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Performance testing of work shoes labeled as slip resistant

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ABSTRACT

The variability in friction and slip propensity across slip resistant (SR) shoes is poorly understood. This study aimed to quantify the impact of shoe design features on the available coefficient of friction (ACOF) across shoes labeled as SR. Differences in ACOF and the slipping rate across SR shoes were also quantified. Twelve shoes were tested across five types of flooring and three contaminant conditions using a whole shoe mechanical slip tester. Geometric and hardness parameters were measured to determine the effect of heel outsole design on ACOF. The rate of slipping was evaluated for three of the shoes on vinyl tile with canola oil using human subjects. Differences in ACOF were significant across shoe outsole designs ($p < .001$). ACOF was correlated with geometrical and hardness parameters. Rate of slipping was lower for the highest ACOF shoe ($p < .001$). This information can be used to guide SR shoe selection and design.

1. Introduction

In 2015, slips, trips, and falls accounted for 27% of reported workplace injuries (U.S. Department of Labor- Bureau of Labor Statistics, 2016). Slipping has been shown to be the initiating event for approximately 40–60% of workplace falling events (Courtney et al., 2001). Thus, a critical need exists to identify solutions for preventing falls from slipping.

The occurrence of a slip is affected by the friction that is available at the shoe-floor interface. The friction that is available between a particular shoe and a certain floor surface is typically characterized by the available coefficient of friction (ACOF), which can be measured with a slip tester (Beschorner et al., 2007; Chang et al., 2001; Grönqvist, 1995). The ACOF is often compared with the friction that is required for walking, commonly quantified by the required coefficient of friction (RCOF) (Beschorner et al., 2016; Burnfield and Powers, 2006; Hanson et al., 1999). Previous research has demonstrated that the proportion of individuals who experience a slip under specific conditions can be predicted by ACOF (Burnfield and Powers, 2006), RCOF (Beschorner et al., 2016) or the difference between ACOF and RCOF (Burnfield and Powers, 2006; Hanson et al., 1999) under those specific conditions. Interventions that can either achieve high levels of ACOF or reduce RCOF may be effective at preventing slip and fall injuries.

Shoe outsole design has an important impact on slipping risk. For example, epidemiology research has demonstrated that wearing shoes marketed as slip resistant (SR) reduces the occurrence of slipping events by about 54% in the limited service restaurant industry (Verma et al., 2011). Previous research has also suggested that variability exists across shoes that are marketed as SR (Health and Safety Laboratory U.K., 2009). Certain outsole features like tread depth, width, orientation and hardness affect ACOF (Blanchette and Powers, 2015a; Li and Chen, 2004, 2005; Li et al., 2006; Strobel et al., 2012; Tsai and Powers, 2008). Most of this previous research used custom outsole designs (Blanchette and Powers, 2015a; Li and Chen, 2004, 2005; Li et al., 2006) as opposed to commercially available shoes. A recent review paper noted the incongruence in complexity between custom outsole designs and actual shoes (Chang et al., 2016). Specifically, this study suggested that “tread pattern evaluations should be expanded to include patterns with more complicated geometries such as those which are available in the market today” (Chang et al., 2016). Therefore, additional research is needed to understand the variability in ACOF across commercially available footwear and the tread features that might explain this variability.

Assessing the ability of shoes to prevent or “resist” slips can be challenging in light of the complex interactions between shoes, floorings and contaminants (Li and Chen, 2004). Therefore, a range of ACOF values exist for a given shoe across different potential test conditions. Furthermore, the rank order of ACOF across different shoes can change across different floorings or contaminants (Grönqvist, 1995; Li et al., 2006). Previous researchers have suggested that tests should be conducted using realistic floorings and contaminants (i.e., environmental fidelity) to account for these complexities (Chang et al., 2003). Current reports on footwear are limited in that they report ACOF on just a few floor-contaminant conditions (Health and Safety Laboratory U.K.,

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2009). There is a clear need to understand how commercially available shoes perform across diverse floor and contaminant conditions.

Human slipping trials have emerged as an important technique in validating ACOF results from mechanical testing. Previous researchers have monitored slips during human gait to assess the ability of slip testers to rank different floorings from most to least slippery (ASTM, 2012; Powers and Blanchette, 2014; Powers et al., 2007, 2010). This technique has also been used to validate the impact of shoe outsole hardness (Tsai and Powers, 2008) and the relevance of under-shoe fluid pressures to slip events (Beschorner et al., 2014). This type of validation is particularly important since shoe design impacts the biomechanics of gait (Chander et al., 2015a, b; Tsai and Powers, 2008), which can subsequently impact the ACOF (Beschorner et al., 2007). Therefore, an understanding of the holistic impact of shoes on slip risk is needed to gain confidence in their ability to prevent slips.

The purpose of this study was to quantify differences in ACOF across shoes marketed as slip resistant based on their performance across different flooring and contaminant conditions. Furthermore, this study aims to identify the shoe outsole features that best predict ACOF and quantify differences in slipping outcomes across shoes marketed as slip resistant.

2. Methods

This study included a mechanical testing component and a human slipping testing component. In the mechanical component, 12 shoe designs were tested in 15 contaminant-flooring conditions. In the human subjects testing component, rate of slipping was assessed across 3 types of SR shoes on vinyl composite tile ("vinyl") by unexpectedly exposing subjects to a canola oil contaminated surface.

2.1. Part 1: mechanical testing of shoes

2.1.1. Materials

Shoe-floor-contaminant ACOF was quantified for 180 different conditions (12 shoes x 5 floorings x 3 contaminant conditions). The selected shoes were aimed at capturing the variability within and across shoe brands by including at least two different styles from five different brands and at least two brands for each style (Table 1). All shoes, flooring and contaminant materials were purchased by the research team through online retailers. Five designs were Oxford-style work shoes, five designs were comfort shoes and two designs were clogs. All shoes evaluated were U.S. Men's size 9 right shoes.

The shoe outsoles were characterized by their contact area, heel width, and hardness (Table 2). Contact area from the posterior-most point of the tread to 50 mm anterior of that point was measured using ink prints made by rolling the ink-coated outsoles across a piece of paper by hand (Fig. 1). A digital image was created by scanning the print, and the area covered by black pixels was calculated as the contact area. Previous research has identified that the majority of fluid pressures occur in the posterior most 50 mm of the heel during slips (Singh and Beschorner, 2014), which suggests that this region may be critical to slip resistance. The heel geometry was further characterized based on the treaded heel width at a location 15 mm anterior to the posterior-most portion of the heel tread (Fig. 1).

Table 1
List of shoe code, style, brand and model. Note that the letter of the shoe code corresponds to the brand, whereas the number corresponds to the style. Slip resistant shoes tend to have a pattern of tread that is repeated across the shoe surface. These patterns are shown to the right of the table for the five brands.

Shoe	Style	Shoe Brand	Model	SR Tread Key
A1	Dress	SR Max	SRM3500	A 
A2	Comfort	SR Max	SRM6200	
A3	Clog	SR Max	SRM7500	
B1	Dress	Shoes for Crews	Cambridge 6006	B 
B2	Comfort	Shoes for Crews	Freestyle 6010	
C1	Dress	Keuka	Equity 5000	C 
C2	Comfort	Keuka	Galley 55014	
D1	Dress	safeTstep	Able 151864	D 
D2	Comfort	safeTstep	Apollo 140060	
E1	Dress	Tredsafe	MNTS0541002	E 
E2	Comfort	Tredsafe	M151044BU	
E3	Clog	Tredsafe	M151045AD	

Table 2
Shoe outsole contact area, treaded heel width, short term hardness and long term hardness.

Shoe	Contact Area (cm^2)	Treaded Heel Width (mm)	Short Term Hardness (Shore A)	Long Term Hardness (Shore A)
A1	58.2	62	47.9	41.2
A2	61.3	54	46.7	39.5
A3	62.5	63	48.7	41.1
B1	49.3	56	48.9	42.6
B2	56.3	55	54.9	46.1
C1	39.9	52	61.6	50.6
C2	44.2	59	58.4	50.6
D1	30.7	58	54.0	45.5
D2	31.8	55	61.0	56.4
E1	43.9	54	60.7	53.4
E2	51.7	59	61.4	52.8
E3	53.5	59	63.3	57.2

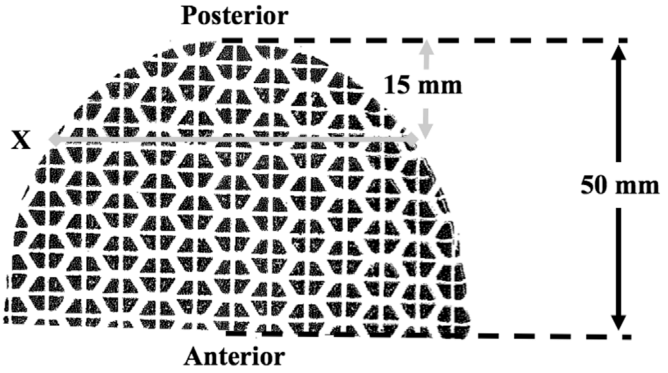

Fig. 1. Measurement of treaded heel width and contact area. The treaded heel width (measurement "X") was taken 15 mm anterior to the posterior-most point of the heel tread. The contact area was calculated for the posterior-most 50 mm of the shoe heel tread.

Short-term and long-term hardness were measured for the shoes using a Shore A durometer based on ASTM standard D2240 (ASTM, 2015). Deviations from the standard included rigidly fixing the shoe to a frame and using smaller material samples. The standard requirements of placing a rubber specimen on a hard surface and using a 12 mm sample were not feasible due to the shoe geometry (ASTM, 2015). The needle of a handheld shore A durometer was applied normal (i.e., 90° angle) to the tread. The peak hardness at initial indentation was recorded as the short-term hardness. The hardness after 60 s was recorded as the long-term hardness. Hardness was averaged across five different locations of the heel.

Five different floor tiles and three contaminants were tested (Table 3). The floorings included two vinyl tile designs, two quarry tile

Table 3
List of tile name, make, model and mean (standard deviation) surface roughness.

Tile	Make	Model	R_a
Reference Vinyl	ASTM	ADJF250801	1.44 µm (0.22 µm)
Other Vinyl	Armstrong	51804	1.76 µm (0.28 µm)
Ceramic	ASTM	ADJF250803	3.82 µm (0.19 µm)
Quarry 1	Daltile	0T01881P	4.74 µm (0.72 µm)
Quarry 2	Summitville	01 010 SM 1	6.51 µm (1.83 µm)