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Effects of forefoot bending elasticity of running shoes on gait and running performance

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ABSTRACT

The aim of this study was to investigate the effects of forefoot bending elasticity of running shoes on kinetics and kinematics during walking and running. Twelve healthy male participants wore normal and elastic shoes while walking at 1.5 m/s, jogging at 2.5 m/s, and running at 3.5 m/s. The elastic shoes were designed by modifying the stiffness of flexible shoes with elastic bands added to the forefoot part of the shoe sole. A Kistler force platform and Vicon system were used to collect kinetic and kinematic data during push-off. Electromyography was used to record the muscle activity of the medial gastrocnemius and medial tibialis anterior. A paired dependent *t*-test was used to compare the various shoes and the level of significance was set at $\alpha = .05$. The range of motion of the ankle joint and the maximal anterior–posterior propulsive force differed significantly between elastic and flexible shoes in walking and jogging. The contact time and medial gastrocnemius muscle activation in the push-off phase were significantly lower for the elastic shoes compared with the flexible shoes in walking and jogging. The elastic forefoot region of shoes can alter movement characteristics in walking and jogging. However, for running, the elasticity used in this study was not strong enough to exert a similar effect.

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1. Introduction

Improving forefoot push-off facilitates the augmentation of forward acceleration and ultimately enhances athletic performance (Goldmann, Sanno, Willwacher, Heinrich, & Brüggemann, 2011; Hunter, Marshall, & McNair, 2005). The stance phase in gait is divided equally into passive and active phases (Neptune, Kautz, & Zajac, 2001; Nishiwaki, 2008). The key factor that influences the active phase is the forefoot push-off; however, current studies regarding footwear design and the feet have mostly emphasized heel shock absorption (Bonacci et al., 2013) and have rarely focused on the role that the forefoot plays in lower limb locomotion (Lieberman, 2012; Lieberman et al., 2010). Consequently, research and development concerning the forefoot region of shoes is frequently neglected. Furthermore, in various competitive sports, sport shoes with appropriate forefoot characteristics can improve athletic performance (Stefanyshyn & Fusco, 2004; Stefanyshyn & Nigg, 2000). Functions of the forefoot are not related only to push-off performance but are also reflected by how the forefoot lands, which can cause numerous sports injuries related to the forefoot (Willems, De Ridder, & Roosen, 2012; Willems, Witvrouw, Delbaere, De Cock, & De Clercq, 2005). By using various forefoot landing approaches, the conduction of force and torque can be changed, thereby reducing the risk of injuries (De Wit, De Clercq, & Aerts, 2000). Therefore, enhancing the forefoot design by increasing the bending stiffness of shoes can improve athletic performance and prevent sports injuries (Nigg, 2009).

Studies have indicated that modifying the flexibility in the forefoot region of running shoes provides a greater range of motion for the forefoot and increases the activation of the shank muscles. In addition, long-term use of flexible running shoes strengthens the shank muscles substantially (Bruggemann, Potthast, Braunstein, & Niehoff, 2005; Goldmann, Sanno, Willwacher, Heinrich, & Bruggemann, 2013). Previous research targeting the forefoot region has shown that through material cutting or slicing, a greater movement angle in the metatarsophalangeal joint (MPJ) can be achieved, which subsequently enhances the muscle activity of the gastrocnemius muscle (Chen, Hsieh, Shih, & Shiang, 2012). The same study also suggested that enhancing the bending elasticity of running-shoe soles can reduce the activity of certain muscles (Chen et al., 2012).

In previous studies, changes have been applied to shoe materials to alter the ground reaction force patterns in human locomotion (Reenalda, Freriks, & Buurke, 2011). Several studies have also asserted that by using a certain material in shoe soles that provides the forefoot with greater bending elasticity, the dissipation of applied forces is diminished (Lin et al., 2013; Stefanyshyn & Nigg, 1998) without changing the joint angle of the lower extremity (Stefanyshyn & Nigg, 2000). Consequently, this optimizes the force conduction efficiency, which improves performance in jumping and landing (Stefanyshyn & Nigg, 1998, 2000; Tinoco, Bourgit, & Morin, 2010). However, other studies have indicated that increasing the bending elasticity of shoe soles does not enhance jumping performance (Toon, Vinet, Pain, & Caine, 2011). Studies on forefoot designs have typically focused on increasing the insole stiffness (Tinoco et al., 2010; Willwacher, König, Potthast, & Brüggemann, 2013). This type of design might also increase the forefoot pressure and the contact between the foot portion and the elastic material might reduce deformation of the material and consequently constrain its ductility. In this study, elastic materials were added to the outsoles of shoes in the forefoot region to maximize energy return. Consequently, we expected an increase in the bending elasticity in the forefoot region of the shoes to improve the energy return effect and alter the kinetics of the push-off phase. Therefore, we compared the forefoot push-off phase of walking and running at moderate intensities and different gait speeds by using two types of shoe with varying forefoot bending elasticity. The hypotheses formed in this study were as follows:

(1) Shoes with a high bending elasticity reduce the contact time and enhance the propulsive impulse as well as the anterior–posterior and vertical maximum propulsive force during walking, jogging, and running in the active phase.
(2) Shoes with a high bending elasticity reduce the activation of the medial gastrocnemius (GAS) and medial tibialis anterior (TA) muscles in the push-off phase of walking, jogging, and running in the active phase.