A 2D APPROACH FOR QUANTIFYING FOOTWEAR FIT

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Fit is an important consideration when purchasing footwear, even though fitting footwear to feet is still rather cumbersome and very unscientific. Some researchers have proposed methodologies to quantify the degree of fit so that matching shoes to feet can be performed without trying them on. This paper reports an experimental study to show the feasibility of such a method. Twenty participants wore and rated the fit of three different dress shoes. By matching the foot outlines to the last outlines, the dimensional differences were quantified and plotted. The plots revealed four distinct minimums, and the forefoot and midfoot fit ratings were strongly correlated with the dimensional differences at these four locations. These locations and the corresponding dimensions can give manufacturers information about the degree of fit so that in the long term, it may be possible to generate a plot similar to the ISO Fits and Tolerances Chart, for the design and selection of good-fitting footwear.

INTRODUCTION

Consumer products such as footwear, garments, sports equipment, and so on are generally bought after trying them on in a retail store or other outlet. With the exponential growth of product variety, people are more selective than ever before in their purchases and may experience information overload and difficulty perceiving comfort differences when selecting such products.

Footwear fit is a dominant factor in the selection of footwear. Even though fit is not well defined, there are numerous studies that have reported anthropometric measurements (Baba 1975; Falcao and D'Angelo, 1992; Freedman et al., 1946; Pheasant, 1994; Rossi, 1983; Rys and Konz, 1994). Even with such a large database of information, fitting footwear to feet is still not perfect. Poor fitting shoes have been shown to cause blistering, chafing, black toes, bunions, pain, and tired feet (Rossi, 1988). Thus, achieving the right fit is very important for comfort as well as foot health. Goonetilleke, Luximon and Tsui (2000) proposed a methodology to quantify the degree of fit so that matching shoes to feet can be performed without trying them on. This paper is an attempt to validate that method.

METHODOLOGY

Participants

Twenty (20) Hong Kong Chinese males aged between 19 to 26 years with a mean age of 21.4 years, who were students at the Hong Kong University of Science and Technology, participated in the experiment. Their foot length was in the range 235 mm and 270 mm and the weight range was 52 to 84 kg. None of the participants had any foot illnesses or abnormalities. All the participants were briefed about the nature of the experiment and filled a consent form before they started the experiment. Each of the participants was paid HK$150 (~US$ 20) for their time.

Stimulus Materials and Equipment

Three dress shoes (UK size 7, 7.5, and 8) were especially fabricated for this test. The manufacturer of the shoes also supplied the shoe lasts. The Yeti® 3D foot laser scanner (http://www.vorum.com) from Vorum was used to obtain the 3-D shape of feet (when standing with half body weight and full body weight on each foot) and the six shoe-lasts (i.e., left and right of all 3 pairs). After scanning the feet and lasts, the 3D surface coordinates were extracted from the Yeti software.

Procedure

Each participant wore a pair of shoes, randomly selected by the experimenter, and rated the subjective perceptions on a 7-point scale with respect to overall fit (q1) (-3 = very bad, 0 = neutral and +3 = very good), heel height (q2) (-3 = too little, 0 = neutral and +3 = too much), free space in front of toes (q3) (-3 = too little, 0 = neutral and +3 = too much), forefoot fit (q4) (-3 = too tight, 0 =neutral and +3=too loose), mid-foot fit (q5) (-3 = too tight, 0 = neutral and +3 = too loose) and rear-foot fit (q6) (-3 = too tight, 0 = neutral and +3 = too loose) when standing. This paper will focus only on the midfoot and forefoot ratings. The same procedure was repeated with the other pairs of dress shoes. If a participant was unable to wear any of the experimental shoes, that pair was not rated. The clearance at the achilles tendon area between shoe and the foot was measured at the throat opening from the back of the shoe to the foot when the participant was standing. After completing the questionnaire, each participant's feet were scanned.

Data Processing and Matching

2D Outline Generation and Matching

The three-dimensional data of feet with half-body weight and full body weight, and the lasts data were converted to 2D outlines using Matlab.

The coordinate system adopted was as follows: x-axis was in the width direction, y-axis was in the lengthwise direction and z-axis was in the height direction (Figure 1).

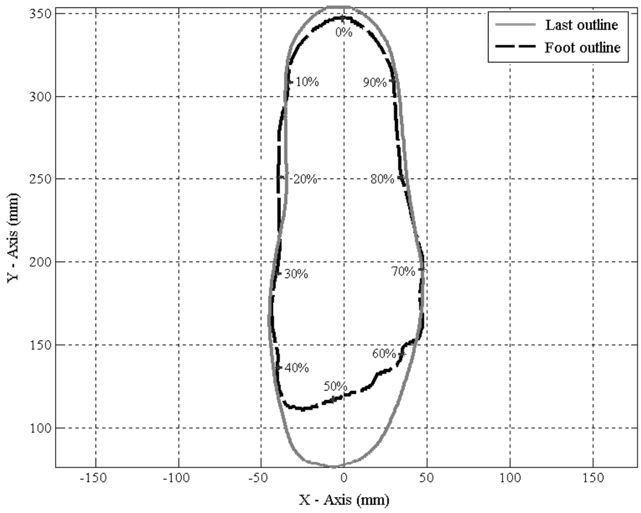

Figure 1. Left foot (half load) of participant 3 aligned with size 8 shoe.

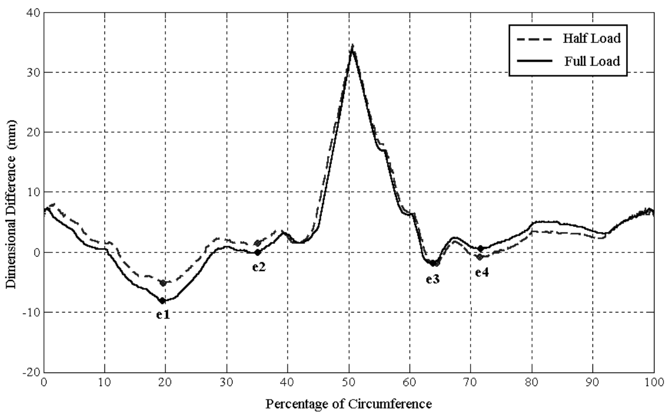

Figure 2. Dimensional difference between left foot of participant 3 and size 8 shoe on a normalized x-axis.

The measured distance at the back of the foot was used to align the 3D scans. The projected distance on to the plantar surface plane was then used to align the 2D outlines in the lengthwise direction. The width-direction alignment was performed by considering equal looseness or equal tightness on the two sides in addition to the subjective ratings. Such a positioning scheme may not be exact, but is a reasonable approximation for understanding and quantifying fit. All feet were normalized with respect to the foot perimeter. The outline perimeter was calculated by taking the cumulative sum of the Euclidean distance between consecutive points from the foot outline (Figure 1).

Dimensional Difference Calculations

After the foot outline and last outlines were aligned, the dimensional differences ("errors") between them were calculated as the shortest Euclidean distance from each point on the foot to the last, which is a special case of the Minkowski distance metric (Osada et al, 2001). Tightness was defined as a negative difference and looseness was defined as a positive error (Goonetilleke et al., 2000). The dimensional errors were plotted against the perimeter of the foot (Figure 2).

RESULTS

The similarity among the dimensional difference plots of participants is quite striking. A global maximum and four local minimum points are present as seen in Figure 2. The maximum point corresponds to forefoot clearance and is at around 50% of the perimeter. The local minimums (e1, e2, e3 and e4) are in the regions of 10 – 30, 30 – 50, 50 – 70 and 70 – 90 percent of the perimeter (Figure 2).

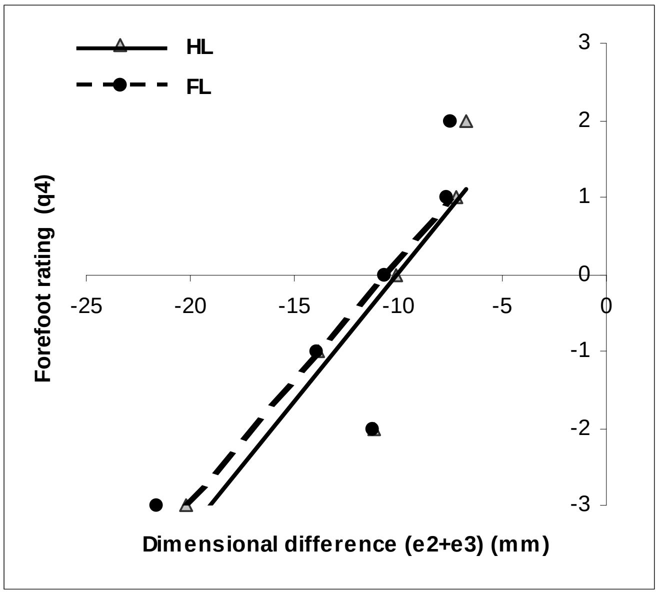

Figure 3. Linear regression analysis of forefoot fit rating and dimensional difference for all shoes under full body-weight (FL) and half body-weight (HL).

These dimensional differences were further analyzed. The forefoot fit rating (q4) showed a high correlation with (e2+e3) at full body weight (FL) and half body-weight (HL) conditions (Figure 3). The linear regression analysis for FL was:

Forefoot rating (q4) = 0.3070 (e2+e3) + 3.2182 (R^2 = 0.74)

For HL:

Forefoot rating (q4) = 0.3347 (e2+e3) + 3.3604 (R^2 = 0.79)

Similarly, the subjective ratings for midfoot fit (q5) showed a high correlation with (e1+e4) (Figure 4). The regression analysis for the FL condition was:
Midfoot rating (q5) = 0.3765 (e1+e4) + 5.6645 (R^2 = 0.91)

For HL:
Midfoot rating (q5) = 0.4014 (e1+e4) + 5.5971 (R^2 = 0.94)

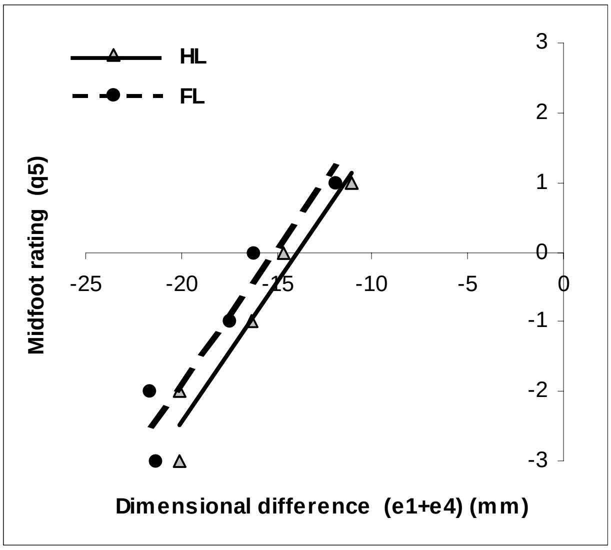

Figure 4. Linear regression analysis of midfoot fit rating and dimensional difference for all shoes under full body-weight (FL) and half body-weight (HL).

DISCUSSION

The dimensional difference between foot and last outlines appear to be remarkably similar when the perimeters are normalized with the local minimums and the maximum falling within fairly consistent ranges. In addition, the dimensional differences are highly correlated with the forefoot and midfoot fit ratings. The midfoot rating is very strongly correlated with (e1+e4) for both half load and full load conditions. Similarly, forefoot rating is highly correlated with (e2+e3). In both, half body-weight as well as the full body-weight conditions, the relationships between the subjective ratings and the dimensional differences are quite striking.

As mentioned earlier, the alignment of the foot outline and the last outline in the width direction may not be exact. Thus, the summation of the dimensional differences (that is e1+e4 and e2+e3) was used rather than the individual dimensional differences. This summation can partially account for some of the alignment errors.

Overall, the findings of this study can have important implications. For example, if the points e1, e2, e3 and e4 are known, then the shoe last can be designed to achieve a given rating of perceived fit. In other words, the method can be used to generate a shoe shape that fits a customer's preference whether it be in the midfoot or forefoot and whether it be loose or tight. The underling approach is very similar to that of Fits and Tolerances between shafts and holes (Hole Basis or Shaft Basis) in classical Mechanical Engineering. In the long term, it may be possible to generate a plot similar to the ISO Fits and Tolerances Chart, for the design of shoe lasts. Such a standardized system can enrich not only a customer's footwear selection process, but also the manufacture of footwear.

This study has its shortcomings. The proposed method should be tested with different types and different sizes of shoes for both men and women. Thus, further investigation may be required to increase the external validity of the findings.

CONCLUSIONS

The proposed method of quantifying the quality of the fit may help lead to significant improvements in the prediction of footwear fit. Kolarik (1995) stated, "The customer will judge their shoe fit by wearing the shoes, but at the factory we must use "substitute" characteristics like length, width, and so on, to design, develop and produce our product". The use of the dimensional difference concept not only improves the fit but will also allow footwear designers to design lasts of any style that match a population. However, further investigations may be necessary to enrich the external validity of the findings and to establish a footwear-fit metric table similar to the ISO Fits and Tolerances Chart.

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