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The influence of footwear tread groove parameters on available friction

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ABSTRACT

The purpose of this study was to determine how footwear tread groove parameters influence available friction (COF). Utilizing a whole shoe tester (SATRA STM 603), 3 groove parameters (width, depth and orientation) were evaluated. Groove orientation had 3 levels (parallel, oblique and perpendicular), width had 3 levels (3, 6 and 9 mm) and depth had 3 levels (2, 4 and 6 mm). In total, the COF of 27 shoes, each with a distinct groove combination, was assessed on wet porcelain tile. The 27 groove combinations produced a wide range of COF values (0.080–0.344). Groove orientation had the greatest impact on COF, explaining the greatest variance in observed COF values ($\eta^2 = 0.81$). The most slip resistant groove combination was an oblique orientation, with 3 mm width and 2 mm depth. The least slip resistant groove combination was a parallel orientation, with a 6 mm width and 6 mm depth.

1. Introduction

Slips are a common cause of falls in society. As such, there is a need to understand the factors that contribute to slip risk. Of the numerous factors that have been cited as contributing to slip risk, the one that is of great importance to the footwear industry is the shoe outsole. An outsole can be broken down into numerous components, 9 of which have been identified as possible contributors to available friction (COF): beveled edge, outsole material, outsole hardness, microscopic and macroscopic roughness, tread groove width, tread groove depth, tread groove orientation, and contact area (Chang, 2004; Chang et al., 2001a; Li and Chen, 2004; Li et al., 2006a; Li et al., 2006b; Wilson, 1990; Wilson, 1996). The function of outside tread is to facilitate ground contact, especially in the presence of a contaminant. Tread is important with respect to contaminant dispersion (Gronqvist, 1995), available friction (Wilson, 1990; Leclercq et al., 1995; Tisserand, 1985), and ultimately slip potential.

Within the marketplace, outsole tread designs are highly variable with few visual consistencies. Currently, there are no published guidelines on how to design outsole tread to meet specific levels of slip resistance. Given the complexity of the shoe-floor interface and the necessity for appropriate slip resistance, a scientific approach for outsole design is necessary.

Several studies have investigated the influence of tread groove parameters on available friction. In 3 separate investigations, Li et al modified the test pad of an articulated strut tribometer to determine the influence of groove width, depth and orientation on COF (Li and Chen, 2004; Li et al., 2006a; Li et al., 2006b). In each study, available friction was assessed on 3 floor surfaces (vinyl, terrazzo and steel) with 3 different contaminants (water, detergent and oily). In their first study, Li and Chen (Li and Chen, 2004) evaluated the influence of groove width on COF using 5 test pad variations: smooth and 4 groove widths (3, 6, 9, and 12 mm). Each test pad had 3 equidistant parallel grooves set perpendicular to the direction of motion. The depth of all grooves was standardized to 7 mm. Results revealed that across the different floor surfaces, wider grooves resulted in greater COF for wet and water-detergent contaminants.

In a second paper (Li et al., 2006b), the influence of groove depth on COF was determined with 10 test pad variations: 5 groove depths (1–5 mm in 1 mm increments) and 2 groove widths (3 mm and 9 mm). Results revealed that for wet and water-detergent conditions on all floor surfaces, COF increased with deeper and wider grooves. Lastly, the influence of groove orientation on COF was evaluated in a third paper (Li et al., 2006a). Using 6 test pad variations: 3 orientations (parallel, perpendicular and oblique to

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direction of motion) and 2 groove widths (3 mm and 9 mm), Li et al. reported that the 9 mm groove width had significantly greater COF values than the 3 mm width for both wet and water-detergent conditions. Furthermore, perpendicular and oblique groove orientations resulted in significantly greater COF values compared to parallel grooves. No difference in measured COF was found between the perpendicular and oblique groove orientations.

Taken together, the studies of Li et al. (Li and Chen, 2004; Li et al., 2006a; Li et al., 2006b) suggest that wider, deeper, and perpendicular or oblique oriented tread grooves provide increased available friction in the presence of a water or water-detergent contaminant. However, a limitation of these investigations is that COF data were obtained using a portable tribometer that measured the available friction of a test pad made of a material not common to footwear outsoles (Neolite). Furthermore, the interaction of the 3 tread parameters (width, depth, orientation) was not evaluated. To date, no study has simultaneously evaluated the influence of all 3 tread groove parameters using actual shoes and with a common outsole material.

The purpose of this study was to evaluate how various combinations of tread groove width, depth and orientation influence available friction as measured by the SATRA STM 603 whole shoe tester. More specifically, we sought to determine which tread groove parameter has the greatest impact on COF. A secondary aim was to determine what combination of width, depth and orientation results in the greatest slip resistance.

2. Methods

2.1. Procedures

Twenty-seven pairs of men's size 10 shoes were assessed using a calibrated SATRA STM 603 whole shoe tester (SATRA, Kettering, Northamptonshire, UK; Fig. 1).

Each shoe's tread differed in groove width, depth and orientation. Shoe outsoles were manufactured using 3 widths (3, 6 and 9 mm), 3 depths (2, 4 and 6 mm) and 3 orientations (parallel, perpendicular and oblique). Parallel grooves were directed along the length of the shoe. Perpendicular grooves were directed at a 90° angle to the length of the shoe. Oblique grooves were directed at a 45° angle to the length of the shoe (Fig. 2). Each shoe was constructed of the same upper and midsole combination. In addition, each outsole was constructed of the same material (styrene butadiene rubber) and hardness (62 Shore A) commonly used in the marketplace (Vibram USA, Concord, MA).

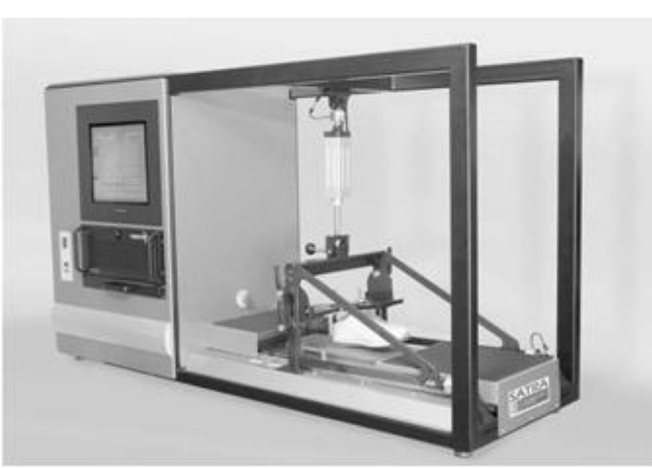

Fig. 1. The SATRA STM 603 whole shoe tester.

Fig. 2. Examples of study footwear. From left to right: parallel, oblique & perpendicular groove orientations. Each outsole depicted has 3 mm wide and 4 mm deep grooves.

Available friction testing followed the guidelines established in EN ISO 13287 (EN ISO 13287–2007, 2007) and the similar ASTM F2913 (ASTM F2913-11, 2011). The mechanical testing parameters outlined in both of these standards were adjusted as follows: normal force 400 N, sliding velocity 50 cm/s, and 9° shoe-floor contact angle. These parameters have been shown in a previous study to reduce COF assessment bias and improve slip prediction accuracy (Blanchette and Powers, 2015).

All COF testing was performed on porcelain tile (ASTM ADJF250803 RS-B) contaminated with distilled water. This flooring-contaminant combination has previously been shown to produce slip events during walking (Blanchette and Powers, 2015; Powers et al., 2010). Five available friction measurements were obtained for each shoe and averaged for statistical analysis.

2.2. Statistical analysis

To determine which groove parameter had the greatest impact on COF, an analysis of effect size was performed using the eta-squared values obtained from a 3-way factorial ANOVA (width x depth x orientation) (Levine and Hullett, 2002). In total, 135 assessments of COF were included in the statistical analysis. To determine which combination of width, depth and orientation produced the greatest slip resistance, the COF of all 27 groove combinations was ranked from highest to lowest. All statistical analyses were performed using SPSS 18.0 Statistical Software (IBM Corporation, Armonk, NY).

3. Results

The 3-way ANOVA results and analysis of effect size are reported in Table 1. Overall, the 27 groove combinations produced a wide range of COF values (0.08–0.34; Table 2). The 3-way ANOVA revealed a significant 3-way interaction among groove width, depth and orientation ($p < 0.001$; Fig. 3). When collapsed across all levels of groove width and depth, groove orientation produced the greatest range of COF values (0.11–0.27; Table 3). The eta-squared analysis revealed that orientation had the greatest impact on COF, explaining 81% of the variance in COF. When collapsed across all levels of groove depth and orientation, groove width produced a small range of COF values (0.19–0.22; Table 3) and explained only 2% of the variance in COF. Similarly, when collapsed across all levels