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Influence of Natural Wear Progression on Shoe Floor Traction – A Pilot Study

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Slips and falls in the workplace are a major concern for injuries. Worn shoes are a known risk factor for slips and falls. The purpose of this pilot study was to analyze changes in shoe traction performance under fluid contaminant conditions as the shoes were progressively worn. Four subjects wore two different shoes with varying tread patterns. Shoes were tested after each month of wear. The two types of shoes responded to wear differently; one shoe experienced a substantial decrease in available coefficient of friction (ACOF) while the other shoe showed no substantive change. Loads supported by the fluid during slipping increased with wear of the shoes. Furthermore, ACOF was influenced by the shoe type and the walking distance. This study suggests that the impact of wear on shoe performance is dependent on the shoe design. Thus, future studies are needed to understand specific effects of shoe design.

INTRODUCTION

Falls are a major concern of safety in the workplace. In 2016, slips, trips, and falls were the second leading cause of all injuries and illnesses in the workplace, accounting for 26 percent (292,580) of these events (U.S. Department of Labor - Bureau of Labor Statistics, 2018). Forty to fifty percent of fall-related injuries are associated with slipping (Courtney, Sorock, Manning, Collins, & Holbein-Jenny, 2001). Slipping is caused by low friction between the shoe and floor surface and often occurs when a fluid contaminant is present. While all three of these components (shoes, flooring, contaminant) influence friction, the shoe design is particularly relevant since it is the most controllable factor by the person who bears the consequences of a fall. Therefore, it is important to understand how the condition of shoes influences slips and falls in order to influence shoe designs and maintenance recommendations that can reduce slip and fall accidents.

A reduction in friction between the shoe and the floor due to the presence of a liquid contaminant leads to a higher likelihood of slipping (Beschorner, Albert, Chambers, & Redfern, 2014; Hanson, Redfern, & Mazumdar, 1999). The available coefficient of friction (ACOF) is the friction that prevents slipping between two surfaces and has often been an important factor when considering the likelihood of a slip. A variety of tribometers have been used to measure ACOF thus quantifying the slip-resistance of shoe-floor interfaces (Beschorner, Redfern, Porter, & Debski, 2007; Chang et al., 2001; Grönqvist, 1995; Singh & Beschorner, 2014).

When considering shoe safety and performance, shoe outsole design is an important element. Slip-resistant shoes have been shown to perform better on contaminated surfaces with increased ACOF compared to shoes without this designation (Beschorner, Jones, & Iraqi, 2017). In addition to recording ACOF, under-shoe fluid pressures have been measured as a shoe experiences a slip. As a shoe encounters a contaminated surface, tread channels serve to disperse fluid, decrease under-shoe hydrodynamic pressures and increase traction (Strandberg, 1985; Tisserand, 1985). As such, shoes without tread have high fluid pressures compared to treaded shoes (Beschorner et al., 2014; Singh & Beschorner, 2014)

Only limited research has estimated the change in traction over a shoe's life. Previous research involving shoe wear across a short period of wear has found that initial wear may improve slip performance (Grönqvist, 1995). Other research has considered changes in performance (under-shoe fluid pressures and ACOF) across the simulated life of a shoe (Hemler, Charbonneau, & Beschorner, 2017; Hemler et al., 2018). The latter research involved mechanical wearing of the sole. Studies investigating natural wear of shoes have found that shoes worn less than six months perform better than those worn for more than six months (Verma et al., 2011), but there were no intermediate checkpoints to quantify changes within those periods. Thus, there is a need to analyze progressive wear of shoes worn in the workplace on an individual basis over smaller increments of wear. The purpose of this pilot study is to begin to understand changes in shoe traction performance as a shoe is worn in the workplace.

METHODS

In this study, data from four subjects were analyzed. Subjects were recruited from facilities in which they walked on man-made surfaces for at least 75% of their work. Two types (different tread patterns) of shoes were provided to the subjects. The shoes were labeled as slip-resistant by their manufacturers and claimed to be made of rubber or synthetic rubber (Figure 1). Hardness measurements were conducted for the two types of tread (Shoe A – 51, Shoe B – 69).

Figure 1. Tread designs of two shoe types. Shoe A (left) had a sharp-edged heel with rectangular tread and Shoe B (right) had a beveled heel with diamond shaped tread.

The experiment was divided into two components (Figure 2). Component 1 consisted of a gait assessment to quantitatively determine subject walking patterns. During Component 2, subjects wore the two pairs of provided shoes at their workplace, alternating between the two sets of shoes (Shoe A & Shoe B) each month. Subjects remained in the study up to 12 months for each pair of shoes (total 24 months). A pedometer (MilestonePod, Milestone Sports, Columbia, MD), (Hunter, Miller, & Suydam) was used to track walking mileage for each pair of shoes according to the subject's anthropometric data. If the shoes were determined as no longer be safe (criteria for removal explained later in this section and in Figure 2), they were removed from the study. Shoe traction performance was quantified at the baseline level and for each subsequent month of wear based on ACOF, under-shoe fluid pressure measurements, and heel contact area ink imprints. These measures were recorded using a robotic slip tester consisting of 3 linear motors controlling vertical and horizontal displacement, a force plate (BP400600-1K-Q2046, AMTI, Watertown, MA, 02472), and an array of four fluid pressures (Gems ® 3100R10PG08F002). The shoes were slid across a vinyl composite tile covered with contaminant (90% glycerol and 10% water by volume, 219 cP). The left and right shoes for Shoe A and Shoe B were tested at a normal force of 250N, at a sagittal plane angle of 7° and 17°, and a speed of 0.3m/s, parameters that have been shown to simulate those seen during a slipping action (Albert, Moyer, & Beschorner, 2017; Iraqi & Beschorner, 2017). Only data from the 17° testing condition is presented since this is considered more relevant to slipping (Albert et al., 2017). The four fluid pressure sensors were each 25 mm apart. The adjustable platform was situated at five positions each separated by 5mm in the direction perpendicular to sliding to record the fluid pressure profile across the shoe in 5mm increments. Thus, five trials for each angle per slip testing sessions were measured.

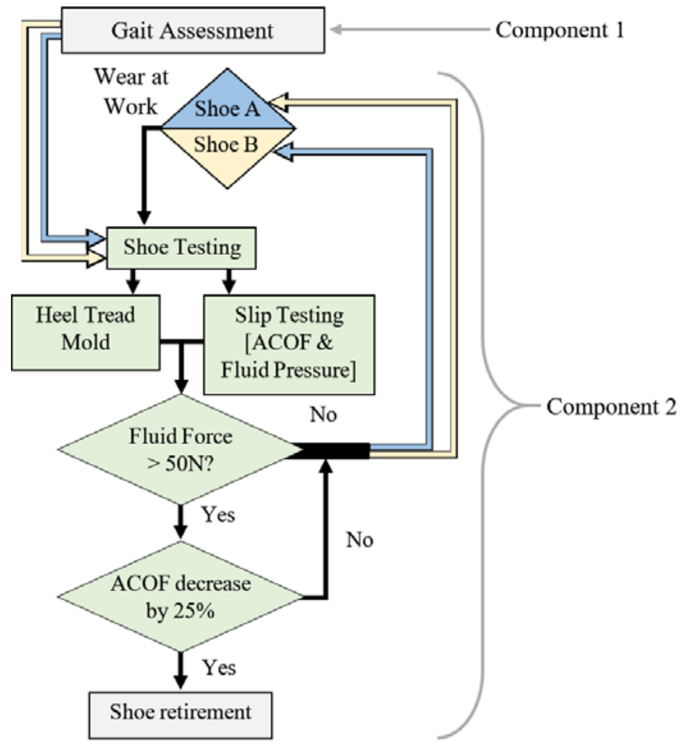

Figure 2. Experimental Protocol Flowchart. Subjects completed a gait assessment in Component 1. During Component 2, subjects alternated each month between wearing Shoe A and Shoe B.

The ACOF was determined during the first 200ms after the normal force of 250N was first reached and was quantified as the magnitude of the shear forces divided by the normal force. A numerical integration technique was used to determine the load supported by the fluid (fluid force) under the shoe based on the recorded fluid pressures (Eq. 1), where p_i is the fluid pressure at the ith frame as the shoe is crossing the fluid pressure array, Δx is the distance between scans in the direction perpendicular to sliding (5 mm), v is the sliding velocity (0.3 m/s), and Δt is the time between each frame (0.002 s) (Singh & Beschorner, 2014). The total fluid force was derived as the sum of fluid forces across the five trials.

$$F_{fluid} = \sum p_i \, \Delta x \, \Delta y = \sum p \, \Delta x \, v \, \Delta t \qquad (1)$$

The wear threshold in which shoes were determined to be unsafe was determined based on ACOF and the under-shoe fluid dynamics. Previous research has indicated that a fluid force exceeding 50N may indicate increased risk of slipping (Hemler et al., 2018). After each set of mechanical testing, if there was a baseline ACOF decrease by 25% and the fluid force was greater power of the study. Second, testing on the robotic slip tester did not account for the supination/pronation angles

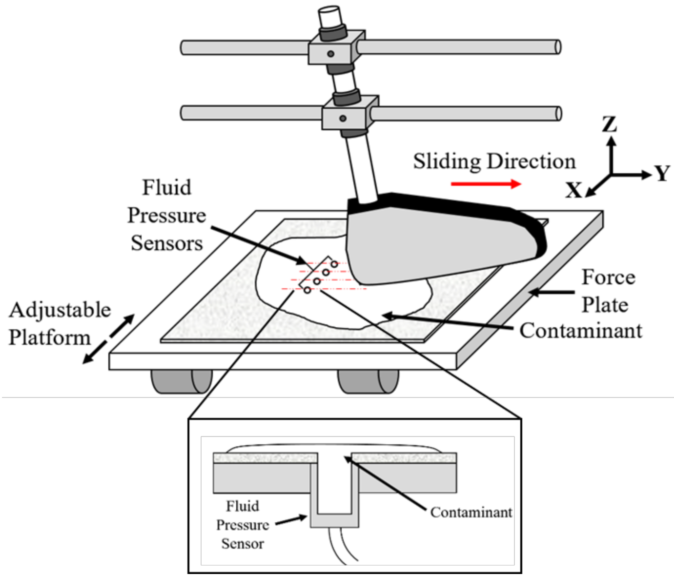

Figure 3. Robotic Slip Tester with cross-sectional view of contaminant and fluid pressure. Shoes were slid across the contaminated tile at 7° and 17°.

than 50N (after baseline) for any shoe (left/right) or angle (7/17), the shoe was retired from the study.

Repeated-measures ANOVA methods were used to determine the effect of shoe type, distance walked, side (left vs. right shoe), and first-order interactions on ACOF and fluid force. Specifically, two models in which ACOF and fluid force were each the dependent variables were implemented.

RESULTS

A total of 21 person-months (4 subjects x 1 to 4 months x 2 shoes) have been collected and analyzed to date. Baseline ACOF values ranged from 0.17 to 0.41 and 0.13 to 0.20, and overall ACOF values ranged from 0.10 to 0.41 and 0.12 to 0.208 for Shoe A and Shoe B, respectively The reduction in ACOF from baseline to the final wear iteration has ranged from 0.06 to 0.23 for Shoe A and -0.04 to 0.06 for Shoe B. Fluid forces ranged from 0 to 23.5N and 0 to 10.1N at baseline levels for Shoe A and Shoe B, respectively (Figure 4).

Statistical analysis showed that ACOF was significantly affected by the shoe type ($p = 0.017$, $F_{1,48} = 6.1$), the distance walked ($p < 0.001$, $F_{1,50} = 26.2$), and their interaction ($p = 0.004$, $F_{1,48} = 9.4$). Fluid forces were significantly affected by the shoe type ($p < 0.001$, $F_{1,48} = 39.4$), the distance walked ($p < 0.001$, $F_{1,51} = 36.2$), their interaction ($p = 0.001$, $F_{1,48} = 13.7$), and the interaction between the side and distance ($p = 0.035$, $F_{1,47} = 4.7$).

This analysis shows that there is a difference among shoe types, that ACOF decreases and fluid force increases with an increase in distance walked. Also, the interaction effect between the shoe type and distance walked confirms that Shoe A was more sensitive to distance than Shoe B in terms of ACOF. Furthermore, the interaction between the side and distance for fluid force shows that the fluid forces of the right shoes were more influenced by the distance walked than the left shoes.

At this point of data collection, all four subjects have worn Shoe A to the point of retirement (up to four months and 408km of wear). However, all of the shoes listed as Shoe B (currently ranging from 2-4 months and 160-605km of wear) have not yet reached the threshold of a fluid force greater than 50N although all shoes have achieved a reduction in ACOF exceeding 25% for at least one shoe and one angle.

When comparing the ACOF for each month of wear across the four subjects, Shoe A showed the highest baseline ACOF and after four months displayed the lowest ACOF for a total average ACOF change of 0.184 (Figure 5). Although the average ACOF for Shoe B at baseline was 39 percent lower of the baseline ACOF for Shoe A, the two shoes had similar ACOF after being worn similar distances.

DISCUSSION

This research supports that the change in shoe safety is influenced by the outsole design and distance traveled. Shoe A started with a higher ACOF than Shoe B but experienced a more rapid decrease in ACOF and increase in fluid forces than Shoe B. These changes may indicate that ACOF of new shoes is not necessarily representative of its performance throughout the shoe's life.

Current standard wear limits for slip resistant shoe wear suggest that after 6 months shoes should be retired (Verma et al., 2014). However, this data suggests that for certain shoe types, substantial changes in performance may occur well before this recommended replacement age based on the high fluid forces accompanying the decrease in ACOF. Shoes with lower hardness levels may wear more quickly and need replacement sooner than shoes with higher hardness values. Also, the analysis shows that the type of shoe tread may have a significant factor in determining the wear threshold of the shoe. Future research would need to indicate how much traction loss is acceptable and how to predict traction loss from the state of the shoe in order to develop replacement thresholds.

A few limitations should be noted. As this data represents the pilot study, continued enrollment and additional data from currently enrolled subjects will yield more generalizable results and will improve the

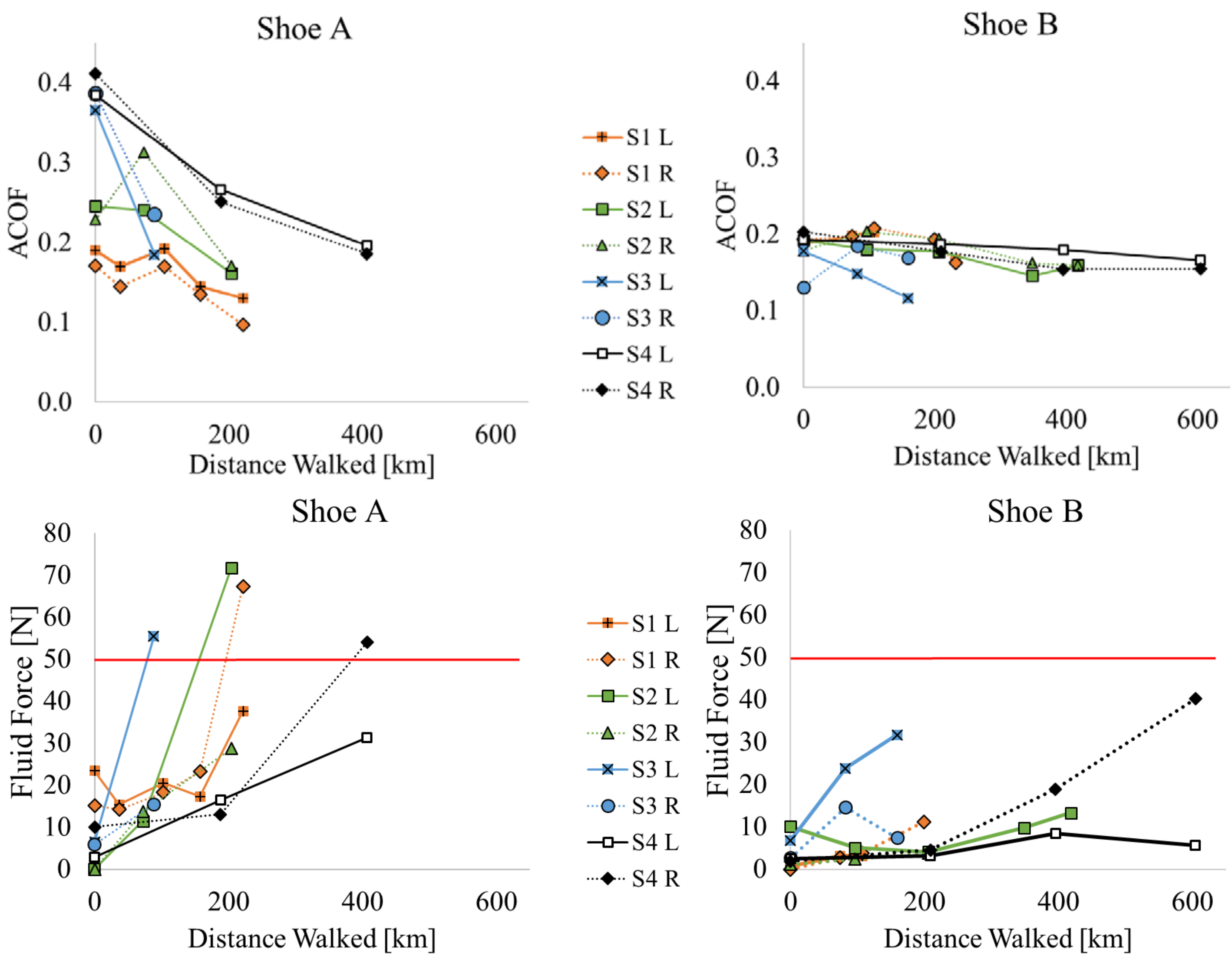

Figure 4. ACOF (top) and fluid force (bottom) values for Shoe A (left) and Shoe B (right). The red line on the fluid force indicates the fluid force criteria for removing the shoes. Each different marker/color represents a different subject. Solid lines are the left shoe (L) and dashed lines are the right shoe (R).

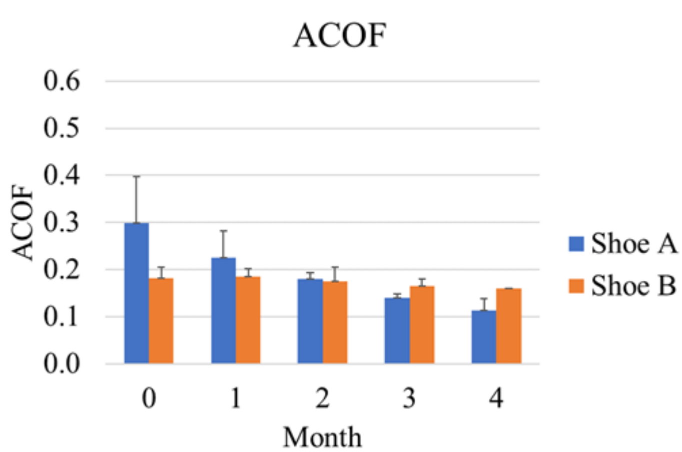

Figure 5. ACOF bars averaged per month of wear per shoe. Error bars represent the standard deviation across all subjects per shoe type.

of the subjects collected during the gait assessment. Thus, future studies may measure ACOF at shoe-floor angles that simulate individual walking patterns. Also, as the distance traveled per participant varied, measures for the entire life of the shoe were not collected. Lastly, as both the tread design and material differed between the two shoe types, we cannot precisely determine which design parameter led to the differences in performance.

This study confirms that shoe slip safety is dependent on the shoe outsole design and it worn condition. As Shoe A tended to perform better initially with rapid decay and Shoe B performed at a steady rate for longer, this study suggests that shoe material and tread design can be optimized for various uses and preferred time of use. Furthermore, this study supports that shoes may have a time of optimal performance (increased ACOF and low fluid forces) followed by poorer performance.

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