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Could Insoles Offload Pressure? An Evaluation of the Effects of Arch-supported Functional Insoles on Plantar Pressure Distribution during Race Walking

QIPENG SONG and KAISHENG XU
Shanghai University of Sport, Shanghai, China

BING YU
University of North Carolina at Chapel Hill, Chapel Hill, USA

CUI ZHANG and WEI SUN
Shandong Sports Science Research Center, Jinan, Shandong, China

DEWEI MAO
Shanghai University of Sport, Shanghai, China

This study investigated the effectiveness of functional insoles on plantar pressure distribution during race walking so as to reduce the high plantar pressure and force on race walkers, who tend to suffer from overuse injury. A total of 20 male race walkers aged 21.19 ± 3.66 years and with a mean height of 178.85 ± 14.07 cm were recruited as participants. Each participant completed a race walking with functional or normal insoles. Plantar pressure insoles were used to collect vertical plantar pressure data. A two-way analysis of variance with a mixed design was used to determine the difference between the

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Qipeng Song and Kaisheng Xu contributed equally to this article.
Address Correspondence to Dewei Mao, Shanghai University of Sport, Shanghai, China. E-mail: deweimao@gmail.com

two conditions. Results showed that the use of functional insoles reduces the peak pressure and the impulse in the metatarsophalangeal joints and heels and thus suggest that functional insoles reduce the overuse injury risks of these parts. The first ground reaction force peak also decreased. This result suggested that functional insoles reduce the risks of foot and leg injuries.

KEYWORDS *athletic footwear, athletic injury, endurance exercise*

INTRODUCTION

Race walking, particularly the 5 and 10 km events, has grown in popularity in recent years and is rapidly becoming the favored pastime of recreational athletes (Francis, Richman, & Patterson, 1998). This trend possibly results from the belief that race walking is a sport that provides valuable health and fitness benefits and has a low risk of injury (Kummant, 1981). However, researchers consider race walking as a sport with a high risk of injury. Francis et al. (1998) conducted a questionnaire study on 682 race walkers and found that approximately two-thirds of the respondents had suffered one or more injuries in the course of their race-walking careers. In their study, 21.3% and 20.7% of injuries are located in the knees and feet, respectively. In particular, 11% suffered from stress fracture, and 6% suffered from foot blisters. Sanzen, Forsberg, and Westlin (1986) noted that 90% of the race walkers they examined complained of intermittent pain during walking, which occurred in the legs and feet, especially in the anterior aspect of the lower leg. Palamarchuk (1980) interviewed 31 race walkers and found that their primary injuries were blisters on the metatarsophalangeal joints (MPJs), heels, and toes, as well as hamstring injuries and medial knee pain.

Race walking is an endurance event that requires athletes to walk 20 km to 50 km. Fifty-kilometer race walking is the longest track and field event and involves distances that are approximately 7.8 km longer than those in marathons. A 67 kg individual walking 50 km must absorb 2016 tons on each foot (Dowling, Steele, & Baur, 2008). Thus, race walkers are prone to overuse injuries, such as blisters, metatarsalgia, stress fractures, and knee pains, in their lower extremities. During race walking, walkers have to recurrently undergo plantar compressive loading for 1 h to 4 h; during this period, the regions experiencing relatively high pressures or forces, such as the MPJs and heels, readily suffer from overuse injury. Karagounis, Prionas, Armenis, and Baltopoulos (2009) noted that repeated plantar loading leads to stress fractures in the metatarsal bones, particularly in the second and third MPJs. Sanzen et al. (1986) found that the increased pressure on the heels causes more strain on the tibialis anterior when landing and possibly contributes to a number of commonly seen lower-extremity injuries in race walking. Song, Ding, Mao, Zhang, and Sun (2013) found that the first ground reaction force (GRF) peak is greater in race walking than in normal walking and can generate strain in the midtibial musculoskeletal structures; when the musculoskeletal system is overloaded, overuse injuries may occur (Willems, Delbaere, Vanderstraeton, De Cock, & Witvrouw, 2004).

For diabetics, orthotic insoles and pressure relief shoes reduce plantar pressure loading (Ibrahim, Hilaly, Taher, & Morsy, 2013; Raspovic, Landorf, Gazarek, & Stark, 2012). In a similar manner, race walkers are at high risk of plantar pressure-related overuse injuries (Palamarchuk, 1980; Song et al., 2013). In this study, arch-supported functional insoles (International Biomechanics Ltd, Hong Kong) were used to reduce plantar pressure loading during race walking (Figure 1). The functional insoles have a complex surface. The thickness of the forefoot is about 4 mm, and it increases to about 8 mm in the arch and decreases to 6 mm at the heel. The middle of the heel is embedded with a round cushion, and the edge of the arch and heel areas rise to form a 'heel cup' to steady the heel during walking. The height of the cup edge is 25 mm, and the foot arch is supported by an arch pad. Compared with the functional insoles, normal insoles, which match the prevalent race walking training shoes (Dowin Ltd, China), were used as control insoles with a flat surface of about 3 mm. The material for both functional and normal insoles is ethylene-vinyl acetate copo (EVA). The functional insoles were expected to increase the arch height as well as the cushion beneath the heel. The loads on the MPJs and heels were transferred to the arch area to reduce

FIGURE 1 Arch-supported functional insoles.

the peak pressure and the GRF in the MPJs and heels as well as the risk of overuse injuries in these areas. This study aims to determine the effects of functional insoles on the plantar pressure distribution during race walking. The hypotheses is that the functional insoles change the plantar pressure distribution by reducing the peak pressure on the MPJs and heels and reducing the GRF upon landing.

METHODS

Participants

A total of 20 male race walkers aged 21.19 ± 3.66 years were recruited from the provincial race walking team of Shandong, China. The participants had a mean height of 178.85 ± 14.07 cm, a mean weight of 69.48 ± 5.43 kg, a mean BMI of 21.72 ± 2.19 kg/m^2, a race walking history of at least 5 years, and no history of lower limb pathology at the time of the study or in the preceding six months. All participants signed informed consents prior to data collection.

Testing Protocol

Each participant had a 30 minute warm up session in which he went through his regular warm-up routine before a training session. Then, each participant did race walking at an average race walking speed (3.5–3.8 m/s) for 400 m in his or her own race walking shoes under two conditions: (1) with a functional insole (functional insoles placed in both shoes), and (2) with a normal insole. Two pairs of timing doors of the Smartspeed system (Fusion Sport Company, Australia) were used to calculate the walking speed. The order of the two conditions was randomized for each participant. Data were collected for ten consecutive steps during the last 100 m of each 400 m walk.

Data Collection

Plantar pressure insoles (Rs-scan International, Olen, Belgium) were used to collect plantar pressure data. Each pressure insole had 99 resistive sensors (2 sensors/cm^2) with sensitivity of 10 kPa and a measurement range of 0 kPa to 2540 kPa. The insole system was calibrated with linear methods. The calibration procedures before measurements were operated with an Rs-scan calibration setting called ‘weight scaling mode’. The subject’s weight was filled into the calibration mode, and the program calibrated footscan insoles automatically. Intraclass correlation coefficients revealed that the reliability of the variables was generally high (ICC > 0.75) (Low & Dixon, 2010). The foot’s initial contact with the ground was defined as the instant when more than two sensors were activated with a resultant force greater than 5 N. An 8 bit A/D conversion board was used to convert analogue signals to digital signals for the computer, and pressure data were collected at a sample rate of 126 Hz.

Data Reduction

During the test, peak pressures of eight anatomical sub-regions and GRF of the whole foot were calculated. Eight anatomical sub-regions were identified (Figure 2) as the medial heels (Hm), lateral heels (Hl), medial arch (Vm), lateral arch (Vl), MPJs 1 to 5 (M1, M2, M3, M4, and M5) and the hallux (T1). Following recommendations made by a previous study (De Cock, De Clercq, Willem, & Witrouw, 2005) that used a similar pressure plate and claimed that small areas on the heel did not fully cover the area underneath the tuber calcaneus, the current study compared larger areas (3.4 cm^2) of the heel with smaller areas in other regions (1.5 cm^2). Total compressive force applied on

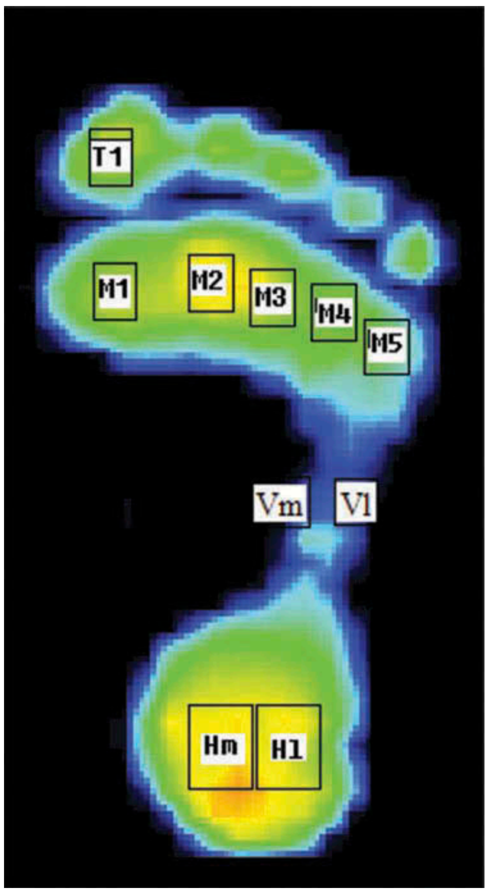

FIGURE 2 Locations of eight sub-areas on the peak pressure footprint: hallux (T1), MPJs 1–5 (M1–M5), medial arch (Vm), lateral arch (Vl), medial heel (Hm), and lateral heel (Hl).

each anatomical sub-region was calculated as the sum of forces measured by all the sensors in the sub-region. The average pressure on each anatomical region was calculated as the total force on the sub-region divided by the area of the region. Impulse was calculated as the pressure-time integral on each anatomical region. The GRF on each foot was calculated as the sum of forces measured by all the sensors of each insole. The GRF on each foot was calculated as the sum of forces measured by all the sensors of each insole. The force on each anatomical region and the ground reaction force on each foot were normalized to the participant's body weight.

Data Analysis

Two-way analysis of variance (ANOVA) with a mixed design was used to compare plantar pressure among ten different parts of the foot and between the two conditions. The condition (i.e. (1) with a functional insole or (2) with a normal insole) was a repeated measure while foot part was an independent measure. Bonferroni adjustment was made for the follow-up t-tests in each ANOVA analysis to guarantee the overall Type I error rate was not greater than 0.05 for each ANOVA analysis. If no significant interaction effect of the condition and foot part on plantar pressure was found but a significant main effect of foot part was found, independent t-tests would be performed to locate differences in plantar pressure among foot parts. If a significant interaction effect of the condition and the foot part on plantar pressure was detected, one-way ANOVA with repeated measures would be performed to compare plantar pressure between conditions for each foot part, and among foot parts for each condition. A Type I error rate of 0.05 would be used as an indication of statistical significance.

RESULTS

During data analysis, the condition and foot part showed no significant interaction effect on the plantar pressure. With normal insoles, the highest pressure was found on the MPJs and heels. The functional insoles reduced the pressures in these areas and increased the pressure of the medial arch. With functional insoles, the peak pressures significantly decreased in Hallux, functional (f) = 373 kPa, normal (n) = 433 kPa, p = 0.012; MPJ1, f = 448 kPa, n = 538 kPa, p = 0.005; MPJ2, f = 334 kPa, n = 445.5, p = 0.000; MPJ3, f = 296 kPa, n = 362 kPa, p = 0.002; MPJ4, f = 241 kPa, n = 299 kPa, p = 0.031; Medial heel, f = 348 kPa, n = 549 kPa, p = 0.000, and Lateral heel, f = 360 kPa, n = 573 kPa, p = 0.000; compared with those with normal insoles (Figure 3), but increased in Medial arch, f = 167 kPa, n = 46 kPa, p = 0.000;

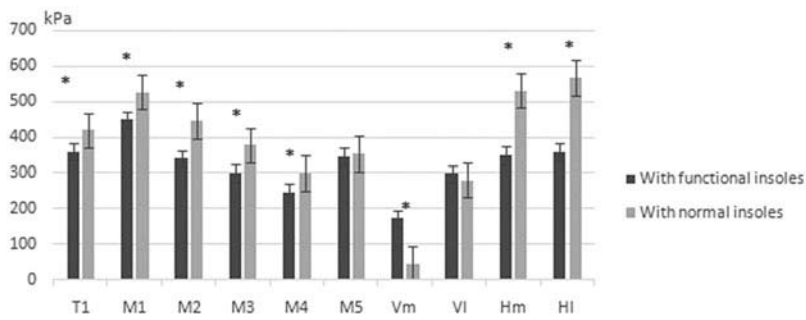

FIGURE 3 Peak pressures on plantar areas.

*Significant difference between two different insole conditions.

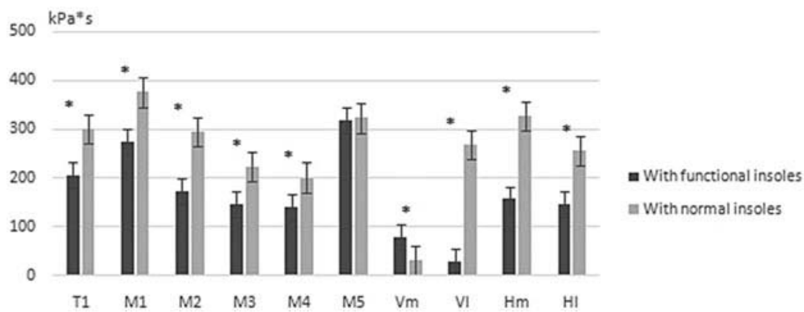

FIGURE 4 Impulse on plantar areas.

*Significant difference between two different insole conditions.

and did not change in MPJ5, f = 351 kPa, n = 368 kPa, p = 0.159; and lateral arch, f = 299 kPa, n = 289 kPa, p = 0.173.

Functional insoles similarly affected the impulse (pressure–time integral). With functional insoles, the impulses significantly decreased in Hallux, functional (f) = 208.3 kPa s, normal (n) = 297.5 kPa s, p = 0.000; MPJ1, f = 271.8 kPa s, n = 358.9 kPa s, p = 0.001; MPJ2, f = 180.6 kPa s, n = 289.5 kPa s, p = 0.000; MPJ3, f = 169.0 kPa s, n = 227.1 kPa s, p = 0.012; MPJ4, f = 148.7 kPa s, n = 206.5 kPa s, p = 0.013; lateral arch, f = 210.0 kPa s, n = 267.7 kPa s, p = 0.006; Medial heel, f = 151.1 kPa s, n = 328.7 kPa s, p = 0.000, and Lateral heel, f = 144.4 kPa s, n = 263.0 kPa s, p = 0.000; compared with those with normal insoles (Figure 4), but increased in Medial arch, f = 83.6 kPa s, n = 36.7 kPa s, p = 0.000; and did not change in MPJ5, f = 326.4 kPa s, n = 333.2 kPa s, p = 0.159.

Meanwhile, the GRF exhibits a normal bimodal pattern. With functional insoles, the first peak decreased (P = 0.034) but the second peak remained unchanged (P = 0.078) (Figure 5).

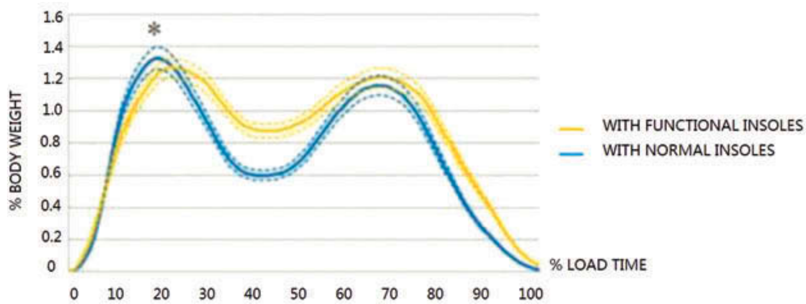

FIGURE 5 GRF in vertical direction.

*Significant difference between two different insole conditions.

DISCUSSION

This study demonstrated that the arch-supported functional insoles reduce the highest peak pressures and impulse on the MPJs and heels and the GRF of the first peak value. These findings coincide with those of previous studies. Ibrahim et al. (2013) noted that in the treatment of people with diabetes, orthotic insoles and pressure-relief shoes reduce plantar pressure loading. Meanwhile, Chang, Liu, Chang, Lee, and Wang (2014) revealed that accommodative insoles significantly reduce the peak pressure, pressure–time integral on the MPJs, and maximal force in older people with metatarsalgia. To the best of our knowledge, not many studies attempt to offload pressures in order to reduce the risk of overuse injuries in race walking even though the strong association between high underfoot pressure and overuse injuries has already been proven (Person & Whitaker, 2012).

Race walkers recurrently undergo foot loading approximately 18,000 to 48,000 times during a single race (Hanley, Bissas, & Drake, 2011). The offloading of pressure during each step greatly reduces the risk of overuse injury. The arch-supported mechanism of the functional insoles shifts the load from the forefoot and rearfoot toward the midfoot; thus, the pressures on the forefoot and rearfoot are reduced (Bus, 2012; Redmond, Lumb, & Landorf, 2000). This study proved that functional insoles significantly reduce the peak pressures in the hallux, MPJs 1 to 4, and heels, all of which are vulnerable to injuries (Werner, Gell, Hartigan, Wiggerman, & Keyserling, 2010). Furthermore, repetitive submaximal stimuli can reduce the individual loading capacity of the bone and lead to structural changes in the areas of maximal stress (Karagounis et al., 2009). After a long period of repeated foot loading, the plantar load is transferred from the toes to the MPJs and causes higher peak pressures in the MPJs compared with that at the start of walking or running; this repeated loading may lead to stress fractures in the MPJ bones, particularly in the second and third MPJs, which are vulnerable because of the discrepancy between the bone strength and imposed plantar pressure (Karagounis et al., 2009). The functional insoles reduce the risk of overuse injury by offloading the peak pressure on the MPJs. This reduced pressure is more helpful for long-distance track events, such as race walking or marathons. Functional insoles also reduce the peak pressures on the heels for three reasons: (1) the medial arch support transfers the loads from the heels to the midfoot area; (2) the heel cup structure realigns the calcaneus to the center of the shoe heel and redistributes the pressure on functional insoles; and (3) the thicker and softer materials of the insoles help absorb pressure. Sanzen et al. (1986) found that increased pressure on the heels increases the strain on the tibialis anterior when landing; this phenomenon possibly contributes to a number of commonly seen lower-extremity injuries during race walking. Song et al. (2013) proved that the highest peak pressures during race walking are found beneath the heel areas and concluded that the heels easily incur injuries. In summary, functional insoles prevent overuse injuries by offloading the peak pressures in the MPJs and heels.

Aside from the peak pressures, the impulse was also investigated in this study. The impulse provides more information on plantar mechanical loading because it includes both the amplitude of the pressure and the time during which the pressure is exerted (Soames, 1985). Compared with the peak pressure, the impulse is a more sensitive indicator of the etiology of foot injury; it also has a higher association with pain or injury (Hodge, Bath, & Carter, 1999) and has greater differentiability when comparing the perceived comfort (Chen, Nigg, & De Koning, 1994). Various surveys have investigated the potential causative factors of stress fractures, several of which were attributed to the excessive plantar loading during landing (Karagounis et al., 2009; Mizrahi, Verbitskya, Isakov, & Daily, 2000). These surveys showed that excessive plantar loading poses additional risks to bone integrity. In summary, functional insoles reduce the plantar loads in the MPJs and heels.

A normal GRF pattern comprises the sequences of the heel-strike, mid-stance, and push-off phases, and there is a loading response to absorb the vertical shock during the heel-strike phase and a propulsive force during the push-off phase (Bobbert, Yeadon & Nigg, 1992). Chiu and Shiang (1996) noted that the peak strength emerges after the heels first come into contact with the ground. This peak force causes vibrations in the lower limbs. Therefore, people often adjust their gait to avoid maximum force when excessive force is exerted on their feet. During normal walking or running, people can bend their knees to cushion against excessive force. However, official race walking rules (i.e., International Association of Athletics Federation) state that the supporting leg must be fully extended during its period of contact. This leg extension limits the cushioning by the knee joints during race walking. As a result, the first GRF peak is significantly greater during race walking than during normal walking (Song et al., 2013) and generates strain in the midtibial musculoskeletal structures. The overloading of the musculoskeletal system can result in overuse injuries. The decrease in the first peak force indicates that the insoles absorb the vertical shock during the strike phase of the heels and thus reduce the risk of injury on the foot and leg.

CONCLUSIONS

During race walking, the peak pressure and impulse in the MPJs and heels were reduced by arch-supported functional insoles. As such, functional insoles can prevent overuse injuries by offloading the peak pressures and impulse in the MPJs heads and heels and so reduce the risk of overuse injuries in these parts. The reduction in the first GRF peak also suggests that the insoles absorb the vertical shock during the strike phase of the heels and thus prevent the potential injury risks in the foot and leg.

LIMITATION

In this research, only small plantar areas were selected to collect data (3.4 cm^2 in heels and 1.5 cm^2 in other regions); important data in other areas may have been missed.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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