

Validation of Walkway Slip Resistance Measurements: A Gait Based Approach

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INTRODUCTION

Tribometers are devices that measure the slip resistance of walkway surfaces. There are over thirty tribometers that are commercially available, and each varies in its mechanical design and friction calculation method (Chang, Gronqvist et al. 2001). As a result, different tribometers yield varied measurements of friction for the same surface (Chang 1999; Gronqvist, Hirvonen et al. 1999; Chang 2002; Powers, Brault et al. 2007). The variability in tribometer-based friction measurements suggests that a value obtained from a given tribometer may or may not represent a measure of a pedestrian's risk of slip; a fact that undermines the validity of all tribometers. The purpose of the current study was to use slip risk (as quantified during human subject walking trials) to create a reference standard against which tribometer readings could be validated.

METHODS AND PROCEDURES

Eighty subjects (23 males, 57 females) between the ages of 20 and 39 were randomly assigned to walk across one of four walkway surfaces conditions (polished black granite, porcelain, ceramic tile and vinyl composition tile). Each floor condition was tested under wet conditions. To control for the influence of footwear, subjects were provided with a pair of Oxford-style shoes in their size. During testing, subjects wore a fall-arresting

body harness attached to an overhead trolley. The ranking of surface slipperiness was based on the number of slip events (either heel or toe slips) observed for each condition. To confirm whether a slip occurred, an eight camera Vicon motion analysis system (Oxford Metric Ltd., Oxford, UK) was used to record the position of reflective markers placed on the heel and second metatarsal.

Following the human subject testing, eleven tribometers were used to measure the coefficient of friction (COF) of the four surfaces. For each surface condition, the COF was measured four times. The results of the tribometer measurements were then compared to the gait-based ranking of surface slipperiness using two criteria: 1) Did the tribometer measurements correctly rank the slipperiness of the different surfaces? 2) Did the tribometer measurements differentiate between surfaces with significantly different levels of slipperiness? To test for differences in the number of slips that occurred for each surface, a chi-squared test was used. A one-way analysis of variance (ANOVA) was used to compare tribometer readings across the four floor conditions. This analysis was repeated for each tribometer. *Post hoc* tests were run using a Fischer least significant difference (LSD) test to identify surfaces that were significantly different from one another.

RESULTS

The results of the human subject walking trials are presented in Table 1. All four surface conditions were significantly different from each other with respect to levels of slipperiness.

Surfaces	No Slips	Toe Slips	Heel Slips	Ranking
Granite	1	6	13	Most slippery
Porcelain	5	11	4	Moderately
Vinyl	13	7	0	Less
Ceramic	20	0	0	Least
Total	39	24	17	N = 80

Table 1. Results of human subject testing

The eleven tribometers produced widely varying friction measurements for the four surfaces (Table 2). Our results revealed that only four of eleven tribometers (Wessex pendulum, Sigler pendulum, Mark II and Mark III) met our compliance criteria by correctly ranking the four floor conditions and differentiating between surfaces of differing degrees of slipperiness. Of the seven tribometers that failed, two did not pass criteria #1 (Tortus III, HPS), two did not pass criteria #2 (Mark I, Bot 3000 static & dynamic) and three did not meet either criterion (English XL, C1028, Tortus II).

DISCUSSION

The results of our tribometer measurements were consistent with the conclusions of previous studies in that different tribometers give varied COF values for the same surface. In the current study, only four of the eleven tribometers tested met our compliance criteria by both correctly ranking all four conditions and differentiating between surfaces of differing degrees of slipperiness as established by the walking trials. These findings reinforce the need for objective criteria to ascertain which tribometers

effectively evaluate floor slipperiness and a pedestrian's risk of slipping. Moreover, this experimental protocol demonstrates that human gait-based measures of slipperiness can be used to create reference standards against which the output of tribometers can be validated.

Tribometer	Granite	Porcelain	Vinyl	Ceramic
English XL	0.18	0.23	0.21	0.49
Bot 3000 S	0.30	0.62	0.85	0.94
Bot 3000 D	0.20	0.23	0.38	0.74
C1028	0.22	0.44	0.65	0.58
Tortus II	0.35	0.47	0.64	0.60
Tortus III	0.14	0.21	0.34	0.24
HPS	0.32	0.61	0.85	0.73
Wessex	0.05	0.19	0.24	0.49
Sigler	0.13	0.16	0.20	0.42
Mark I	0.21	0.42	0.48	0.67
Mark II	0.18	0.22	0.31	0.69
Mark III	0.20	0.32	0.37	0.63

Table 2. Tribometer COF measurements. For the Bot 3000, S denotes static mode and D denotes dynamic mode.

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