MIDFOOT SHAPE WHEN STANDING ON SOFT AND HARD FOOTBEDS

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In this study, the plantar shape of the midfoot was determined when the participants were standing on three different surfaces. Foot impression castings of sixteen participants were made when they were standing on a custom-made device. These castings were laser scanned in order to quantify the shape differences. The results showed that, when the amount of cushioning on the support surface was changed, the plantar mid-foot sag changed by 5.0 mm. The results have important implications for footwear design as midfoot shapes in footwear are somewhat standardized and are not adjusted to account for the cushioning properties of the footbed. The mismatched deformations between feet and shoes as a result of design, structure and material used in the heel and forefoot regions of shoes can contribute to unwanted strain on the plantar fascia of the human foot.

INTRODUCTION

Person-product compatibility is a necessary condition for improved comfort and reduced injury. Many previous studies have investigated the effects of foot shape under different loading conditions (Rossi, 1983; Tsung, Zhang, Fan and Boone, 2003). In addition, higher heel heights result in differing load distributions on the foot relative to that of standing on flat ground (Broch, Wyller and Steen, 2004; Mandato and Nester, 1999) and thereby affect the shape of the foot (Kouchi and Tsutsumi, 2000; Srujders, 1986). Most previous studies have investigated shape changes on the dorsum side of the foot. However, little is known about shape changes on the plantar surface of the foot even though most load bearing occurs on this surface and it is extremely critical in the design of the shank shape of a shoe (Alemány, Nácher, Alcántara, González and Sanchis, 2003). This study seeks to determine the variations in the midfoot shape of the plantar surface of the foot when a person is standing on three different surfaces. Understanding the variations in foot shape in conjunction with differing footbed properties can allow the shoe designer and manufacturer to design footwear that have shank shapes that are compatible with feet.

METHOD

Participants

Sixteen Hong Kong Chinese males participated in this study. Their ages ranged between 20 to 35 years with an average age of 25.4 years. The range of foot length (both left and right) was from 23.6 cm to 27.7 cm with an average of 25.6 cm. None of the participants had any foot illnesses or foot abnormalities. Each of the participants was paid HK$ 100 for the time spent participating in the study.

Apparatus

A special device was fabricated that could accommodate differing materials for supporting the foot. The rearfoot and forefoot parts of the device were made of a rigid material, whereas the midfoot rested on the material that was varied and tested. This configuration allowed us to eliminate interaction effects of the midfoot with both the heel and the forefoot. Three surfaces, hereafter referred to as SS25, SS60 and PU, were used in this study (Table 1). The heel height was set at 20 mm relative to the forefoot height, thus simulating a typical man's dress shoe. The length of the rigid heel was 45 mm. The heel wedge angle and the toe spring angle (the upward curvature in the toe area) were both 0 degrees. The dimensions of the three surfaces are given in Table 1.

Table 1. Surface dimensions

Supporting Surface	SS25	SS60	PU
Material	Spring Steel	Spring Steel	Polyurethane
Thickness (mm)	0.25	0.60	3.20
Width (mm)	140.0	140.0	140.0
Length (mm)	300.0	300.0	300.0

Procedure

The experimental procedure was approved by the Research Ethics Committee at the Hong Kong University of Science and Technology. Each participant completed a voluntary consent form. The foot length (left and right feet), stature, body weight and age of each participant were recorded. Eleven anatomical locations were identified and marked on the right foot with 6 mm diameter self-adhesive stickers. Five of the landmarks were on the top of metatarsal-phalangeal joints (MPJ), one each on the side of first and fifth MPJ, one each on the medial and lateral malleolus, and one each on the medial and lateral sides of the calcaneous, such that they were 30 mm from the pternion and 15 mm above the ground. The latter two marks and the mark on top of the second MPJ were used for aligning the surfaces when comparing the shapes.

Since the support surfaces were opaque, the plantar foot shape could not be scanned when the subject was standing. Hence, foot impression castings were made that were later scanned using a 3D foot scanner. Four castings (i.e,. one casting when standing on each of the three supporting surfaces and one when standing on flat "ground") were made of each participant's right foot with Plaster of Paris ($CaSO_4 \cdot {}^1/_2 H_2O$). All impression castings were kept under standard laboratory conditions for 12 (± 0.5) hours prior to laser scanning.

After registering the scans so that the axes of the feet were aligned, the dimensional differences (DD) were computed for all three pair-wise combinations of each set of castings obtained when standing on the three surfaces. The DD was calculated as the shortest Euclidean distance from each point of one scan ("reference") to the other scan ("non-reference") using procedures described by Witana, Feng, and Goonetilleke (2004). The dimensional differences are good indicators of the shape differences when a subject is standing on surfaces. Positive and negative DDs indicate points that are inward or outward relative to the reference casting respectively.

RESULTS

To investigate the shape differences in 3D, the foot shape was divided into eight regions as follows:

upper and lower regions separated by a plane of 5mm height measured from the plantar surface. Each of the upper and lower regions was subdivided in to four areas to distinguish the rear-foot, mid-foot, MPJ and forefoot. The rear-foot region comprised the volume within the heel seat length (i.e., 45 mm). The MPJ region enclosed the volume from 10 mm behind the fifth MPJ to 10 mm in front of the first MPJ as shown in Figure 1. The mid-foot region was that between the rear-foot and MPJ regions. The forefoot region was defined as the region anterior to the MPJ region (Figure 1). The minimum, maximum and absolute mean values of the dimensional differences in each of these regions were calculated between two castings at a time. Table 2 shows the descriptive statistics of the dimensional differences in each region, calculated from the foot shapes when Participant No. 10 was standing on SS60 and SS25.

Pair-wise comparisons among the three shapes of each participant's right foot showed that the greater difference in midfoot shape was between SS60 and SS25 (mean of the maximum difference = 5 mm) and between SS60 and PU (mean of the maximum difference = 4.9 mm). Consequently, the upper region of the mid-foot and MPJ experienced high deformation. As expected, the lower regions of the rear-foot and forefoot had the lowest deformation due to the rigid surfaces in these two regions.

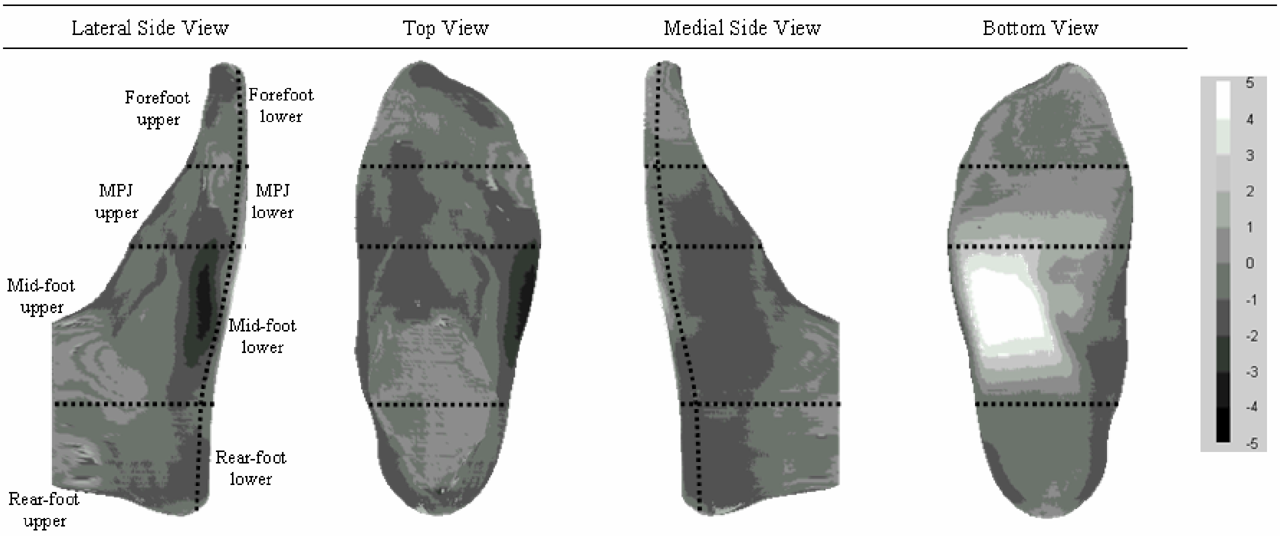

Figure 1. Dimensional differences between the SS60 foot shape and the SS25 foot shape (reference: SS60 foot shape) for Participant No. 10. The dotted lines separate the eight regions.

Table 2. Descriptive statistics of the dimensional differences for each region between the shapes when standing on SS60 and SS25 (reference is the shape on SS60) for Participant No. 10. All values are in mm

Region	Rear-foot Lower	Mid-foot Lower	MPJ Lower	Forefoot Lower	Rear-foot Upper	Mid-foot Upper	MPJ Upper	Forefoot Upper
Abs. Mean	0.76	1.97	0.95	0.53	0.98	1.04	1.00	0.80
Max.	0.79	5.69	3.05	1.71	2.24	1.69	1.32	1.71
Min.	-1.68	-1.46	-1.11	-1.70	-2.59	-3.47	-2.60	-1.89

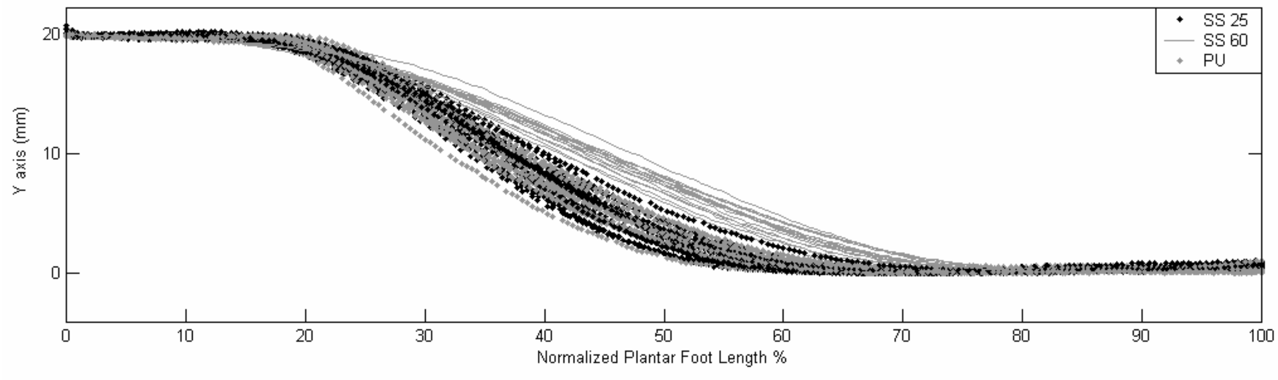

Figure 2. Normalized 2D plantar foot shapes of participants when standing on the SS60, SS25 and PU surfaces.

The 2D plantar foot shapes were extracted from the 3D foot scans. The length of every plantar foot shape was calculated using the sum of the Euclidean distances between consecutive points in an effort to normalize the shapes of the sixteen participants. The normalized shapes are shown in Figure 2. The figure shows that the deformations in the range of 20 to 70% of the normalized plantar foot length when standing on SS60 are lower than those when standing on SS25 and PU.

DISCUSSION

The results clearly show that the midfoot shape can be different depending on the material properties supporting the foot even though the heel and forefoot parts of the foot are rigidly supported. The materials with lower stiffness, SS25 and PU, were less supportive, thereby resulting in higher deformation in the mid-foot region. On the contrary, the thicker and stiffer plate made from SS60 deforms less in the midfoot region. The higher deformations can “dig” into the feet thereby causing discomfort and possibly injuries such as plantar fasciitis (Cole, Seto, and Gazewood, 2005; Riddle, Pulisic, Pidcoe, and Johnson, 2003) in the long-term. In addition, providing the optimum level of support using a shape that matches the loaded foot (Alemány et al., 2003) can help lower plantar pressures as high plantar pressures may induce pain and discomfort (Godfrey, Lawson and Stewart, 1967; Hodge, Bach and Carter; 1999). Overall, the results have strong implications for the design and manufacture of comfortable footwear.

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References

Alemány, S., Nácher, B., Alcántara, E., González J. C., & Sanchis E., (2003). Morphological analysis of the lateral foot shape at different heel heights, *In Proceedings of the ISB Technical group on Footwear Biomechanics, 6th Symposium on footwear biomechanics*, Queenstown, NZ.

Broch, N.L., Wyller, T., & Steen, H., (2004). Effects on heel height and shoe shape on the compressive load between foot and base, *Journal of the American Podiatric Medical Association*, 94(5) 461-469.

Cole, C., Seto, C., & Gazewood, J., (2005). Plantar fasciitis: Evidence-based review of diagnosis and therapy, *American Family Physician*, 72(11): 2237-2242

Godfrey, C.M., Lawson, G.A., & Stewart, W.A., (1967). a method for determination of pedal pressure changes during weight-bearing: Preliminary observations in normal and arthritic feet, *American Journal of Public Health*, 78: 1563-1567.

Hodge, M.C., Bach, T.M., & Carter, G.M., (1999). Orthotic management of plantar pressure and pain in rheumatoid arthritis, *Clinical Biomechanics*, 14: 567-575.

Kouchi, M. & Tsutsumi, E., (2000). 3D Foot shape and shoe heel height, *Anthropological Science* 108 (4) 331-343.

Mandato, M.G. & Nester, E., (1999). The effects of increasing heel height on forefoot peak pressure, *Journal of the American Podiatric Medical Association*, 89(2) 75-80.

Riddle, D.L., Pulisic, M., Pidcoe, P., & Johnson, R.E., (2003). Risk factors for plantar fasciitis: A matched case-control study, *Journal of Bone and Joint Surgery*, 85(5): 872-877

Rossi, W. A., (1983). The high incidence of mismated feet in the population. *Foot and Ankle*, 4(2), 105-112.

Srujders, C.J., (1986). Biomechanics of Footwear, *Clinics in Podiatric Medicine and Surgery*, 4(3), 629-644.

Tsung, B.Y., Zhang, M., Fan, Y.B., & Boone, D.A., (2003). Quantitative comparison of plantar foot shapes under different weight-bearing conditions, *Journal of Rehabilitation Research and Development*, 40(6) 517-526.

Witana, C.P., Feng, J.J. & Goonetilleke, R.S., (2004). Dimensional Differences for Evaluating the Quality of Footwear Fit, *Ergonomics*, 47(12) 1301-1317.