MIDFOOT SHAPE FOR THE DESIGN OF LADIES' SHOES

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Abstract: This study is an attempt to model the midfoot height of adult females. The right feet of 24 Hong Kong Chinese females were laser scanned. The midfoot heights were then determined at intervals of 1.2 mm. These heights showed a significant relationship with normalized length along the foot. The fitted model had R^2 = 0.937 and has important implications for the design of the vamp area of a shoe.

Introduction

Good fit is a necessary condition for footwear comfort [1, 2] and misfits between feet and shoes can result in foot injuries and even foot deformities [3, 4]. Sizing systems such as the Mondo-point, US and Chinese systems are used to account for differences in foot length [5]. At the same time, some manufacturers use the "regular", "wide" or "narrow" conventions to designate different widths of shoes. However, differences in height, especially in the midfoot region, are only accomplished through the use of "open" or lace-type of shoes.

Midfoot shape is important for the design of the shoe vamp [6, 7]. If the vamp is low, the dorsum side of the foot will have high pressure, which can result in blisters [8]. And, if the vamp of a shoe is too high, the foot will slide back and forth resulting in compression of the toes [1, 9]. Thus, knowing the midfoot shape is useful to achieve the right fit between foot and shoe.

Materials and Methods

Participants: A total of 24 Hong Kong Chinese adult females participated in this study. None of them had any visible foot illness or abnormalities and their descriptive statistics are shown in Table 1. Each participant filled an informed consent form prior to the experiment.

Table 1: Descriptive statistics of the female participants (N=24)

Variable	Mean	SD	Max.	Min.
Age (years)	**21.42**	**1.32**	**24**	**19**
Stature (mm)	**1594.5**	**57.10**	**1700**	**1482**
Weight (kg)	**53.34**	**11.53**	**94.25**	**39.10**

Foot Landmarking and 3D Scanning: Nine anatomical landmarks were put on each participant's right foot: five were on the top of each metatarsal-phalangeal joints (MPJ), one on the most medial prominence of the first MPJ, one on the most lateral prominence of the fifth MPJ, and two on the medial and lateral malleolus respectively. Thereafter, the participant's right foot was aligned and laser scanned on a YETI™ I laser scanner [10] with half-body weight on each foot. The scanned data points of the foot together with the nine landmarks were stored and processed with a VC++ program to extract foot heights in the midfoot region.

Data Processing: A registration procedure as described in [11] was used to align the feet. Then, the midfoot region was determined as the region between points P_1 (the most medial prominence of the first MPJ) and P_4, which was 5 mm from point P_3 (Figure 1). Point P_3 was determined as the most anterior point of the plane that passes through the medial malleolus P_2 and which is parallel with the XY plane. The midfoot region so determined was then sectioned into strips of width 1.2 mm along the x-axis (these strips are shown as 1, 2, 3, …. i,.. in Figure 1). The height of each strip was then determined from the point cloud of data found and used in order to develop a mathematical model for midfoot shape.

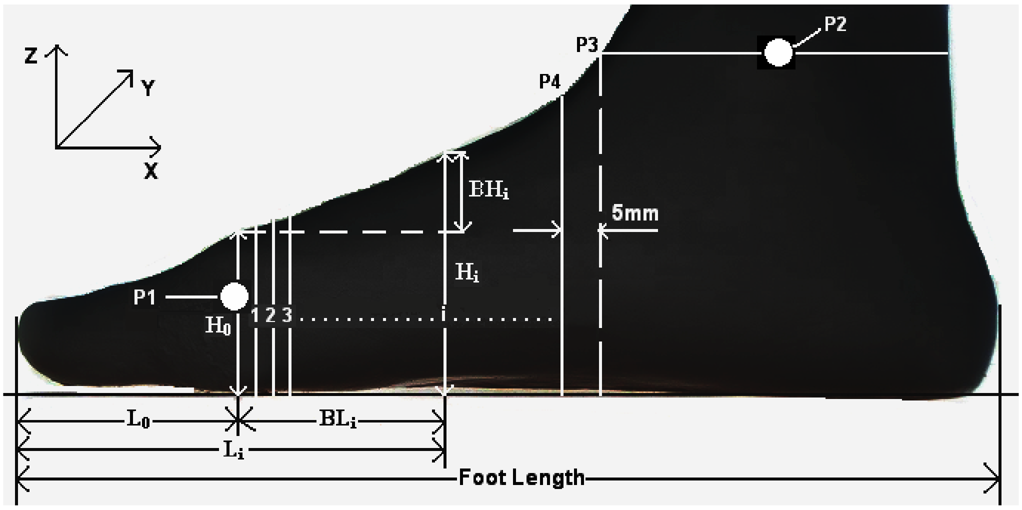

Figure 1: Foot heights in the midfoot region

Data Analysis and Results

A linear regression of the form (Y=a+b*X) was used to model midfoot shape. All statistical analyses were performed using the SAS statistical package.

As the feet of the experimental participants were of different size, it was necessary to normalize the foot dimensions. The normalization used was as follows: (1) for strip i, the ball-to-strip height (BH_i) and the ball-to-strip length (BL_i) were determined using the equations, $BH_i=H_i-H_0$ and $BL_i=L_i-L_0$ (Figure 1); (2) ball-to-strip length (BL_i) was normalized with respect to foot length (FL) to get normalized ball-to-strip length, $NBL_i = BL_i/FL*100$.

After the normalization, BH and NBL of all midfoot strips of all participants were pooled together and modelled using a line of best fit (Figure 2). The least squares fit between BH and NBL had $R^2=0.937$ ($p < 0.0001$) and the relationship was as follows:

$$BH\ (mm) = 1.079 * NBL + 0.314$$

NBL has the unit of percentage in the above equation.

Discussion and Conclusions

The relationship between BH and NBL is relatively strong ($R^2 = 0.937$) indicating that the normalized variables can be modelled fairly well with a linear form. Without such a normalization, there is no strong relationship between length and height. The advantage of the normalization is that it can be used across feet of different lengths and/or sizes as the normalization helps to unify the differences. The model generated can be used quite easily in the design of shoe last.

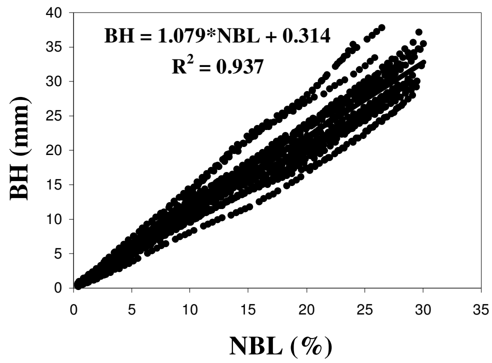

Figure 2: Plot of BH (mm) and NBL (%) of all participants and the least squares model

Figure 2 shows that the differences among participants increasing with increasing NBL with the highest variation at around maximum NBL (near foot and lower leg junction, see figure 1). This variation is due to the abrupt change of foot curvature near this junction and this discrepancy will not affect most footwear, except boots.

Hong Kong females were participants in this study and it is unlikely that the model will hold for other populations or even males [12]. The external validity of the model should be checked in order to generate a universal model applicable to any person's foot.

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