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Full Length Article

Lower limb mechanics during moderate high-heel jogging and running in different experienced wearers

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ABSTRACT

The aim of this study is to investigate the differences in lower limb kinematics and kinetics between experienced (EW) and inexperienced (IEW) moderate high-heel wearers during jogging and running. Eleven experienced female wearers of moderate high-heel shoes and eleven matched controls participated in jogging and running tests. A Vicon motion analysis system was used to capture kinematic data and a Kistler force platform was used to collect ground reaction force (GRF). There were no significant differences in jogging and running speed respectively. Compared with IEW, EW adopted larger stride length (SL) with lower stride frequency (SF) at each corresponding speed. During running, EW enlarged SL significantly while IEW increased both SL and SF significantly. Kinematic data showed that IEW had generally larger joint range of motion (ROM) and peak angles during stance phase. Speed effect was not obvious within IEW. EW exhibited a significantly increased maximal vertical GRF (F_{z2}) and vertical average loading rate (VALR) during running, which was potentially caused by overlong stride. These suggest that both EW and IEW are at high risk of joint injuries when running on moderate high heels. For wearers who have to do some running on moderate high heels, it is crucial to control joint stability and balance SL and SF consciously.

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1. Introduction

The high-heel design has been remaining one of the dominant features of women's footwear. Social and fashion customs encourage the continued use of high-heel shoes (Hong, Lee, Chen, Pei, & Wu, 2005) despite of detrimental effects on the musculoskeletal system, such as lower back pain, ankle sprains, foot pain, hallux valgus and increased predisposition toward degenerative knee osteoarthritis (Barkema, Derrick, & Martin, 2012; Chien, Lu, & Liu, 2014; Chien, Lu, Liu, Hong, & Kuo, 2014; Dawson et al., 2002; Gu et al., 2014; Lee, Jeong, & Freivalds, 2001).

Forcing ankle to a plantar-flexed state, high-heel shoes with narrow supporting base lead to a series of kinematic and kinetic changes of lower limbs during walking. Changes in spatiotemporal parameters have been well documented.

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Unanimous results revealed that increase of heel height contributed to slower self-selected walking speeds and shorter strides with generally unchanged cadence (Barkema et al., 2012; Cronin, Barrett, & Carty, 2012; Esenyel, Walsh, Walden, & Gitter, 2003; Lee et al., 2001; Opila-Correia, 1990a). Most studies on high-heeled gait concerned changes of knee joint. Compared with barefoot or flat shoes condition, walking in high heels has been believed to increase knee flexion during stance phase and at heel strike as compensatory mechanisms attenuating GRF (Ebbeling, Hamill, & Crussemeyer, 1994; Mika, Oleksy, Mika, Marchewka, & Clark, 2012; Opila-Correia, 1990a; Simonsen et al., 2012). According to the notion that larger knee abduction moment is associated with the development of knee osteoarthritis (Baliunas et al., 2002), the increase of peak knee abduction moment as the result of increasing heel height has been highlighted (Barkema et al., 2012; Esenyel et al., 2003; Kerrigan, Todd, & Riley, 1998; Simonsen et al., 2012). Studies concerning alternations in ankle joint during high-heeled walking concluded that risk of lateral ankle sprain would increase as heel height increased with increasing plantarflexion and inversion (Foster, Blanchette, Chou, & Powers, 2012; Stefanyshyn, Nigg, Fisher, O'Flynn, & Liu, 2000). Barkema et al. (2012) found systematically increased peak ankle eversion moment during late stance phase with increased heel height. As to hip joint, increased flexion and abduction moments were verified as assistant to attenuate GRF during the first half of stance phase and compensate the reduced ankle plantarflexion moment during push-off (Esenyel et al., 2003; Simonsen et al., 2012). All these studies recruited habitual high-heeled wearers as subjects, accordingly, whether these changes were immediate effects or chronic adaptations have not been fully explored.

Habitual wearers of high-heel shoes were reported to experience long-term adaptations in muscle-tendon architecture, such as increased Achilles tendon stiffness and tendon hypertrophy (Csapo, Maganaris, Seynnes, & Narici, 2010), shortening of gastrocnemius medialis fascicles (Cronin et al., 2012). These adaptations could shift the stretch distribution of muscle-tendon unit away from tendinous tissues toward muscle fascicles during walking, which potentially alters neural activation patterns and decreases muscle-tendon unit efficiency (Cronin et al., 2008; Lichtwark & Wilson, 2007). Opila-Correia (1990b) noted that biomechanical adaptations varied between experienced and inexperienced high-heel wearers including increased knee flexion of the former and exaggerated upper trunk rotations of the latter during stance phase when walking at preferred speed. Other differences as increased abductor and reduced internal rotator moment at hip; reduced ranges of flexion-extension and adduction-abduction at knee; increased external rotation, pronator and external rotator moments at ankle were also observed in self-selected walking task wearing 7.3 cm high-heel shoes (Chien, Lu, & Liu, 2014; Chien, Lu, Liu, Hong, et al., 2014). In contrast, studies instructing subjects to walk at fixed speed showed no significant differences in any of spatiotemporal parameters, joint angles and GRF between experienced and inexperienced high-heeled wearers (Ebbeling et al., 1994; Simonsen et al., 2012). One reason concerning significant level of differences may be that the fixed speeds were greater than actual preferred speeds in high-heeled walking.

Studies on changes of GRF in high-heeled gait remain limited. Ebbeling et al. (1994) reported that regardless of wearing experience, the first and second maximal vertical GRFs increased as heel height increased during walking at a fixed speed. Research of Stefanyshyn et al. (2000) obtained similar conclusions from habitual subjects. This study also indicated that there was a threshold for the increase of impact force and maximal vertical loading rate as heel height increased. Loy and Voloshin (1987) also reported that when heel height increased from 7.6 cm to 8.5 cm, both impact force and loading rate decreased, which might be an injury prevention strategy employed by high-heel wearers.

In general, kinematic and kinetic alternations of lower limb in studies mentioned above were responses to high heels at walking level. However, in modern society, running for a bus, darting across a busy street or dashing to get the last train push most busy women find themselves in need of a little turn of speed every now and then. Previous study demonstrated that the maximal vertical GRF increased linearly from 1.2 BW (body weight) to approximately 2.5 BW during walking and running respectively (Keller et al., 1996). Joint motions of lower limb during walking also significantly differ from that during jogging and running. There are few studies concerning effects of high-heeled jogging and running on lower limb mechanics. Gu, Sun, Li, Graham, and Ren (2013), Gu, Zhang, and Shen (2013) noted that motion range of knee abduction-adduction and hip flexion-extension increased significantly as heel height increased during jogging which may induce high loading force in knee joints. This study only recruited habitual moderate high-heel wearers; however, whether these changes in inexperienced moderate high-heel wearers are the same or even worse and whether increased speed of running has extended effects remain unclear.

The purpose of this study was to clarify differences in lower limb kinematics and GRF between EW and IEW during moderate high-heel jogging and running. It was hypothesized that EW would show faster self-select speeds of jogging and running than IEW; EW would decrease joint instability while increase GRF in comparison with IEW; changes of lower limb joints (range of motions and peak angles) and GRF would increase as speed increased for all wearers.

2. Method

2.1. Participants

Eleven experienced female wearers of moderate high-heel shoes (EW: age: 24.2 ± 1.2 years; height: 160 ± 2.2 cm; mass: 51.6 ± 2.6 kg) and eleven matched controls (IEW; age: 23.7 ± 1.3 years; height: 162.3 ± 2.3 cm; mass: 52.6 ± 4.5 kg) participated in this test with informed written consent, as approved by the Ethics Committee of Ningbo University. All the subjects were informed of the objectives, requirements and experimental procedures. None of the subjects suffered from any

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