CAN WE DO AWAY WITH THOSE CUMBERSOME SHOE LACES?

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Abstract: Footwear manufacturers attempt to cater to a wide variety of users by providing shoes of different lengths and widths. But, footwear users such as ski-boot wearers who require a specialized fit use custom-made implements with mechanical clamps as footwear fit and function are known to affect human performance. Shoe laces that restrict the deformation of feet may hamper fit, function and thereby human performance. This study is two fold: it investigates the need for shoe laces and whether a model can be developed that will allow a specific shoe to fit a foot so that the necessary freedom for the foot can be given for it to function effectively.

1. INTRODUCTION

Item packaging for mailing has not only increased, but has significantly developed over the years. In ancient times, rope or several braids of string were wrapped and sealed to hold the contents of a box together. However, with the development of high strength plastics and superior adhesives, string or rope is hardly used for packing these days. Instead, packaging tape is the more common alternative with ribbon being used as a decorative element. The same cannot be said about shoes. Shoe laces are still used to hold the two sides of a shoe together and in some instances decorative fabric are used for the laces to give the shoe some appeal.

Shoes come in different lengths and widths. It is not easy to find shoes of different heights. The adjustment related to this height or third dimension is primarily performed with laces. Shoes, such as men’s dress shoes and ladies’ pumps, that that do not have laces are quite common due to their ease of use and also due to the lower surface area in contact with the foot. Even though zippers are sometimes used, laces have really made their mark as the sole means to hold a shoe on a foot. A possible reason may be related to the variations in the preferred fit among people. A shoe last has a relatively large variation in height from the toe area to the midfoot area (Figure 1), and mismatches in height are accounted for and corrected by adjusting the shoe laces.

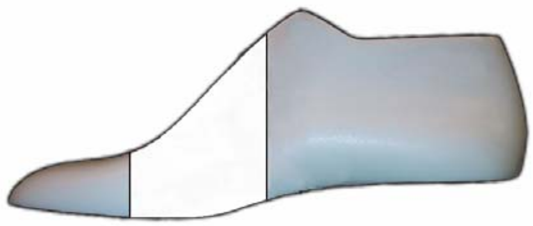

Figure 1. A last showing the relatively large variation of height along its length in the unshaded region

The dorsal shape of the foot is important for designing the vamp or top surface of “closed” shoes (Janisse, 1992; Xing, Deng, Ling, Chen and Shen, 2000). This top surface is an area where some shoe wearers have discomfort due to misfits between the vamp and the navicular area of the foot even with fully adjustable laces. If the vamp is lower than the surface of the foot, the wearer will experience undue pressure that can result in blisters, calluses or even corns (Miller, 1976). On the flip side, a relatively high vamp will allow the foot to slide back and forth thereby compressing the toes and hampering foot function

(Goonetilleke, Luximon and Tsui, 2000). Hence, the objectives of this study were to understand the variations in the height dimension among people and develop a systematic procedure to account for those variations so that fit in the height or third dimension can be accounted to improve footwear fit and function.

2. METHODOLOGY

Twenty four female students at the Hong Kong University of Science and Technology (HKUST) participated in the experiment. Their age range was 19 to 24 years. The foot length of the participants ranged from 214.0 to 259.8 mm with a mean of 238.0 mm. None of the participants had any visible foot abnormalities. The most medial prominence of the first metatarsal-phalangeal joint (MPJ), top of the second third, fourth, and fifth metatarsal-phalangeal joints, the most lateral prominence of the fifth metatarsal-phalangeal joint, medial malleolus, lateral malleolus were identified and marked on each participant's right foot. The Yeti^{TM} (Vorum Research Corporation, 2000) 3D laser scanner was used to capture the surface shape of the right foot of each subject under a half body-weight condition. That is, the participant stood on both feet with equal load on each of them when the right foot was scanned.

3. ANALYSIS AND RESULTS

All statistical analyses were performed using SAS and Excel. In order to get the dorsal heights, the 3D point cloud data were processed with a VC++ program. The point cloud data was first aligned to let the heel centerline, which was defined as the line separating the heel region (rear 13% of foot length) into equal halves (Luximon, Goonetilleke and Zhang, 2005), so that this centerline was parallel to one of the coordinate axes (x-axis). Thereafter, the scanned foot was divided along the x-axis into strips that were 1.2 mm thick. The maximum height H_i (z-value) of each such strip i was determined from the point cloud data with the VC++ program. The heights of the strips (H_i) along the length of the foot (L_i) are shown in Figure 2. The figure clearly shows that the variation in height is relatively high with a height difference of 10 mm at a length of 60 mm from the toes and a height difference of 21 mm at a length of 120 mm from the toes. In other words, the use of shoe laces is quite justifiable given the variations in heights that exist among participants even within a similar population. Figure 2 clearly shows that the "flat" part of the curve at the start, which represents the height at toes quickly starts diverging from the first metatarsal-phalangeal joint (MPJ1) onwards. To account for this large variation even within and between persons, we attempted to develop a procedure that can minimize these variations across different sizes of feet. The starting point for such a procedure was built around a normalization that could account for the large variations among persons.

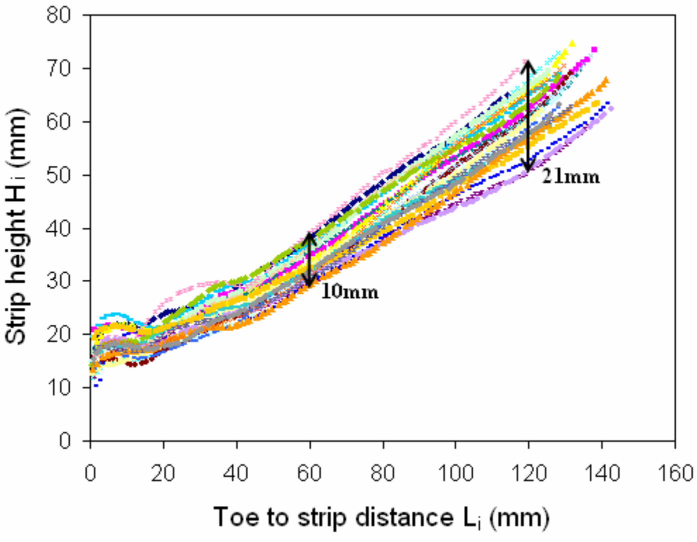

Figure 2. Strip Height (H_i) versus Toe-to-Strip-Distance (L_i) (including the toe area)

Figure 3 shows curves similar to Figure 2 except that the starting point is at the first metatarsal-phalangeal joint (MPJ1). The variations, in the starting point of the curves in Figure 3 among the participants are due to the variations in the length of toes. Thus, the height (H_0) and length (L_0) of the MPJ1 appear to be variable among the different participants. It is also known that foot length (FL) varies among people. To account for such variations, the new variables $BH_i=(H_i-H_0)$ and $NBL_i=(L_i-L_0)*100/FL$ were generated. The plots of BH_i versus NBL_i (%) for each participant, excluding the toe areas, will have a zero intercept and showed strong linearity (R^2 values range from 0.984 to 0.999 for 24 female participants). In other words, $BH_i = H_i-H_0= m*(NBL_i)$ where m is the slope of the line which varies among participants. However, the slope 'm' is difficult to determine unless a foot scan or other means is used for each participant. A simpler way would be if one height dimension such as the height at 50% of foot length (i.e., the midfoot height, H_{50}) could be used. In order to do this, the relationship between ($H_{50}-H_0$) and the slope m was explored. Figure 4 shows such a plot with a relationship of the form ($H_{50}-H_0$) = 20.087*m +3.217 having R^2= 0.837. In other words, ($H_{50}-H_0-3.217$) is proportional to the slope, m. Thus, the variable, ($H_{50}-H_0-3$) can be used as a normalizing factor to minimize the variations in the slope, m, for the different participants. Thus, the new variable $NBH_i= BH_i/(H_{50}-H_0-3)=(H_i-H_0)/(H_{50}-H_0-3)$ was calculated and plotted against NBL_i for each participant. All the curves were pooled and a line $NBH_i = 4.948* NBL_i$ was fitted (Figure 5), which had R^2 = 0.984.

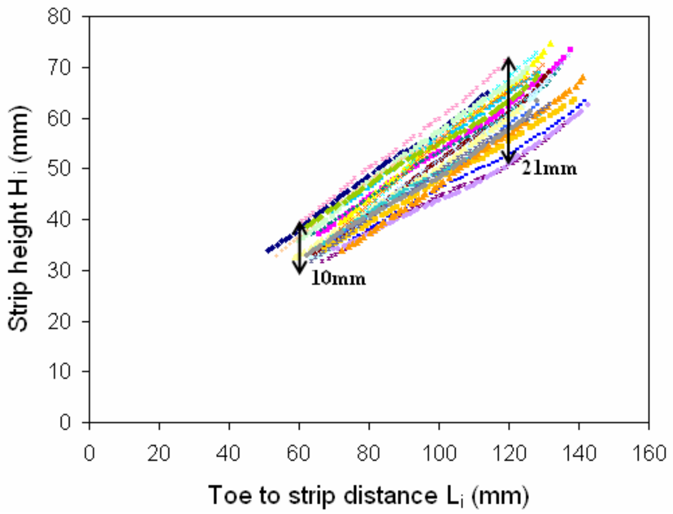

Figure 3. Strip Height (H_i) versus Toe-to-Strip-Distance (L_i) in the midfoot region beyond the first metatarsal-phalangeal joint (i.e., excluding the toe area)

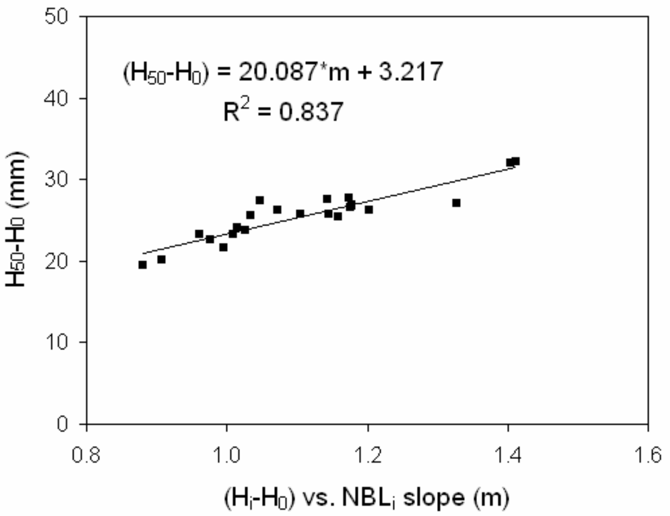

Figure 4. The relationship between (H_{50}-H_0) and the foot dorsal slope m of the line, (H_i-H_0) versus NBL_i, for 24 female participants

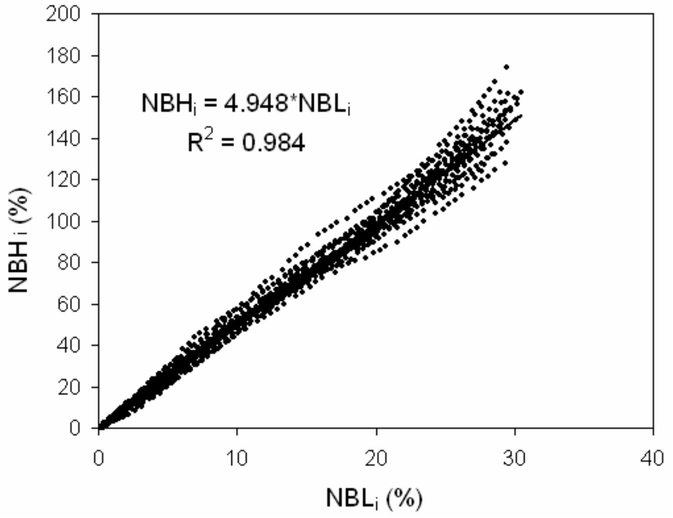

Figure 5. Data plots of normalized variables NBH$_i$=(H$_i$-H$_0$)/ (H$_{50}$- H$_0$-3)*100 and NBL$_i$=(L$_i$-L$_0$)/FL*100 of all participants and the corresponding least squares model

Using the relationship between NBH$_i$ and NBL$_i$ (Figure 5), we can thereafter predict the height H$_i$ of a person's foot at various lengths, L$_i$, knowing the midfoot height (H$_{50}$) and the height (H$_0$) and length (L$_0$) of MPJ1. The model was validated with the same set of participants. The predicted heights for the 24 participants tested were first calculated and their differences from the actual heights, which represent the modeling error, were then plotted. The plots of each participant are shown in Figure 6. The maximum value of the absolute error for the 24 participants were all within 5mm and the mean value of the absolute error for all participants was 0.80mm (SD=0.51) in the modeled region.

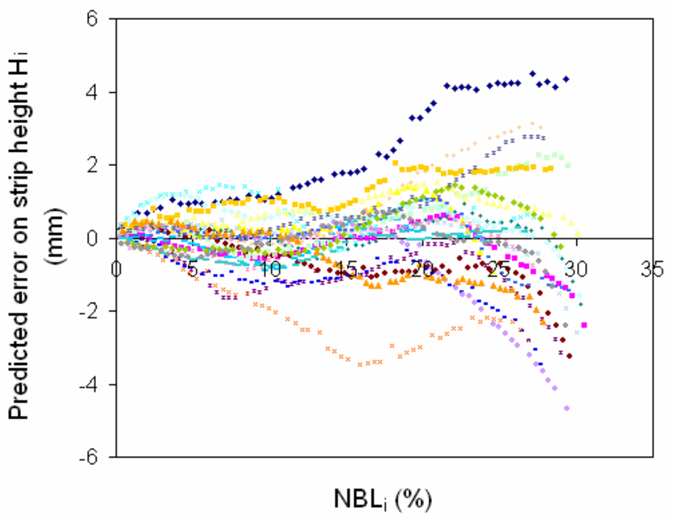

Figure 6. Difference in height H$_i$ (mm) between predicted and actual values for 24 female participants

4. DISCUSSION AND CONCLUSIONS

For the participants tested, the variation in height along the length of the foot can be as high as 20 mm among people. Hence the use of shoe laces is justified as the required adjustments in the height dimension, for proper fit and function, can be achieved using laces. However, the normalization procedure that we developed along both the length and height dimensions can predict the height along the foot of any person using a mathematical formulation reasonably well. The model assumes that the first metatarsal-phalangeal joint height and length and the midfoot height are known. In a previous study, Xiong and Goonetilleke (2006) demonstrated that the model $BH_i=1.096*NBL_i$ ($R^2=0.937$) can be used to predict midfoot height. For the 24 participants that we tested, the use of $BH_i=1.096*NBL_i$ gives a mean absolute error of 1.64 mm (SD=1.07) and a maximum absolute error of 9 mm. Hence it is clear that the additional normalization of BH_i with respect to H_{50} helps reduce the mean modeling error from 1.64 to 0.8 mm. The use of such models will give manufacturers more freedom to design and develop more innovative and alternative adjustment mechanisms that will allow finer adjustments to shoe fit rather than the gross adjustments that are performed with shoe laces today.

The use of smart materials and light-weight micro (MEMS) and nano devices may also be ways to attain a “micro-fit” between feet and shoes when the macro-fit is obtained with the surface shapes generated using the proposed model. In short, it is time to do away with the tying mechanisms of shoes to pave the way for a new generation of footwear that is smart in terms of their usability and functioning, with potential improvements in performance.

This study has its weaknesses. The model that has been developed may not be applicable to other populations even though the likelihood of generating a similar model to any population is possible. In addition, the model should be validated with a larger sample of participants as well to determine possible exceptions.

5. ACKOWLEDGMENT

The authors would like to thank the Research Grants Council of Hong Kong for funding this study under grant HKUST 613406.

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