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Assessment of Perceived and Measured Tribometer Readings in Evaluating Wet Barefoot Slip Resistance: A Gait-Based Approach

***ABSTRACT*:** The purpose of this study was to assess the viability of using slip risk (as quantified during human subject walking trials) to create a better understanding of the perceived verses measured levels of slip resistance for surfaces intended to be walked upon under wet barefoot (i.e.; floors, bathtubs, swimming pool decks, etc.)

First, human subjects were used to objectively rank the slipperiness of five different surfaces against a control reference surface. Second, three NFSI Approved tribometers were used to independently measure the Dynamic Coefficient of Friction (DCOF) of all five surfaces. The human subject slipperiness ranking determined from the subject trials was considered the reference against which the tribometer measurements were compared.

KEYWORDS: wet barefoot, walkway safety, coefficient of friction, slip resistance, forensic science.

Background- According to the U.S. Consumer Protection Safety Commission (CPSC) "There were an estimated 791,200 bathtub- and shower- related injuries among children less than 18 years of age who were treated in US emergency departments in 1990 –2007, with an average of 43,600 cases per year or ~5.9 injuries per 10,000 US children per year. The largest number of injuries involved children 2 years of age and children less than 4 years of age accounted for 54.3% of injuries. The most common diagnosis was lacerations (59.5%). The most common mechanism of injury was a slip, trip, or fall, accounting for 81.0% of cases or 4.6 injuries per 10 000 US children per year. The most frequently injured body part was the face (48.0%), followed by the head/neck (15.0%). The majority (71.3%) of injuries occurred in a bathtub. Of the cases with a known place of injury, 97.1% occurred at home. An estimated 2.8% of patients were admitted, transferred to another hospital, or held for observation."

Human gait studies have revealed that as a person's gait is extended the required level of slip resistance increases. The required level of wet barefoot slip resistance therefore is greater for flooring materials where a person's stride is longer than for bathtubs, showers, and spas, where the user's gait and stride is greatly reduced. The quantification of measured verses perceived slip resistance has not been studied. Many bathing related slip and fall events occur as the individual is pivoting or shuffling their feet while standing in a bathing unit while other falls will occur as a person is stepping into or onto a wet surface. In 2016 the ASTM withdrew the F-462 Standard Consumer Safety Specification for Slip-Resistant Bathing Facilities without replacement. Currently there are no test standardized test methods for measuring the slip resistance (Traction) of surfaces intended to be walked upon under wet barefoot conditions.

There is a wide range of skin variables on human feet including skin thickness on different areas of the foot (toes, heels, soles, et.) Human sensory also varies between individuals and is age related. Musculoskeletal factors, calluses, and foot neuropathy all can impact how people perceive the slip resistance of a surface when walking barefooted. Given the need for additional research in this area, the goal of this study was to assess the viability of using perceived slipperiness (as quantified during human subject walking trials) which tribometer readings could be correlated as to define acceptable traction ranges for pedestrians walking on wet barefoot surfaces. To achieve this goal, we conducted a two-part study. First, human subject objectively ranked the slipperiness of five different surfaces which were contaminated using a 0.1% Sodium Lauryl Sulfate (SLS) solution. Second, three NFSI Approved tribometers were used to measure the wet DCOF of each surface and to rank them in order from lowest DCOF to highest DCOF. The human subject and tribometer rankings were then compared using the two criteria described above.

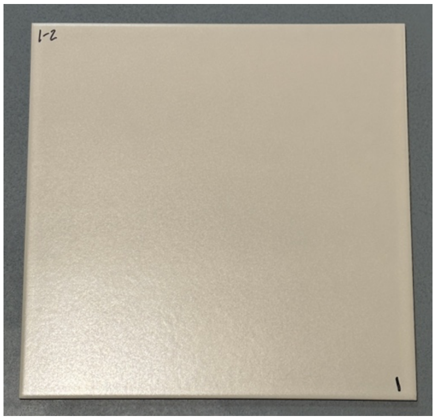
Methods- Human Subject Testing

Test Subjects - 70 volunteer subjects (35 males, 35 females) between the ages of 17 or less and 65+ years (mean age 41.5 years) were recruited for the study. All subjects were healthy and capable of independent ambulation. And did not have any physical disabilities.

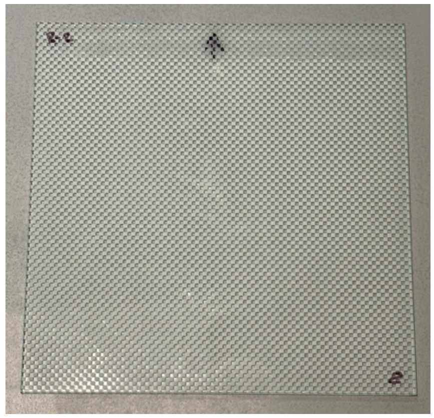
Walkway Surfaces and Conditions - Five smooth to moderately smooth surfaces materials and one reference surface were affixed to a plastic tray mounted on the floor of an enclosed metal handrail fixture. Each surface was wetted using a 0.1% dilution of Sodium Lauryl Sulfate (SLS).

Surfaces- 1. CINCA NOVA Arquitectura 3332M Glazed Ceramic Tile, Matt finish, 2. NFSI High-Traction Validation Reference Surface, 3. NFSI Low-Traction Validation Reference Surface, 4. Porcelain Enamal Finished Steel Coating, (Bootz Corporation) 5. Casalgrande

Padana Granito Unicolore Bianco Assolute Polished Porcelain Tile, Control Reference Surface- NFSI Calibration Reference Surface Tile.



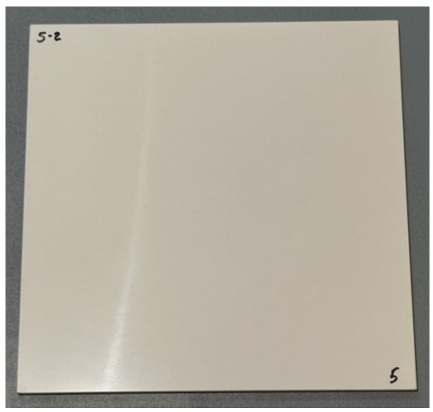
Surface 1.



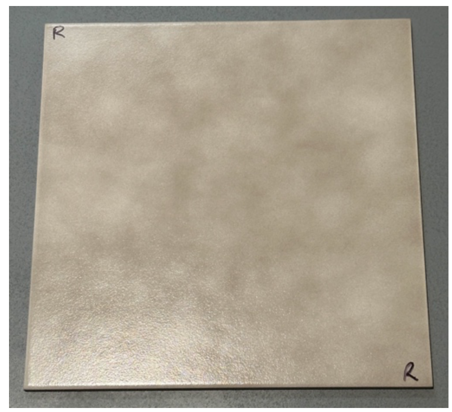
Surface 2.

Surface 3.

Surface 4.



Surface 5.



Reference Surface.

Procedures- All testing was performed at the at the National Floor Safety Institutes Research Center in Southlake, Texas. The temperature and humidity in the laboratory were controlled. Participants entered the metal handrail fixture (See below) containing each of the five surfaces and one reference surface. Subjects were barefooted and were instructed to step onto each test surface and take a series of short steps along its surface. Subjects ranked their perceived level of slipperiness of each surface on a scale of one to ten. Each subject was monitored by an NFSI technician.

Slipperiness Definition- After completing each trial, each subject completed a survey ranking their perceived level of slip resistance of each of the five surfaces. Rankings were based on a scale from one to ten where a rank of one represented a surface with a higher level of slip resistance than that of the control and a rank of ten represented a lower level of slip resistance than that of the reference control.

Tribometers—Three NFSI Approved tribometers were used to measure the Dynamic Coefficient of Friction (DCOF) of the six surfaces and included: the TRACSCAN 2.0[1], ASM-925[2], and GS-1.[3] Each tribometer was operated by a factory trained and experienced technician and testing was performed according to the tribometer manufacturer's instructions.

Tribometer Testing- The DCOF of each surface was tested using the NFSI B101.3 Test Method for Measuring the Wet DCOF of Hard Surface Walkways.

Procedures—Tribometer testing was conducted first on all six surfaces using the NFSI B101.3 Test Method for Measuring the Wet DCOF of Hard Surface Walkways. The same solution and wetting protocol used in the human subject tests was used for the tribometer tests. When testing wet surfaces, each tribometer's test foot was dried thoroughly before testing the next wet surface. For each surface condition, the DCOF was measured four times: once in each of four perpendicular directions, (i.e., at 0, 90, 180, and 270 degrees) as specified by the NFSI B101.3 standard. Surface average wet DCOF test results are listed in Table 1.

Table 1.

Surface	GS-1	TRACSCAN2.0	ASM925
1.	0.34	0.30	0.308
2.	0.60	0.62	0.726
3.	0.17	0.19	0.194
4.	0.75	0.74	0.828
5.	0.32	0.26	0.309
Reference	0.20	0.25	0.215

Human Subject Ranking Results- The results of the human subject walking trials are presented in Table 2.

Table 2.

Volunteer	Gender	Age Range	Surface 1	Surface 2	Surface 3	Surface 4	Surface 5
1	Female	Under 17	3	1	4	3	7
2	Female	Under 17	5	1	4	3	8
3	Female	Under 17	4	1	2	1	8
4	Female	Under 17	5	4	1	2	10
5	Female	Under 17	4	2	3	1	10
AVG.			**4.2**	**1.8**	**2.8**	**2**	**8.6**
6	Male	Under 17	2	2	5	4	10
7	Male	Under 17	5	1	2	1	5
8	Male	Under 17	5	3	3	1	8
9	Male	Under 17	4	2	3	2	8
10	Male	Under 17	5	3	3	3	9
AVG.			**4.2**	**2.2**	**3.2**	**2.2**	**8**
11	Female	18 - 25	3	5	9	1	8
12	Female	18 - 25	4	1	3	1	8
13	Female	18 - 25	3	2	2	1	7
14	Female	18 - 25	2	2	4	1	7
15	Female	18 - 25	4	2	3	1	7
AVG.			**3.2**	**2.4**	**4.2**	**1**	**7.4**
16	Male	18 - 25	3	2	2	3	7
17	Male	18 - 25	4	2	3	6	9
18	Male	18 - 25	4	3	3	2	8
19	Male	18 - 25	6	2	2	3	8
20	Male	18 - 25	8	2	3	1	8
AVG.			**5**	**2.2**	**2.6**	**3**	**8**
21	Female	26 - 35	4	1	3	1	8
22	Female	26 - 35	4	2	3	2	7
23	Female	26 - 35	6	4	3	2	10
24	Female	26 - 35	5	3	1	2	9
25	Female	26 - 35	5	3	1	1	9
AVG.			**4.8**	**2.6**	**2.2**	**1.6**	**8.6**
26	Male	26 - 35	8	1	9	1	10
27	Male	26 - 35	8	2	2	1	9
28	Male	26 - 35	2	2	5	4	10
29	Male	26 - 35	6	4	2	1	9
30	Male	26 - 35	6	3	3	1	9
AVG.			**6**	**2.4**	**4.2**	**1.6**	**9.4**
31	Female	36 - 45	10	2	7	2	10
32	Female	36 - 45	4	2	3	2	7
33	Female	36 - 45	4	2	3	2	7
34	Female	36 - 45	6	2	4	2	8
35	Female	36 - 45	6	1	3	1	9
AVG.			**6**	**1.8**	**4**	**1.8**	**8.2**
TOT. AVG.			**5.3**	**2**	**3.8**	**2.2**	**8.7**
RANK			**4**	**1**	**3**	**2**	**5**

Volunteer	Gender	Age Range	Surface 1	Surface 2	Surface 3	Surface 4	Surface 5
36	Male	36 - 45	5	2	3	3	5
37	Male	36 - 45	5	2	3	3	5
38	Male	36 - 45	4	1	2	1	8
39	Male	36 - 45	6	3	5	2	9
40	Male	36 - 45	7	3	4	3	10
AVG.			**6.4**	**2.2**	**3.4**	**2.4**	**7.4**
41	Female	46 - 55	8	1	6	1	10
42	Female	46 - 55	7	1	3	2	10
43	Female	46 - 55	8	1	4	1	10
44	Female	46 - 55	5	2	2	1	10
45	Female	46 - 55	8	2	3	1	10
AVG.			**7.2**	**1.4**	**3.6**	**1.2**	**10**
46	Male	46 - 55	4	2	3	2	7
47	Male	46 - 55	5	3	2	2	10
48	Male	46 - 55	4	1	2	1	8
49	Male	46 - 55	7	2	2	1	9
50	Male	46 - 55	5	2	3	2	7
AVG.			**5**	**2**	**2.4**	**1.6**	**8.2**
51	Female	56 - 65	5	3	4	2	8
52	Female	56 - 65	4	2	7	1	9
53	Female	56 - 65	4	8	6	7	10
54	Female	56 - 65	4	2	6	1	8
55	Female	56 - 65	8	5	3	6	10
AVG.			**5**	**4**	**5.2**	**3.4**	**9**
56	Male	56 - 65	8	2	6	1	10
57	Male	56 - 65	3	1	6	2	10
58	Male	56 - 65	5	2	3	2	9
59	Male	56 - 65	8	3	5	6	10
60	Male	56 - 65	7	3	5	4	9
AVG.			**6.2**	**2.2**	**5**	**3**	**9.6**
61	Female	Over 65	8	1	5	2	10
62	Female	Over 65	8	1	5	4	10
63	Female	Over 65	3	1	4	3	7
64	Female	Over 65	5	1	4	3	8
65	Female	Over 65	8	3	5	4	9
AVG.			**6.4**	**1.4**	**4.2**	**3.2**	**8.8**
66	Male	Over 65	7	3	5	5	10
67	Male	Over 65	4	1	5	2	10
68	Male	Over 65	4	1	9	2	10
69	Male	Over 65	4	2	3	1	10
70	Male	Over 65	2	2	5	4	10
AVG.			**4.2**	**1.8**	**5.4**	**2.8**	**10**

Data Analysis- Comparison of Human Subject and Tribometer Ranking—The slipperiness ranking determined from the walking trials was considered the reference against which the tribometer measurements were compared. The results of the tribometer measurements were then compared with the gait-based subject ranking of each surfaces perceived slipperiness and are listed in Table 3.

Table 3.

Surfaces	GS-1	TRACSCAN 2.0	ASM 925	Subject Rank
1.	3	3	4	4
2.	2	2	2	1
3.	5	5	5	3
4.	1	1	1	2
5.	4	4	3	5

Surface Rankings (1=Least Slippery, 5=Most Slippery

Conclusion- Wet DCOF levels of 0.34 or less were perceived by all the test subjects as being slippery to very slippery. Wet DCOF levels of 0.60 or greater were perceived by all the test subjects as to not be slippery. Subjects identified surfaces with a wet DCOF level of 0.34 to 0.26 to be more slippery than the reference surface whose wet DCOF ranged between 0.20-0.25. This may have been attributed to texture variances of each of the smooth surfaces. Enameled bathing surfaces provide a sufficient level of slip resistance.

Discussion-Tribometers are routinely used to assess the safety of pedestrian walkways and offer great benefit when used for testing the DCOF of bathtubs, showers, spas, and other surfaces intended to be used under wet barefoot conditions. Our experimental protocol demonstrated that a subjective gait-based system of analysis can be used to establish accurate levels of required slip resistance for surfaces intended to be walked upon under wet barefoot conditions.

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