available online xxx

Keywords:
Footwear
Rocker sole
Rocker bottom
Gait analysis
Running

ABSTRACT

Objectives: Load reduction is an important consideration in conservative management of tendon overuse injuries such as Achilles tendinopathy. Previous research has shown that the use of rocker shoes can reduce the positive ankle power and plantar flexion moment which might help in unloading the Achilles tendon. Despite this promising implication of rocker shoes, the effects on hip and knee biomechanics remain unclear. Moreover, the effect of wearing rocker shoes on different running strike types is unexplored. The aim of this study was to investigate biomechanics of the ankle, knee and hip joints and the role of strike type on these outcomes.
Design: Randomized cross-over study.
Methods: In this study, 16 female endurance runners underwent three-dimensional gait analysis wearing rocker shoes and standard shoes. We examined work, moments, and angles of the ankle, knee and hip during the stance phase of running.
Results: In comparison with standard shoes, running with rocker shoes significantly ($p < 0.001$) reduced the positive (16%), and negative (32%) work at the ankle joint. Plantar flexion moment peak and impulse were also reduced by 11% and 12%, respectively. Reduction in these variables was almost two times larger for midfoot strikers than for rearfoot strikers. At the knee joint running with rocker shoes significantly increased the positive work (14%), extension moment peak (6%), and extension moment impulse (12%).
Conclusions: These findings indicate that although running with rocker shoes might lower mechanical load on the Achilles tendon, it could increase the risk of overuse injuries of the knee joint.

1. Introduction

To date, several studies have investigated the effects of using rocker (bottom) shoes on biomechanics of walking and running.[1–3] A common finding of these studies is that wearing rocker shoes, either custom-made[2,3] or commercially produced,[1,4] could result in significant changes in foot and ankle biomechanics.

Rocker shoes can produce alterations in ankle biomechanics especially during the push-off phase of gait. Among these changes are a reduction in plantar flexion moment (PFM), and ankle power generation. The Achilles tendon is subjected to repetitive mechanical overload during running activities which can exceed eight times body weight per step.[5] The triceps surae produce the PFM during push off,[6] and they are the main contributors to the power, needed for forward acceleration of the body.[7,8] Based on inverse dynamics calculations, it is estimated that the force in the Achilles tendon is proportional to the PFM created by triceps surae muscles.[5,9] In running, the peak force within the Achilles tendon occurs at the start of push-off, the same time as the peak PFM.[5,9] It has been proposed that reduced PFM and ankle power generation per step can cumulatively contribute to significant reduction in Achilles tendon load.[1,10] Load management is an important step in conservative treatment of tendinopathies which not only helps to relieve pain but also allows for tendon adaptation. From a clinical point of view, therefore, wearing rocker shoes might be valuable in treatment of Achilles tendinopathy.[1,10]

Although more attention has recently been paid to these aforementioned aspects of rocker shoes in running activities, knowledge is still limited in this area. The results of a recent study[2] have shown that (slow) running with rocker shoes caused a significant decrease in maximum power generation at the ankle joint. Since the running speed was kept constant in that study; the reduction in the ankle

* Corresponding author.
E-mail address: sobhan132@gmail.com (S. Sobhani).

http://dx.doi.org/10.1016/j.jsams.2016.04.008
1440-2440/

power should potentially result in a compensation in lower limb kinetic chain (i.e. increase of power generation at the knee/hip). This relation, however, was not examined.[10] Another explanation might be the simultaneous reduction of the ankle power at both generation and absorption phases of running. In fact, in a previous study on rocker shoes (Masai Barefoot Technologies), it was found that ankle power (both generation and absorption) was reduced by rocker shoes compared with a standard shoe, whereas knee power was increased.[1] In that study, however, running speed was not similar between the shoe conditions (i.e. lower speed for rocker shoes). The compensatory increase in mechanical work at the knee and hip joints can place them at risk of overuse injuries. Hence, the first aim of this study was to further investigate the knee and hip biomechanics during stance phase of running with rocker shoes. We hypothesized that decreased work at the ankle will be accompanied by increased work at the knee and/or hip joints.

In the second part of this study, we conducted an exploratory analysis on the influence of various strike patterns on running biomechanics with rocker shoes. While the majority (around 75–89%) of runners at elite and recreational level adopts a rearfoot strike pattern, some runners have a midfoot and forefoot strike type.[11] Running biomechanics differ among these landing types. For instance, runners with a non-rearfoot strike have a greater PFM and higher load on their Achilles tendon compared with rearfoot strikers.[12] The capability of rocker shoes in reducing peak and impulse of PFM (Achilles tendon loading parameters) was previously reported only for the rearfoot strikers.[2] Our aim was, therefore, to examine whether rocker shoes could influence such parameters in a similar way for other strike types (e.g. midfoot or forefoot strike). This information can provide an initial insight into implications of rocker shoes for different running styles.

2. Methods

This study was part of a larger research project designed to determine if different running shoes could be biomechanically beneficial or detrimental for running overuse injuries.[13,14] For the whole project, we decided to study females because of the higher incidence rate of stress fractures reported for this gender[15] and to eliminate gender differences in running mechanics.[16]

Two local track and field clubs were contacted to recruit experienced female endurance runners. The other inclusion criteria were: age between 18 and 55 years, regular long-distance training (running for at least 10 km/week for a minimum of 5 km per session), and no history of self-reported severe musculoskeletal injuries in the lower extremity that could affect running performance at the time of measurement. The local Medical Ethics Committee approved the experimental protocol of this study (METc 2012.014), and all participants gave written informed consent.

Two types of shoes were compared in this study: standard running shoes as the baseline condition, and rocker shoes as intervention. Rocker shoes were from the same brand and model as standard shoes with the difference that they had a stiffened rocker profile added to them by a certified orthopedic shoe technician (supplementary). The location of the apex (rolling point) of rocker shoes was proximal to metatarsal region at 53% of the shoe length.[17] The apex of standard shoes was located at 65% of the shoe length. The rocker profile thickness for different sizes was on average 2.2 ± 0.1 cm at the apex and under the heel. Depending on shoe size a pair of standard running shoes weighed on average 541 ± 44 g, and a pair of rocker shoes 858 ± 96 g.

A balanced two-way crossover design was used in which participants were randomly assigned to the two sequences of shoe conditions (in sequence 1 rocker shoes used first, and in sequence 2 control shoes used first). Participants were accustomed to the shoes as they had run on a treadmill (Valiant®; Lode, B.V., Groningen, The Netherlands) for 9 min with each pair of shoes. The evaluation of lower limb motion was based on Vicon® lower body Plug-in-gait model. Reflective markers were placed bilaterally on the anterior superior iliac spine, posterior superior iliac spine, lateral thigh, lateral femoral epicondyle, lateral shank, and lateral malleolus on the surface of the shoes at the location of the calcaneus and the second metatarsal head. During the measurements markers were tracked by an eight-camera motion capture system (Vicon®, Oxford, UK, $f_s = 200$ Hz) to measure the kinematic data. A pair of flexible pressure insoles (Pedar®, Novel GmbH, Munich) was fitted in the shoes for the measurement of plantar pressure (to determine the strike pattern).

Testing was performed on a 22 m runway with two force plates (Bertec Corporation, Columbus, Ohio, $f_s = 2000$ Hz) embedded in the middle of it. During the measurement, we monitored the speed using two photo-cells positioned 1.5 m before and after the force plates. Before the data collection, participants performed 5 running trials along a 22-m runway at their self selected speed to determine their comfortable speed. Participants were then positioned in a way that they would make a full foot contact on the force plate with their dominant foot (defined as the foot they would kick a ball with). A trial was accepted if the participant hit the force plate completely and the speed was within 5% of determined comfortable speed. Moreover, a trial was repeated if the assessor had the impression that participant had targeted the fore plate. After collecting five acceptable trials, the same procedure with the other shoes was carried out.

Power (W/kg), internal moment (Nm/kg), and angle (degree) of the ankle, knee and hip joints in the sagittal plane were determined for the dominant limb using the Vicon Plug-In-Gait model. Joint power was calculated as the product of net joint moment and joint angular velocity. A customized Matlab™ script was used to further process these data. Kinetic data was filtered using a 4th order Butterworth low-pass filter with a cut-off frequency of 10 Hz. The data were time normalized to 100% of stance phase using a linear interpolation and normalized for body mass (kg). The stance phase was defined as the period between initial ground contact (vertical ground reaction force exceeded 10 N) and toe-off (vertical ground reaction force dropped below 10 N). Kinematic and force plate data were used to calculate the time–distance parameters.

To identify the strike pattern, we used the data gained from an in-shoe plantar pressure system (Pedar®, step-analysis software). We only analyzed the data of the dominant limb. First we excluded the first 25% of steps (acceleration) and the last 25% of steps (deceleration) of the recorded steps in each trial. For the remaining steps of each trial (ranged from 3 to 5 steps), the location of the center of pressure at initial contact in anterior-posterior direction (CoP-AP, mm) was determined. This parameter was then normalized to the insole length (mm). The location proximal to 33% of the insole length was defined as rearfoot strike; the location between 33% and 67% was defined as a midfoot strike; and the location distal to 67% was defined a forefoot strike.[18]

Work (positive, negative and net, J/kg) done at the ankle, knee and hip joints was analyzed as our primary outcome. Work values were calculated as the areas under the power–time curves in stance without normalization. The total network was also calculated as the summation of network values of the ankle, knee and hip joints. In order to have a more complete picture of biomechanical adaptations in the lower extremity, we analyzed several additional parameters including joint moments and angles as well as time–distance parameters. Regarding the joint moments, the maximum value (peak, Nm/kg) and moment over time (impulse, Nm s/kg) were assessed for the ankle plantar flexion, knee extension and hip flexion. Moment impulse was calculated as the area under the PFM–time curve in stance without normalization.