



THE PROBABILITY OF SLIPPING DURING WALKING: EXAMINATION OF TRIBOMETRIC MEASURES OF FLOOR SURFACE SLIP RESISTANCE AND UTILIZED COEFFICIENT OF FRICTION

JM Burnfield, Ph.D., P.T.^{1,2} and CM Powers, Ph.D., P.T.¹

¹ Department of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, CA

² Pathokinesiology Laboratory, Rancho Los Amigos National Rehabilitation Center, Downey, CA



Introduction

Slips have been identified as a leading cause of falls and injuries in the home and work environments. A slip is expected to occur when the utilized coefficient of friction (COF_U) of an individual exceeds the available slip resistance of the floor surface (Figure 1).

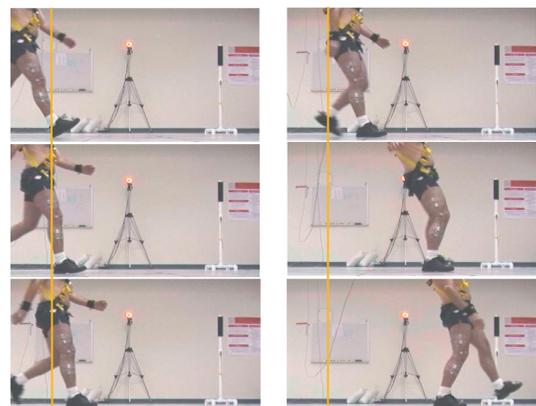


Figure 1. Right heel slip during a walking trial

Floor surface slip resistance is commonly measured using a tribometer, however, different styles of these devices often yield measurements that do not correlate well with each other. Although several standards have been developed for tribometers that measure static COF, it is unclear to what extent measurements of static COF are predictive of the probability of a slip occurring. The purpose of this study was to investigate the relationship between static measures of slip resistance (determined using a variable incidence tribometer, VIT) and peak COF_U (as measured from a force plate) on the probability of a slip occurring during level walking.

Methods

Subjects

Fifty-two healthy adults (28 males, 24 females; 26 ± 4 years; mass 78 ± 18 kg) participated.

Instrumentation

- AMTI force plates (1200 Hz; 4th Order, 45 Hz low-pass Butterworth filter)
- VICON 6-camera system (120 Hz)
- English XL VIT (Figure 2)

Procedures

- Ground reaction force and kinematic data were recorded simultaneously as subjects walked along a 10-m walkway
- Participants wore Rockport shoes and walked at a self-selected speed under conditions of normal and reduced floor surface slip resistance
- Subjects were not told during which trial the contaminant (WD-40) would be applied, nor the location of the contaminant.
- Participants wore a fall-arresting body harness attached to an overhead trolley to ensure safety (Figure 3)
- Four measurements of the available slip resistance were recorded following the slip trial (Figure 4)



Figure 3. Non-slip walking trial

Data Analysis

- The ratio of shear to vertical GRF's was used to calculate COF_U
- During weight acceptance, the peak COF_U resulting from a shear force that would contribute to a forward foot slip was identified

Statistical Analysis

Two separate logistic regression analyses were used to determine the relationship of the observed slip events to:

- Slip resistance difference (i.e., the difference between the available slip resistance and the peak COF_U)
- Available slip resistance



Figure 2. Variable incidence tribometer

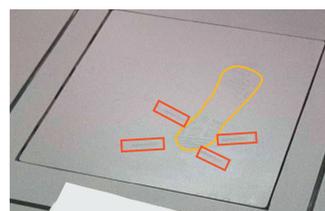


Figure 4. Location of VIT measurements (orange) and foot imprint (yellow)

Results

- Fourteen of the original 52 subjects were excluded from final analysis as they either perceived in advance that the surface might be slippery (n=3) or they did not fully step on the force plate where the contaminant had been placed. On the average, the self-selected walking velocity of the remaining 38 participants was 97 ± 13 m/min, the mean peak COF_U was $\mu = 0.21 \pm .04$, and the average available slip resistance was $\mu = 0.23 \pm .04$. Fourteen of thirty eight subjects (37%) experienced a heel slip during the trial in which the contaminant was applied.
- Slip Resistance Difference was a significant predictor of slip outcome ($p = 0.004$; Figure 5, Table 1). Overall the model correctly predicted 90% of the slip outcomes, and accounted for 49% of the variance in slip outcomes ($R_L^2 = .485$).

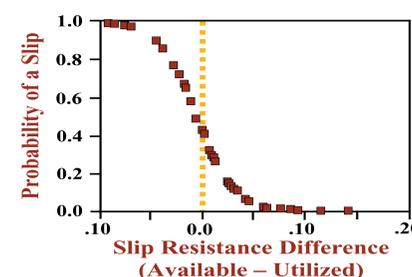


Figure 5. Scatter plot of Slip Resistance Difference vs. the probability of a slip event occurring as calculated by logistic regression ($R_L^2 = 0.485$).

- Available Slip Resistance also significantly predicted slip outcome ($p = 0.012$; Figure 6). Overall, the second model correctly predicted 79% of the slip outcomes, and accounted for 16% of the variance in slip outcomes ($R_L^2 = .162$).

Probability of Slip Event Occurring	Slip Resistance Difference
.01	+0.077
.05	+0.047
.50	-0.006
.95	-0.060
.99	-0.090

Table 1. Logistic regression prediction of Slip Resistance Difference and corresponding probabilities of a slip event occurring.

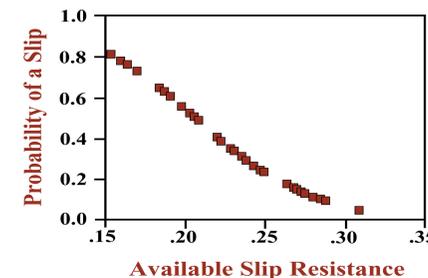


Figure 6. Scatter plot of Available Slip Resistance vs. the probability of a slip event occurring as calculated by logistic regression ($R_L^2 = 0.162$).

Discussion

- Available slip resistance, as measured by the VIT, can accurately predict slip events.
- Knowledge of the available slip resistance, in combination with an individual's peak COF_U allowed for the greatest accuracy in predicting slip outcome (90%).
- With knowledge of only the available slip resistance, the accuracy of prediction was reduced to 79% over the range of floor surface slip resistance values evaluated in this study.

Conclusions

- Knowledge of an individual's peak COF_U and the available friction (as measured by the VIT) can be used to predict the probability of a slip event during level walking in young adults. Use of the VIT to assess floor surface slip resistance in the work and home environments may provide valuable information to reduce the risk of slip and fall related injuries.
- As measures of static coefficient vary across tribometers, the relationships reported in the current study will likely apply to the VIT only. However, other tribometers could be assessed using similar procedures.

Acknowledgment

This work was funded, in part, by a grant from the American Society of Safety Engineers.