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Comparison of foot shape between recreational sprinters and non-habitual exercisers using 3D scanning data

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ABSTRACT

In this study, the 3D foot scanning data of 787 male participants were used to compare the foot shape of the recreational sprinters (n = 41) and non-habitual exercises (n = 746). Fourteen foot dimensions together with two foot type indicators were included in the comparison. The heel breadths of both feet of the recreational sprinters were significantly narrower than those of the non-habitual exercisers ($p < 0.05$), while the toe lengths of both feet of recreational sprinters were significantly longer than those of the non-habitual exercisers ($p < 0.05$). The participants' Arch Height Index (AHI) and Normalized Navicular Height Index (NNHI) suggested that on average the foot type for both groups fell into 'normal arch foot'. Discriminant Analysis (DA) reached a hit ratio of 80.5%, which showed that the foot shapes of the recreational sprinters and non-habitual exercisers were distinguishable based on the foot dimensions. These findings could provide useful information for running shoe design and production.

1. Introduction

It is believed that ill-fitting shoe would cause the deformity of the foot and lead to injuries (O'Connor et al., 2006). The ill-fitting shoe might also influence the performance during walking or running activities. To avoid these problems, the design of shoes should base on the target users' food shape and foot dimensions. Foot characteristics varied a lot according to demographic factors such as gender (Krauss et al., 2008; Wunderlich and Cavanagh, 2000) and ethnic (Lee et al., 2015; Shan and Bohn, 2003) Manna et al. (2001) found that wearing shoes can cause foot problems and footwear deformation, and these problems were more serious in the right foot than the left foot. It is believed that the side of feet may also be an influential factor of the shoe last design (Manna et al., 2001). Human activities would also influence the shape of foot (Barisch-Fritz et al., 2014; Butler et al., 2006; Orendurff et al., 2008). It is important to include the various characteristics of foot shape into shoe last design so as to improve the comfort of footwear.

Generally, foot length and foot breadth were often used to determine the size and shape of shoe last. Y. C. Lee, Chao, and Wang (2012) found that foot length and foot breadth were two important dimensions that influenced the foot shape of Taiwanese and they developed a new sizing system according to these two dimensions (Lee et al., 2012). However, proper footwear design should include more than length and breadth information since lots of other foot dimension information would influence the fit of footwear (Witana et al., 2004). Dimensions such as foot arch height, instep height, and contour of outer foot were also used in previous studies to describe the variety of foot shape. Methods used by the researchers included *t*-test (Krauss et al., 2008; Wunderlich and Cavanagh, 2000; Zeybek et al., 2008), regression analysis (Ozden et al., 2005), Discriminant Analysis (DA), and Principal Component Analysis (PCA) (Lee and Wang, 2015; Lee et al., 2012).

Many researchers indicated that professional sprinters had different foot shape characteristics compared with normal people (Baxter et al., 2011; Lee and Piazza, 2009; Scholz et al., 2008). To increase the contact time with ground and increase the time spent in the acceleration phase of sprint, professional sprinters usually had significantly longer fascicles and longer toes (Lee and Piazza, 2009). Scholz et al. (2008) also indicated that shorter Achilles Tendon Moment Arm (ATMA) and narrower heel breadth would lead to a lower metabolic cost, which was a beneficial feature for sprinters (Scholz et al., 2008). It could be inferred that the foot shape characteristics of the professional sprinters were related to the improvement of their sprinting performance. The different foot shape features between sprinters and normal people should be considered when designing shoe last for professional runners.

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Three-dimensional (3D) scanning technique has been proved to be a precise and robust approach for anthropometric data collection (Kouchi and Mochimaru, 2011; Lee and Wang, 2015; Li et al., 2008). Three-dimensional foot shape scanning data have been collected in several studies (Krauss et al., 2008; Rout et al., 2010; Lee et al., 2012). Although the foot characteristics of professional sprinters have been proved to be different from normal people, the information of whether the recreational sprinters also have similar foot shape characteristics has been rare. Therefore, the objective of this study was to compare the foot shape characteristics between recreational sprinters and non-habitual exercisers and to figure out important features for running shoe design for recreational sprinters. A total of 787 3D male foot scanning, including 41 for recreational sprinters and 746 for non-habitual exercisers were used in the comparison. Findings of this study would provide valuable information for running shoe design for the recreational sprinters to improve the fit, comfort, and running performance.

2. Method

2.1. Participants

The foot dimensions of two specific populations were of interest, the recreational sprinters and the non-habitual exercisers. The definition of recreational sprinters is: amateur sprinters who receive fast running training with strong explosiveness for a short distance within 400 m for more than three times per week. They should also participate in sprint competitions on an irregular and amateur basis. Non-habitual exercisers refer to those who do not have fixed exercise habits. Three-dimensional foot scanning data of the participants were selected from a larger pool of Taiwanese foot data (Lee et al., 2012). When the data were scanned, the participants evaluated their exercise experience according to the definition of recreational sprinters and non-habitual exercisers, and then reported the relevant information. The participants were then grouped as recreational sprinters (41 participants) and non-habitual exercisers (746 participants) according to their self-reported exercise experience. The age of the 787 participants ranged from 18 to 60 years old with a mean of 34.61 (SD = 10.75). The stature of the 787 participants ranged from 150 to 190 cm and body weight ranged from 45 to 108 kg. The summary of their demographic information (age, weight, height, and BMI) were listed in Table 1.

2.2. Apparatus

A three-dimensional foot scanning system (INFOOT USB scanning system, IFU-S-01, I-Ware Laboratory Co., Ltd, Japan) was used to collect participants' foot measurements (Kouchi and Mochimaru, 2001). The 3D foot scanner has 8 charge-coupled device (CCD) cameras and 4 laser heads, which could reach an accuracy within 1.0 mm. To complete one scanning, it usually takes about 10 s.

2.3. Procedure

Two markers were placed on participant's foot by experimenter, the 1st and 5th metatarsal head of the foot. Each participant was scanned with a natural standing posture without support. To avoid any noise or reflections to interfere with the results, each foot was scanned for three times. Only the two scans with close values were used to calculate the average. The participants were instructed to distribute their weight evenly on medial and lateral side and to hold breathe during scanning to minimize body and foot swing. In total, 14 dimensions of both feet were obtained for further comparison. Twelve dimensions were directly collected from the 3D scanner with the help of the two markers. They were: foot length, ball girth circumference, foot breadth, instep circumference, heel breadth, instep length, fibulare instep length, height of top of ball girth, height of instep, toe #1 angle, toe 5# angle, and height of navicular. Toe length and hallux length were calculated based on the foot length, instep length, and fibulare instep length (see formula (1) and (2)). These dimensions were commonly used in footwear design. The definitions of these dimensions were in accordance with ISO standard (2004) and illustrated in Fig. 1.

$$\text{Toe length} = \text{Foot length} - (\text{Instep length} + \text{Fibulare instep length})/2 \quad (1)$$

$$\text{Hallux length} = \text{Foot length} - \text{Instep length} \quad (2)$$

2.4. Data analysis

The data analysis was conducted using SPSS 17.0. To compare the foot dimensions between recreational sprinters and non-habitual exercisers, we calculated the mean differences (MDs) and mean difference percentages (MDPs) between the two groups and conducted *t*-test on each of the dimension.

Two foot type indicators, Arch Height Index (AHI) and Normalized Navicular Height Index (NNHI) were calculated. AHI was the ratio of Height of instep and Instep length, while NNHI was the ratio of Height of navicular and Instep length. The value of these indicators was used to classify the foot type into a flatfoot, a normal arch foot, or a high arch foot. A less than 0.275 AHI or a less than 0.21 NNHI indicated that the foot was a flatfoot. When the AHI was between 0.275 and 0.356, or the NNHI was between 0.22 and 0.31, we could classify the foot as a normal arch foot. If AHI was above 0.356 or NNHI above 0.31, the foot was a high arch foot. (Butler et al., 2006; Rajakaruna et al., 2015; Willems et al., 2001).

DA was conducted to test whether the foot shape of recreational sprinter and non-habitual exerciser could be correctly distinguished based on the measured foot dimensions. To make sure that both samples had the same size, the scanning of the 41 recreational sprinters were all remained and a total of 41 non-habitual exercisers' data were extracted from the 746 non-habitual exercisers' scanning using a systematical sampling technique. The hit ratio of DA was calculated. It should be greater than 1.25 * proportional chance criterion (C*pro*, see Formula (3)) to ensure a satisfactory DA (Hair et al., 2009).

$$Cpro = p_1^2 + p_2^2 + \ldots p_i^2 + \ldots + p_m^2 = \sum_{i=1}^{m} p_i^2 \quad (3)$$

where:

p_i is the proportion of samples in each group *i*, e.g. $p_i = \frac{n_i}{\sum n_i}$.

3. Results

3.1. Foot dimension comparison

The means and standard deviations of the 14 foot dimensions of right foot (R) and left foot (L) of the recreational sprinters and the non-habitual exercisers were summarized in Table 1. We applied independent *t*-test to compare these dimensions and found that the foot lengths and foot breadths of both feet of the two groups of participants were not significantly different. However, the heel breadths of both feet of the recreational sprinters were significantly narrower than those of the non-habitual exerciser ($p < 0.05$). The MDPs were 2.15% and 1.87% for right foot and left foot, respectively. The toe lengths of both feet of the recreational sprinters were significantly longer than those of the non-habitual exercisers ($p < 0.05$), with a MDP of 2.19% for the right foot and 2.16% for the left. Compared with non-habitual exercisers, there were three foot dimensions of recreational sprinters that were only significantly different on the right foot. For the recreational sprinters, the ball girth circumference (R) was significantly larger. The height of navicular (R) was significantly higher. The hallux (R) was significantly longer than that of non-habitual exercisers ($p < 0.05$), with MDP of 1.60%, 4.80%, and 3.29%, respectively. The significant mean differences were all larger than the scanner accuracy (1 mm),