HUMAN MOVEMENT
2012, vol. 13 (4), 350–354

INVESTIGATION OF LOCALISED PRESSURE APPLIED TO SPECIFIC SITES ON THE LATERAL ASPECT OF THE FOOT'S DORSUM BY THE UPPER PARTS OF FOOTWEAR DURING SPORTS SPECIFIC MOVEMENTS

doi: 10.2478/v10038-012-0041-2

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ABSTRACT
Purpose. Localised peak pressure linked to overuse injuries has been documented extensively at the plantar surface during human locomotion. There is however a paucity of research investigating pressure applied to non-plantar regions of the foot during movement. This study investigates the magnitudes of peak pressures applied to the lateral side of the 5th metatarsal head (5MTH) and calcaneus (CC) by the uppers of footwear during sports movements. **Method.** A plantar pressure measuring system was adapted to fit into a sock covering the lateral aspect of the L5MTH and LCC. Six male participants (26.7 ± 2.4 years, 75.2 ± 5.5 kg) performed ten trials each of starting, stopping, sprinting, cutting and sidestepping at self-selected velocities, whilst wearing the pressure measuring device. Repeated measures ANOVA's were used to examine differences between peak pressures at different aspects of the lateral side of the dorsum of the foot. **Results.** The results indicate significant differences ($p \le 0.05$) between peak pressures at the LCC compared to the L5MTH. Significant differences in peak pressure at the L5MTH were also found between movement strategies. No significant differences ($p > 0.05$) were reported at the LCC between different movements. **Conclusions.** The results identify a need for athletes pre-disposed to injuries in the uppers of the feet to consider the possible influence of footwear on the magnitudes of peak pressures applied to the lateral side of the dorsum of their feet.

Key words: pressure, biomechanics, footwear, sports

Introduction

High localised plantar pressure can lead to detrimental outcomes such as stress fractures of the metatarsal bones in the foot [1] and various skin pathologies [2–3]. Localised pressure formations between the dorsum of the foot and the uppers in footwear facilitates the onset of corns and calluses which may lead to considerable discomfort and serve to restrict physical activity [3]. Previous research has highlighted the relationship between occurrences of corns and calluses and inappropriate footwear, abnormal foot mechanics and high levels of activity [4–5]. This relationship becomes increasingly significant when considering participants with a history of diabetes, as within this population segment feet are a common site for medical problems [6]. Diabetics can suffer from both macroangiopathy (peripheral vascular disease) and neuropathy (decreased vibration and pain sensation), which expose diabetics to an increasing susceptibility to corns and calluses [7]. In patients suffering from multiple foot ulcerations, between 37% and 59% of such injuries were present in dorsal foot area [8].

Using a pressure measuring system inserted inside the shoe, localised plantar pressure can be recorded at specific areas of the foot, such as the metatarsal heads, mid-foot or heel, during ground contact during human locomotive movement. Whilst studies have investigated the pressures applied to the plantar region of the foot during sport-specific movements [9], there is a lack of information on the pressure distribution between the dorsum of the foot and shoe uppers. One study used a capacitive plantar pressure measuring device to research the pressure between the prosthesis and the dorsal aspect of the foot in a patient who had undergone rotationplasty [10]. This surgical procedure alters the anatomical position of the foot, so that the foot is rotated to a vertical posterior-facing position. Although pressure distribution characteristics on the dorsal aspect were recorded, due to the altered position and function of the foot, the data could not be generalized to participants who had not undergone this surgical intervention.

In gait, there are periods in which the majority of the anterior and lateral forces acting on the foot are not applied through the plantar region [11]. Therefore, the components of these forces acting from the shoe on the foot must be applied through the upper parts of the shoe. Previous research found that in-shoe plantar pressure obtained during soccer specific movements showed characteristic pressure distribution patterns corresponding to the movements performed [12]. Therefore, it may be important to consider the influence of different movements on force distribution by the upper part of footwear. Studies investigating changes in directions within spe-

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cific sports, such as basketball, indicate that the ground reactions forces (GRFs) have reasonably large mediolateral (MP) and ante-roposterior (AP) components [13]. These components may result in areas of high localised pressure being exerted on the various sides of the foot's dorsum by the uppers of the shoe. Overuse injuries are a function of the magnitude of the peak pressures experienced and the frequency of these peaks [12]. Footwear should therefore be designed to attempt to reduce peak pressure experienced during high frequency sports specific movements that feature high levels of peak pressures.

Decreasing the pressure by using footwear of extra width or by changes in the composition of the materials used in the uppers may help reduce the occurrence of injuries at various anatomical locations. By identifying areas of the dorsum of the foot experiencing high peak pressures, enhancements in the protective function of footwear may assist in reducing the magnitude of pressure, and thus the occurrence of discomfort and injuries. As such, the aim of the current investigation was to measure peak pressures at two specific sites (lateral boarder of the calcaneus [LCC] and 5th metatarsal head [L5MTH]), which were analysed by adapting existing commercially available technology (Fig. 1). These sites were chosen due to the excessive wear that was observed in footwear at these sites, as well as the lack of quantitative data explaining the magnitude of peak pressures applied to the dorsal aspects of the feet that may cause injuries and discomfort.

Material and methods

There are currently no specific pressure measuring devices specifically designed to measure pressure across the lateral side of the upper parts of footwear. In order to measure the pressure in this specific area, an F-Scan 3000 (Tekscan Inc., USA) in-shoe pressure measurement sensor was used. The insert records pressure by four sensors per square centimetre, and although designed for measuring in-shoe plantar pressure, the sensors can be cut to shape and can measure pressure over any area [10]. The insert was calibrated by using a standard method where the participant stood with the insert under the plantar region of the foot. By entering the known mass of the participant, the Tekscan software is able to calibrate the system from the changes in the electrical resistance of each sensor as it records the known applied force over the entire device. The insert was then cut to the desired shape (Fig. 1) and inserted into the participant's sock on the lateral side of the right foot's dorsum with small pieces of double sided adhesive tape applied to hold the sensor in place (Fig. 2).

Six male participants (aged 26.7 ± 2.4 years, mass 75.2 ± 5.5 kg) with no known musculoskeletal conditions performed five specific sports movements: starting, stopping and sprinting (Fig. 3a), cutting at 45° (Fig. 3b)

Figure 1. Adapted pressure sensor

Figure 2. Pressure sensor inserted into sock

and sidestepping (Fig. 3b, c), all at a self-selected velocity to best simulate natural movement. The tests were conducted in a carpeted biomechanics laboratory. Using data from the literature [14], the minimum required sample size was estimated for a statistical power of 80% (significance level was set at $\alpha = 0.05$), where it was determined that six subjects were adequate. All sample size and power calculations were completed using the freely available G*Power Software [15]. Ethical approval was obtained from the University Ethics Committee and each participant provided written consent in accordance with the Declaration of Helsinki.

All participants wore the same laboratory provided sports footwear (Viper shoe model, Gryphon, Australia) to control for any possible variability in pressure and to provide comparable readings previously reported for plantar pressure during sports movements [16]. By palpating the foot through the uppers of the shoe the location of lateral border of the 5th metatarsal and calcaneus were identified. Pressure was then applied using a blunt-headed pointer to these two anatomical landmarks (Fig. 4). According to the pressure-sensor manufacturer, it is possible to accurately reference the lateral side of the dorsum of the participant's right foot in contact with the pressure sensor by recording the position of these points from the pressure data recorded via the sensors. This facilitated the recording of peak pressures within the areas under investigation so as to be consistently measured during the trials. Ten trials were recorded for each movement by each participant, which, based on previous research, would provide a suitable statistical power for the sample population [17].

Differences in peak pressures at the two areas of the lateral side of the dorsum of the foot during the five selected movements were examined using repeated measures (2 × 5) ANOVA, with statistical significance accepted at a level of $\alpha = 0.05$. Post-hoc analyses were performed using a bonferroni correction to control for type I error. Effect sizes were calculated using Eta^2 (η^2). All statistical procedures were conducted using SPSS 17.0 (SPSS Inc., USA).

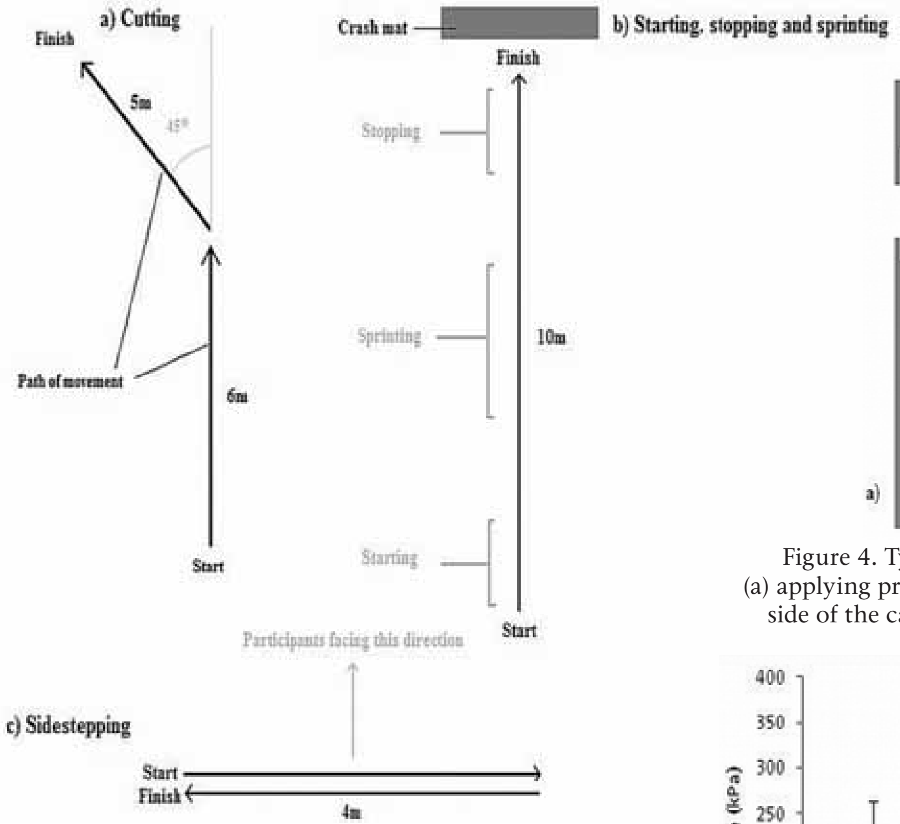

Figure 3. Diagram showing the analysed movements for (a) cutting, (b) starting, sprinting and stopping and (c) sidestepping

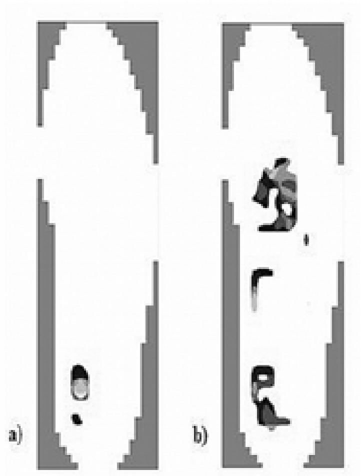

Figure 4. Typical pressure distribution patterns: (a) applying pressure with a blunt pointer to the lateral side of the calcaneus (b) during cutting movement

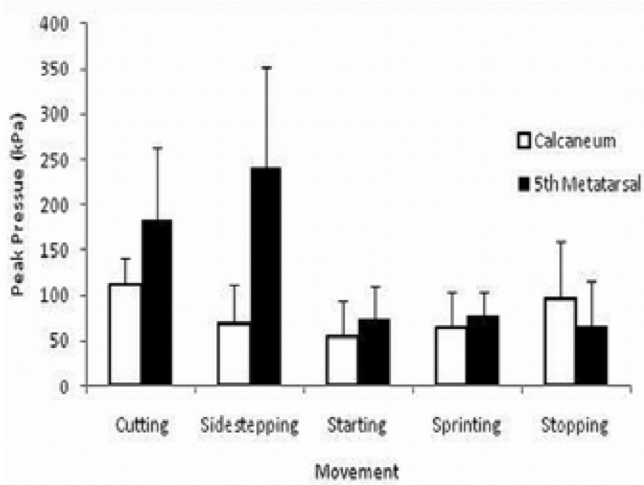

Figure 5. Mean (± standard deviation) in-shoe peak pressure recorded during sports specific movements at the lateral side of the dorsum of the foot for all participants

Results

The Shapiro-Wilk statistic for each condition confirmed that the data were normally distributed and the sphericity assumption was met in all cases. A significant main effect $p = 0.046$, $\eta^2 = 0.39$, was found for the peak pressures reported at the LCC and the L5MTH. Larger mean peak pressures were found to be applied to the L5MTH in most of the conditions with only the stopping movement reporting a larger mean peak pressure at the LCC. Between the movements an ANOVA test reported significant differences $p = 0.001$, $\eta^2 = 0.41$ between the mean peak pressures applied when comparing the effect of the movement. Post-hoc analysis revealed that peak pressures were significantly greater during the sidestepping and cutting movements in comparison to the starting ($p = 0.002$ and $p = 0.003$), sprinting ($p = 0.009$ and $p = 0.010$) and stopping ($p = 0.025$ and $p = 0.016$) movements (Fig. 5). Furthermore, a significant interaction was also observed $p = 0.006$, $\eta^2 = 0.52$. Post-hoc paired *t*-tests showed that peak pressures were far greater during the sidestepping and cutting movements at the L5MTH in comparison to the remaining movements at the LCC. However, only the start and sprint movements at the LCC were found to differ significantly at the Bonferroni corrected level ($p = 0.0083$) from the sidestepping ($p = 0.002$ and $p = 0.003$) and cutting ($p = 0.003$ and $p = 0.004$ respectively) movements at the L5MTH.

Discussion

The aim of the current investigation was to investigate the magnitudes of peak pressures applied to the L5MTH and LCC by the upper parts of footwear during sports movements using an adapted plantar pressure measuring system. This study also represents the first investigation to quantify the pressure applied to the lateral side of the dorsum of the foot during sports movements.

The results of the in-shoe movement testing recorded pressure distribution patterns which are dependent on the movement being performed (Fig. 5). Higher peak pressures are present in movements involving a specific lateral component (cutting and side-stepping). It was clear from the observations of the recorded pressure distribution patterns that high peak pressures were prevalent at the L5MTH and the LCC during lateral movement (cutting and side-stepping). As the magnitude of localised pressure is an important factor in assessing the possible risk for injury, the results were not normalised to the participants' bodyweights in order to allow for clearer identification of the reported values. The results show similar peak pressures reported in the plantar region of the feet during locomotion [18]. This finding is in agreement with previous research on human locomotion, where a large proportion of the reaction forces act on the skeletal system through the uppers of footwear [11].

The results also show that the pressure in the uppers can be relatively higher in different areas between the dorsum of the foot and the uppers of the shoe. This was most notable during sidestepping, where the mean peak pressure recorded during sidestepping (241.6 kPa) was 360% larger than the peak pressure between the upper of the shoe and the side of the calcaneus (67.5 kPa). This would suggest that during sidestepping, most of the friction between the shoe and the surface would be generated in the forefoot plantar region. For sports involving a high frequency of the investigated movements over a sustained period of time, there is a need to consider the distribution of pressure by the uppers of the footwear used by an athlete. Reducing this pressure on the feet may help reduce discomfort, skin abrasion and the onset of corns and calluses [4].

Modifications to footwear insoles have been identified as being effective in reducing specific localised peak plantar pressure values [19]. Therefore, adaptations made to the support surface provided by the uppers of sports footwear may have similar effects on the pressure distribution applied to the dorsum of the foot by the uppers. By using the technique described in this study to test footwear, both additional injury prevention and increased comfort may be possible. By designing shoe uppers with supports on the lateral sides of footwear, in places where the foot experiences lower levels of peak pressures such as the lateral side of the dorsum at the midfoot, peak pressures in the uppers may be decreased by redistributing a larger component of the force away from the areas at most risk. This design feature may be particularly useful for sports participants who have suffered previous injuries in areas that are covered by the upper parts of footwear. By choosing the correct shoe upper design it may be possible to alleviate the peak pressures experienced in the area of concern, allowing the athlete to reduce their risk for injury while reducing the detrimental effect that discomfort may have on movement, and thus performance.

Previous studies used real-time plantar pressure feedback to enable participants to adapt their movement characteristics during normal gait [20]. A similar system may help sports participants who perform movements at risk of high lateral pressure on the lateral side of the dorsum of the foot to adapt their movement strategies to prevent exposure to such high lateral pressures. Although this is an area that warrants further investigation, it was found during this investigation not to be possible with currently available technology. This would require placing pressure sensors inside the anterior end of the shoe to record the necessary data due to the shape of the shoes and the sensors' arrangement.

Although not identified in this research, foot shape may be an additional factor brought under consideration in future research. It has been shown to influence loading and pain at the plantar surface [21–22], suggesting a similar effect on the interaction of the upper part of the foot and the dorsum.

Conclusion

This study recorded localised pressure between the lateral side of the dorsum of the foot and the uppers of a shoe by adapting sensors originally designed for the plantar surface. The study's main finding was that different areas of the upper parts of the feet experience different magnitudes of peak pressures dependent on the movement being performed. Further research investigating more areas of the foot will enhance the understanding of force transmission through the upper parts of footwear during human movement.

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Paper received by the Editors: May 18, 2012
Paper accepted for publication: September 14, 2012

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