# ASSESSMENT OF SLIP-RISK USING A PORTABLE SLIP SIMULATOR

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## INTRODUCTION

According to the Bureau of Labor Statistics (BLS), falling events account for 25% of non-fatal occupational accidents [1]. A slip is likely to initiate when the friction required (RCOF) to sustain gait is less than the available friction at shoe-floor interface (ACOF) [2]. ACOF can be measured using a slipmeter on different floor surfaces, under both dry and contaminated conditions, whereas RCOF is measured on dry surfaces [3]. ACOF varies across different slipmeters [2], which makes the use of these devices to predict the risk of slips and falls challenging. Hanson et. al. developed a method to evaluate the relationship between slip resistance measurements and actual slips and falls. However, their study involved only one type of shoe. Different shoes have significantly different slip-resistant properties [4] and the ability of slip-testers to assess the slip risk across these shoes has not been sufficiently quantified. An in depth understanding of friction properties of shoes is required to minimize injuries due to falls from slips. The aim of this study is to test the ability of the Portable Slip Simulator, a whole-shoe tester capable of testing shoe-floor-coefficient of friction, to predict the outcomes of slipping accidents.

## METHODS

Slip-resistance and slipping risk were characterized for three shoe and three boot conditions. In order to get a robust number of shoe/boot conditions, data from three similarly-conducted studies were combined for this post-hoc analysis [5,6]. The shoes included a standard work shoe (S1), a slip resistant shoe in new condition with full tread (S2T) and one in completely worn condition with not tread (S2NT), and three boot designs with identical tread but different hardness materials (Soft: B1, Medium hardness: B2; and Hard: B3, Table 1). The fluid contaminant was diluted glycerol for all conditions, however, the concentration varied across the studies (Table 1).

Experiments to quantify ACOF were conducted using the Portable Slip Simulator [7]. This device tests an entire shoe heel and utilizes three vertical electromagnetic motors to apply a normal force and a linear motor to move the shoe across the flooring. Ground reaction forces (GRF) were measured using a 6DOF force plate (Advanced Mechanical Technology, Inc ®, Watertown, MA). Coefficient of friction (COF) values were measured at a sliding speed of 0.3 m/s, normal force of 250 N and shoe-floor angle of 7°. COF was quantified as the average ratio of resultant shear force to normal force during the first 200 ms after the normal force reached 250 N. Each test condition was repeated for 5 cycles.

**Table 1:** Shoe-floor-contaminant conditions and the number of subjects unexpectedly slipped.

| Shoe # | Fluid Contaminant | Floor | n |
|---|---|---|---|
| S1 | 75% glycerol-25% water | Vinyl | 26 |
| S2T | 90% glycerol-10% water | Vinyl | 7 |
| S2NT | 90% glycerol-10% water | Vinyl | 7 |
| B1 | 50% glycerol-50% water | Vinyl | 16 |
| B2 | 50% glycerol-50% water | Vinyl | 16 |
| B3 | 50% glycerol-50% water | Vinyl | 18 |

RCOF was calculated based on a method by Chang, et. al. [3] from baseline walking trials for previous studies conducted by our research group. The RCOF was considered only when the vertical force was above the 100 N threshold. Another criteria was that the longitudinal component of GRF had to be positive at the instant of the RCOF to correspond with the friction required for an anterior slip. Once the first two criteria were achieved, the RCOF was considered only when the instantaneous COF was increasing with time. This criterion bypasses peaks 1 and 2 of the COF data and considers the third peak.

All of the slipping trials were conducted by unexpectedly placing a liquid contaminant on the floor surface (Table 1 for different fluid contaminants) using a consistent method that obstructed the condition of the floor with dim lighting and distracting the subjects (Table 1 for number (n) of subjects for each shoe condition). The first and second unexpected slips were used for each of these studies. Slipping was tracked with a marker placed on the subject's heel. For slipping trials, occurrence of a slip event was considered when a slip distance was more than 1 cm [8].

A logistic regression model was used to determine if the mean difference between ACOF and RCOF (ACOF-RCOF) (Eq. 1) for each shoe was predictive of slip risk. The outcome was the occurrence of a slip and the prediction variable was the mean ACOF-RCOF, respectively.

$$Slip\_Risk = 1/(1+exp(\beta_0+\beta_1*(ACOF-RCOF))) \quad \text{Eq.1.}$$

## RESULTS AND DISCUSSION

The logistic regression demonstrates that as the ACOF-RCOF increases, slip risk is reduced ($p<0.0001$) (Fig. 1). The average difference between the logistic fit curve and the actual proportion of subjects who slipped was 3.95 % (standard deviation: 3.422 %).

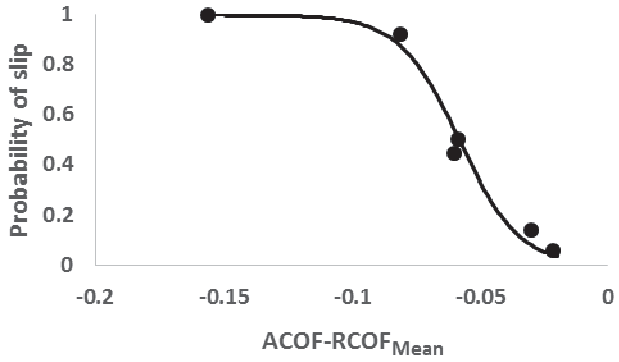


**Figure 1**: Logistic regression model comparing ACOF-RCOF to the predicted probability of slip.

This study suggests that the average ACOF and RCOF should both be considered when predicting the overall slip risk. For example, Shoes 2T and B2 both had an ACOF (0.151) (Fig. 2) however, shoe 2T had a much lower RCOF (0.181) than B2 (0.209). The difference in RCOF may explain why shoe 2T had a lower slip risk (14.29%) than B2 (50.00%) despite their similar ACOF values. The Tribometer used in this study showed a bias for slips of -0.058, i.e., ACOF-RCOF point where 50% of slips occur [4].

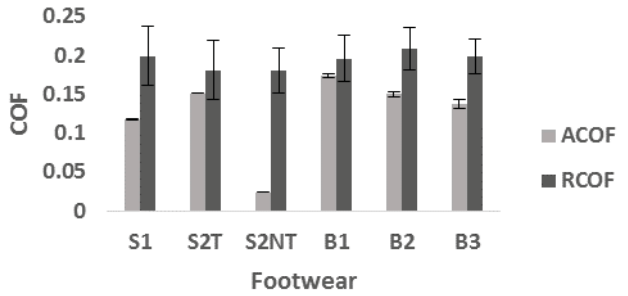


**Figure 2**: ACOF and RCOF across different shoes.

The Portable Slip Simulator provides valid measurements of slip risk for different shoes. Difference between ACOF and RCOF across the shoes and boots predicted the risk of slipping consistent with a logistic regression fit. Thus, the ACOF values from this slip-tester can be used to predict slipping risk as long as the RCOF for that shoe is known.

## REFERENCES

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