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No. 70767-1

King County Superior Court No. 12-2-07790-8SEA

COURT OF APPEALS, DIVISION I, OF THE STATE OF WASHINGTON

TWYLA KILL and TERRY KILL,
Appellants,

vs.

CITY OF SEATTLE,
Respondent

BRIEF OF RESPONDENT

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I. INTRODUCTION

In this slip and fall case, the trial court concluded on summary judgment that no evidence in the record indicated that the City breached any duty it owed to the walking public. Accordingly, the court granted the City's motion for summary judgment. The bulk of the briefing below dealt with the expert testimony offered by the Kills, particularly statements by Joellen Gill regarding the slip resistance (coefficient of friction or COF) of a utility cover rim (also known as a "handhole"). The trial court determined that Ms. Gill's testimony was inadmissible under ER 702 and 403. The admissibility of Ms. Gill's offered testimony is the key issue on appeal.

Ms. Gill tested the utility rim cover in question twice using a tribometer. Under a 2011 ASTM (American Society for Testing and Materials) standard, tribometer readings are not valid unless the machine is both validated and calibrated prior to the test. Ms. Gill's machine was not calibrated before either test, as her calibration readings were not within the 95th percentile confidence interval set by the manufacturer. On appeal, the Kills rely heavily on the declaration of Peter Widas, the vice president and chief operating officer of the company that made the tribometer used by Ms. Gill. He opines that the tribometers his company makes need not actually satisfy the 95th percentile confidence interval his company set in

accordance with ASTM F2508, so long as they satisfy a lesser standard that Mr. Widas apparently developed during the course of this litigation. The Kills in essence argue that, despite the fact that their own expert and the manufacturer of the machine in question both recognize ASTM F2508 as a controlling standard, Ms. Gill's tribometer need not satisfy the standard in this case.

Ms. Gill's opinion is also fundamentally flawed because she bases her opinion on a false premise: that 0.5 Coefficient of Friction is a scientifically recognized minimum for establishing reasonable safety. Nothing in the record supports that assertion. It is further flawed because she offers the opinion that tribometers can provide universal as opposed to relative readings. Confronted with peer-reviewed published studies showing that there can be no firm safety standard because of how tribometers work—or fail to work—Ms. Gill points to no contrary studies. Instead, she relies on standards that do not apply to her tribometer and on materials self-published by the prior owner of the company that manufactured her tribometer, William English. Because her opinion lacks adequate foundation, her opinion is not admissible. The record contains no issues of fact on the Kills' claims, as evidence of Ms. Kill's fall is not evidence that the handhole was not reasonably safe. Accordingly, the trial court did not err in granting the City's motion.

II. ISSUES PERTAINING TO ASSIGNMENTS OF ERROR

1. Where the Kills offered no evidence indicating that Ms. Gill's tests conformed to the requirements of the applicable standard—ASTM F2508-11—did the trial court properly conclude that Ms. Gill's test results were inadmissible as unreliable and therefore unhelpful to the jury?
2. Where the Kills offered no foundation to support Ms. Gill's assertion that any measurement of a coefficient of friction below .5 indicates a surface that is unreasonably dangerous for ordinary travel, did the court properly exclude that portion of Ms. Gill's testimony as unreliable and therefore unhelpful to the jury?
3. Where the Kills offered no admissible evidence to demonstrate that the City breached a duty regarding sidewalk safety for ordinary travel, did the trial court err in granting the City's motion?
4. Where the Court ruled that Ms. Gill's opinions were inadmissible under ER 403 and 702, is any potential *Frye* issue regarding her statements moot?
5. Where the Kills failed to raise any challenge to the ASTM F2508 until they moved for reconsideration, have they waived any challenge regarding the applicability of the standard?

III. STATEMENT OF THE CASE

Ms. Kill alleges she slipped and fell while walking on a wet utility cover on November 13, 2009 in downtown Seattle.[1] (As an aside, as noted by the trial court, the source cited by the Kills to support Ms. Kills contention that it was raining at the time of her fall indicates that it had not been raining for hours prior to her fall.[2]) It is unknown when the cover was installed, other that it was in 1989 or before.[3] The utility cover included two inch flat metal rim.[4] Ms. Kill contends that she slipped on that rim.[5]

City records indicate no prior slips on the handhole.[6] The flat metal rim around the handhole, although installed over 25 years ago, meets present industry standards.[7] The City adopted the .5 coefficient of friction standard for new handhole installation in 2011, and did not have a coefficient of friction standard before then.[8] The standard applies only to dry surfaces, not to wet surfaces. The City has no coefficient of friction standard for wet handholes. Under the 2011 City of Seattle Standard

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[1] CP 19. (*Declaration of Twyla Kill* ¶¶ 2 and 3.).
[2] CP 1200 – 1201 (*Order Denying Plaintiff's Motion for Reconsideration and Motion for a Frye Hearing* at pp 2-3, fn 1.)
[3] CP 37 – 38 (*First Interrogatories to City of Seattle With Answers Responses and Objections thereto.*)
[4] CP 571-572 (*Fourth Declaration of Joellen Gill* Ex. 1, 4-5.).
[5] CP 28 (*Myers Decl. in Supp. Of Pls.' Mot. For Partial Summ. J.*, 1/18/2013, Ex. 1 (Dep. of Twyla Kill), 34:2-3.)
[6] CP 301. (*Declaration of Steven Read* at ¶ 18).
[7] CP 164. (*Declaration of Jeff Baker* at ¶¶ 5-7). .
[8] CP 298 (*Declaration of Steven Read* at ¶ 8).

Specifications For Road, Bridge, And Municipal Construction, new handholes are to be "non-skid."[9] Specification 1-07.1(3) Non-Skid Surface (2011) provides that coefficient of friction measurements regarding such surfaces are to be taken pursuant to ASTM test method C 1028-96 on *dry* surfaces.[10]

The parties cross-moved for summary judgment below and during the course of briefing Ms. Gill prepared six different declarations that the Kills submitted to the trial court.[11] The crux of her opinion is that (1) any walking surface with a coefficient of friction (COF) of less than 0.5 is dangerously slippery; (2) she twice measured the metal rim and both times obtained measurements of less than 0.5 COF using an English XL tribometer and (3) she therefore concluded that the rim was not reasonably safe.[12] The primary work relied upon by Ms. Gill, *Pedestrian Slip Resistance* by William English, 39 (2003), lists a number of "Myths About Pedestrian Slip-Resistance." "Myth No. 1" is that "[a] static coefficient of

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[9] Seattle 2011 Construction Specifications1-07.1(3), 9-34.6, pp. 1-47; 9-138. Available at http://www.seattle.gov/util/groups/public/@spu/@engineering/documents/webcontent/01_011339.pdf (last visited Feb. 11, 2014).
[10] *Id.*
[11] CP 52 – 67, CP 261 – 291, CP 484 – 486, CP 562 – 587, CP 630 – 651, CP 924 – 926 (Six declarations submitted by Ms. Gill below)

friction of .5 is required for safe ambulation."[13] Mr. English's publication was not peer-reviewed and is self-published.[14]

Ms. Gill measured the rim on February 24, 2011 and June 12, 2013, measuring a .35 COF and .21 COF, respectively.[15] After Ms. Gill's first test, the American Society for Testing and Materials ASTM enacted a new consensus standard for ensuring that tribometers were working properly and taking meaningful measurements.[16] Ms. Gill is a voting member of that ASTM committee.[17] Had the standard not been approved by a 90% vote of at least 60% of the committee, it would not have been adopted.[18] The Standard, ASTM F2508, is based on research demonstrating that different tribometers, even of the same make and model, do not take consistent readings and commonly measure slip resistant surfaces at below 0.5 COF.[19]

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[12] *See id.*
[13] CP 393-99 (*Declaration of Joseph G. Groshong* Ex. 2.)
[14] *Id.* at vii-ix. *See also* CP 411 (*Declaration of James Flynn* at ¶12).
[15] CP 53 (*First Gill Decl.*, ¶7); CP 564 (*Fourth Gill Decl.* ¶8).
[16] CP 410 (*Declaration of James Flynn, P.E.*, ¶8.) CP 410.
[17] CP 264. (*Second Declaration of Joellen Gill*, ¶11.)
[18] CP 1143-1189. (*Declaration of Joseph Groshong*, Exhibit 2 (Bylaws of ASTM)):
"12.2 *Main Committee Ballot Voting Requirements*:
"12.2.1 An affirmative vote of at least 90% of the combined affirmative and negative votes cast by voting members is required with not less than 60% of the voting members returning ballots."
[19] CP 408-10; 413-29 (*Declaration of James Flynn, P.E.*, ¶¶5-8, Ex. 1, 2, 3).

Until 2007, no published studies relied on human test subjects to come with a relative scale of slipperiness.[20] Prior to the first of these tests in 2007, only two prior studies attempted to relate COF readings to slipperiness, only one of the studies analyzed flat ground, and the flat ground study did not use an English XL tribometer.[21] The 2007 test used human test subjects to analyze 6 different surfaces.[22] Fourteen subjects walked across each surface.[23] They wore rubber soled shoes and goggles that prevented them from seeing the test surface before they stepped on it. The results of the testing are summarized here:[24]

TABLE 3—*Number of slip events on the six surfaces.*

Surfaces	No Slips	Toe Slips	Heel Slips	Group
Dry HPL	14	0	0	Not slippery
Dry Delrin®	14	0	0	
Wet HPL	14	0	0	
Dry Teflon®	6	8	0	Slippery
Wet Delrin®	2	2	10	Very slippery
Wet Teflon®	0	1	13	
Total	50	11	23	$N=84$

HPL, high-pressure laminate.

[20] *Id.* at Ex. 2.
[21] *Id.*
[22] *Id.*
[23] *Id.*
[24] *Id.*

The English XL used in the study measured a .21 average coefficient of friction for the Wet HPL, a surface that none of the test subjects slipped on.[25]

In subsequent testing in 2010, the tested surfaces include polished granite, porcelain, vinyl composition tile and ceramic.[26] Test subjects were fitted with harnesses and made to walk across those surfaces when wet.[27] Test subjects wore shoes with smooth rubber soles, and did not know when they would step on a wet surface.[28] The resulting slips are summarized here:

TABLE 3—*Slip results: walking trials.*

Surfaces	No Slips	Toe Slips	Heel Slips	Ranking
Black granite	1	6	13	Most slippery
Porcelain	5	11	4	Moderately slippery
VCT	13	7	0	Less slippery
Ceramic	20	0	0	Least slippery

VCT, Vinyl composition tile.

Of those tested, 95% of people slipped on black granite, most as a heel slip.[29] Conversely, no one slipped on the ceramic surface.[30] Seven of

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[25] *Id.*
[26] CP 413-18 (*Declaration of James Flynn*, Ex. 1.).
[27] *Id.*
[28] *Id.*
[29] *Id.*
[30] *Id.*

twenty subjects experienced toe slips on the vinyl composition tile, but toe slips are notably less hazardous than heel slips.[31]

Another test performed by James Flynn, P.E., in 2008 used eight English XL tribometers and the same reference surfaces used in the 2010 study.[32] Those tribometers came up with average readings of between .113 and .258 for Vinyl Tile and .238 and .543 for the Ceramic surface.[33] The average result for the Ceramic Surface was .3675.[34] By comparison, in the 2010 test using a variety of tribometer makes, the measurements of vinyl composition tile ranged from .20 and .85; with the English XL tribometer in the test measuring a .21.[35] On the porcelain tile, which 75% of the test subjects slipped on, the measurements ranged from .16 to .62.[36] On the ceramic surface, the various devices measured between .20 and .95, with the English XL measuring a .49.[37] Validation testing in 2012 of two different types of English XL tribometers also produced inconsistent results for the same surfaces.[38] One tribometer measured vinyl tile at .168,

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[31] CP 459 (*Second Declaration of James Flynn*, ¶ 8).
[32] CP 460-465 (*Second Declaration of James Flynn* ¶13, Ex. 1, 2).
[33] CP 465 (*Second Declaration of James Flynn*, Ex.2).
[34] *Id.* (eight results averaged by counsel).
[35] CP 459 (*Second Declaration of James Flynn*, Ex. 1.)
[36] *Id.*
[37] *Id.*
[38] CP 456-459 (*Second Declaration of James Flynn* at ¶¶ 6-7).

the other at .359.[39] The measurements on the other tiles did not match either.[40]

ASTM F2508 provides that the results of tribometer testing cannot be relied upon unless the tribometer is a validated type of tribometer that is also calibrated.[41] Validation may only be done by tribometer suppliers or an independent testing facility.[42]

The validation test set forth in the ASTM uses four reference surfaces: polished black granite, porcelain, vinyl composition tile and ceramic.[43] ASTM F2508 – 11 §7. For the validation procedure, each reference surface is tested 40 times by the manufacturer or an independent testing facility.[44] The results are used to come up with a Standard Deviation, Standard Error and 95th percentile confidence interval.[45] A tribometrist, like Ms. Gill, is required to test a tribometer for calibration prior to testing a surface for slip resistance using a manufacturer or

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[39] *Id.*
[40] *Id.*
[41] CP 432. ASTM F2508 – 11 §5.1. ("To be meaningful, walkway tribometer results must correlate the slip characteristics of a surface or contaminant, or both, to the actual propensity for human slips. To achieve this goal, walkway tribometers must be validated against a standard with relevance to human ambulation.").
[42] CP 434. ASTM F2508 – 11 §11.1.
[43] CP 432. ASTM F2508 – 11 §7.
[44] CP 433-34.
[45] CP 433.

independent testing facility's published validation report.[46] That testing involves taking 16 measurements on each reference tile.[47]

A tribometer is not in calibration unless the average result for each reference surface is within the manufacturer's reported 95th percentile confidence interval.[48] If the tribometer fails calibration, the tribometer is not fit to use for friction testing, because it is not functioning properly.[49] *Id.* at §13.3.

The City moved for summary judgment on the grounds that Ms. Gill's opinions were inadmissible and no evidence in the record created a fact issue regarding breach of duty.[50] On reconsideration, for the first time, the Kills attacked the validity of ASTM F2508 as a standard that Ms. Gill was required to meet.[51] In previous briefing, the Kills had argued that Ms. Gills' machine met ASTM F2508 without arguing that her tribometer

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[46] CP 434.
[47] *Id.*
[48] *Id.* ASTM F2508 13.2 ("To be considered a calibrated walkway tribometer, the mean for each reference surface· shall lie within the supplier's reported 95th percentile-confidence interval.).
[49] *Id.* ASTM F2508 13.3 ("Failure to meet this calibration criterion shall beconsidered an unsatisfactory result. The walkway tribometer shll be recalibrated or adjusted, or both....).
[50] CP 652-67 (Order Granting Defendant City of Seattle's Motion for Summary Judgment).
[51] CP 696-99, CP 1196 (Motion For Reconsideration and Reply in Support of motion for reconsideration. (Arguing that application of ASTM F2508 as written is "problematic" and that Excel could set its own confidence interval for validation, rather than the 95% interval specified in F2508)).

was not required to satisfy the 95% confidence interval set by ASTM F2508.[52]

IV. ARGUMENT

A. Although Summary Judgment orders are reviewed de novo, new issues raised for the first time on reconsideration are not considered on appeal

On appeal, summary judgment orders are reviewed *de novo*. *Hearst Communications, Inc. v. Seattle Times Co.,* 154 Wn.2d 493, 501, 115 P.3d 262 (2005). However, issues first raised in a motion for reconsideration following a grant of summary judgment are not generally considered on appeal. *Schreiner Farms. Inc. v. Am. Tower, Inc.,* 173 Wash.App. 154, 158, 293 P.3d 407 (2013) (citing RAP 9.12). "'[N]ew issues may be raised for the first time in a motion for reconsideration, thereby preserving them for review, where ... they are not dependent upon new facts and are closely related to and part of the original theory.'" *Id.* (quoting *Nail v. Consol. Res. Health Care Fund I,* 155 Wn.App. 227, 232, 229 P.3d 885 (2010).

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[52] *See e.g.* CP 631 (*Fifth Declaration of Joellen Gill* ¶ 7 "The tribometer I used to test the rim at issue on June 2, 2013 was calibrated in accordance with ASTM F2508. This opinion is based upon my review of ASTM F2508, application of the calibration protocol in ASTM F2508 and my discussions with the manufacturer of the English XL VIT regarding ASTM F2508 calibration.").

Under CR 56, summary judgment should be granted if there is no genuine issue as to any material fact, and the moving party is entitled to judgment as a matter of law. On motion for summary judgment, the moving party can show the absence of issues of material fact by pointing out the lack of evidence supporting an essential element of the non-moving party's case. *Young v. Key Pharmaceuticals, Inc.*, 112 Wn.2d 216, 225-26, 770 P.2d 182 (1989), citing *Celotex Corp. v. Catrett*, 477 U.S. 317, 325, 106 S.Ct. 2548, 2554, 91 L.Ed.2d 265 (1986). Once this has been done, the burden shifts to the plaintiff to set forth affirmative evidence in support of its case. *Id.* If the plaintiff fails to produce admissible evidence on one of the points raised by a defendant, "there can be 'no genuine issue as to any material fact' since a complete failure of proof concerning an essential element of the nonmoving party's case necessarily renders all other facts immaterial." 477 U.S. at 322-23, 106 S.Ct. at 2552- 53. The elements of the Kills' negligence cause of action against the City are, as in all negligence cases, duty, breach, causation, and injury. *See, Bodin v. City of Stanwood*, 130 Wn. 2d 726, 731, 927 P.2d 240 (1996).

A court's decision not to conduct a *Frye* hearing is reviewed *de novo, State v. Gregory,* 158 Wn.2d 759, 830, 147 P.3d 1201 (2006), while the denial of a motion for reconsideration is reviewed for abuse of

discretion. *Rivers v. Washington State Conf. of Mason Contractors,* 145 Wn.2d 674, 685, 41 P.3d 1175 (2002).

B. The City is not an insurer of pedestrian safety

In this context, the City's duty is to maintain its public ways in reasonably safe condition for ordinary travel. *Keller v. City of Spokane*, 146 Wn.2d 237, 249, 44 P.3d 845 (2002). This does not require absolutely safe sidewalks, for that would impermissibly make the City an insurer of the public's safety. *Hoffstatter v. City of Seattle*, 105 Wash.App. 596, 599-600, 20 P.3d 1003 (2001) (municipality is not an insurer of pedestrian safety); *see also Clevenger v. City of Seattle,* 29 Wn.2d 167, 172, 186 P.2d 87 (1947) ("a person using a public sidewalk is bound to use reasonable care and diligence to avoid injury, but he has a right to assume that the sidewalk is in a reasonably safe condition for travel and can act accordingly.); *Fritsche v. City of Seattle,* 10 Wn.2d 357, 360, 116 P.2d 562 (1941). ("It is hardly necessary to say that a city is not an insurer of the personal safety of everyone who uses its public walks. Its duty is performed when it keeps them reasonably safe for use for those who use them in the exercise of ordinary care."). *Accord* 19 Eugene McQuillin, Beth A. Buday, Dennis Jensen, Donna M. Poczatek, Municipal Corporations sec. 54.35 (3d ed. rev. 1994) ("Although the city has a duty

to maintain its streets and sidewalks in a reasonably safe condition, it is not an insurer of the safety of pedestrians who traverse its streets.").

The test has been described as follows: "whether a reasonably cautious man, having the duty to preserve and repair the sidewalks, would or would not consider a particular defect as one where pedestrians might be injured. Each case must rest upon its own facts and be determined accordingly." *Fritsche*, 10 Wn.2d at 360-361, 116 P.2d at 564. *See also* WPI 140.1.

C. Evidence of a fall is not evidence of dangerousness

"It is common knowledge that people fall on the best of sidewalks and floors. A fall, therefore, does not, of itself, tend to prove that the surface over which one is walking is dangerously unfit for the purpose." *Knopp v. Kemp & Hebert*, 193 Wn. 160, 164-165, 74 P.2d 924, 926 (1938). The two early *Smith* cases, cited by the Kills, do not support the proposition that evidence of a fall on a wet metal surface is sufficient to create an issue of fact regarding breach of duty. In the first *Smith* case, the Court affirmed a jury verdict against the City of Tacoma for a slip and fall where the plaintiff slipped on a metal coal hole cover. *Smith v. City of Tacoma,* 51 Wn. 101, 103, 98 P. 91, 92 (1908). However, in that case the court ruled that the combination of (1) wear on the cover, (2) a number of prior slips and (3) an incline combined to create an issue of fact. None of

those three issues are present in this case. Similarly, *Smith v. City of Spokane*, 103 Wn. 314, 316, 174 P. 2, 3 (1918), involved a manhole cover that had been worn smooth, an incline, and prior slips on the cover. Again, there is no evidence of wear, incline, or prior slips regarding the cover at issue.

D. Construction standards enacted after installation of the cover cannot be used against the City

Contrary to the Kills' argument and statement of the case, the record is silent as to when the cover was installed; it is known only that it was installed prior to 1990. Notwithstanding, the Kills rely on a 1986 City standard, effectively asking the Court to speculate that the 1986 standard was in effect at the unknown time when the cover was installed.[53] There is no evidence in to support the Kills' argument that the 1986 standard predated the installation such that it was in effect at the time the cover was installed. The Kills' reliance on the deposition testimony of Steven Read likewise fails. Relying on Mr. Read's discussion of current standards at his deposition, the Kills urge that the cover should have been retrofitted or replaced prior to Ms. Kill's fall. As a matter of law, however, the City is not required to update its facilities when a standard changes. *See Tanguma v. Yakima County*, 18 Wash.App. 555, 560, 569

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[53] Kills' Appellate Brief at 3.

P.2d 1225, 1228 (1977). ("There is no duty to replace every highway structure not conforming to present-day standards.");[54] *see also Ruff v. County of King* 125 Wn.2d 697, 705, 887 P.2d 886, 890 (1995) (no duty to update every road and roadway structure to present-day standards); *Lucas v. Phillips*, 34 Wn.2d 591, 596-597, 209 P.2d 279, 282 (1949) (court rejected the argument that infrastructure must be updated when standards change, as that would place an "imponderable [financial] burden" on counties and, implicitly, municipalities.). Moreover, regardless of current standards, Mr. Read does not offer the opinion that either (1) the rim was not safe for walking or (2) did not comply with the standard in effect when it was installed.[55] Absent either statement, the fact that the rim does not meet current standards does nothing to help the Kills' case.

It is true that the City now specifies a 0.5 COF for utility covers.[56] However, as noted above, that specification is for dry, not wet surfaces, and calls for a different method of measurement than the tribometer used by Ms. Gill.[57]

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[54] In *Tanguma* the court concluded that the County could not be liable for failing to update a bridge built in the 1940's using 1935 standards to conform to 1965 standards prior to a 1973 accident. 18 Wash.App. at 560.
[55] *See, e.g.* CP 296-302 (Declaration of Steven Read, P.E.).
[56] CP 298 (Declaration of Steven Read, P.E.).
[57] Seattle 2011 Construction Specification 9-34.6 (specifying non skid surface made of slip resistant steel plate), p. 9-138; 1-07.1(3) (A new nonskid or slip resistant surface shall have a minimum static coefficient of friction in accordance with ASTM test method C 1028-96 on a dry surface of .50 for non-skid surfaces not otherwise required to meet a

E. Ms. Gill's testimony is inadmissible under ER 702 and 403, and therefore no Frye hearing was required.

The trial court excluded Ms. Gill's testimony for five reasons: (i) the record does not contain any evidence that Ms. Gill's machine was working properly during the initial test and her own declarations show that her machine failed the ASTM F2508 requirements for the second test; (ii) Ms. Gill's statements that her tribometer is capable of providing objective measurements—as opposed to relative measurements—and her statement that .5 is an absolute safety threshold would mislead the jury under ER 403; (iii) the variability of the reference tiles used by Ms. Gill to calibrate her machine makes her results unreliable; (iv) Ms. Gill's failure to account for potential surface contamination renders her results unreliable; and (v) Her testimony amounted to the statement that metal can be slippery when wet, a proposition not beyond the common knowledge of the jury.[58] *Order Denying Plaintiffs' Motion for Reconsideration and Motion for a Frye Hearing* at 12-17. For the reasons explained below, which loosely follow those relied on by the trial court, this Court should affirm the trial court.

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higher dry surface standard). Available at http://www.seattle.gov/util/groups/public/@spu/@engineering/documents/webcontent/01_011339.pdf (last visited Feb. 11, 2014).

[58] CP 1210-1215 (*Order Denying Plaintiffs' Motion for Reconsideration and Motion for a Frye Hearing* at 12-17.).

i. No *Frye* hearing is required where offered testimony fails ER 702

"[E]xpert testimony is admissible only when the underlying scientific principle satisfies the threshold *Frye* requirements *and* the testimony meets the 2–part test of ER 702: (1) the witness qualifies as an expert and (2) the expert testimony would be helpful to the finder of fact." *State v. Cauthron*, 120 Wn.2d 879, 906, 846 P.2d 502, 516 (1993) (emphasis in original). "Frye and ER 702 work together to regulate expert testimony: Frye excludes testimony based on novel scientific methodology until a scientific consensus decides the methodology is reliable; ER 702 excludes testimony where the expert fails to adhere to that reliable methodology." *Lakey v. Puget Sound Energy, Inc.*, 296 P.3d 860, 865 (2013).

To admit evidence under *Frye,* the trial court must find that the underlying scientific theory and the "'techniques, experiments, or studies utilizing that theory'" are generally accepted in the relevant scientific community and capable of producing reliable results. *Anderson v. Akzo Nobel Coatings, Inc.,* 172 Wn.2d 593, 603, 260 P.3d 857 (2011) (quoting *State v. Riker,* 123 Wn.2d 351, 359, 869 P.2d 43 (1994). To admit expert testimony under ER 702, the trial court must determine that the witness qualifies as an expert and the testimony will assist the trier of fact.

Cauthron, 120 Wn.2d at 890. ER 702 provides that "[i]f scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise." "When a scientific theory has protocols for assuring reliability, an expert's errors in applying proper procedures go to the weight, not the admissibility, of the evidence, **unless the error renders the evidence unreliable**." *Lakey,* 176 Wn. 2d at 920 (*citing State v. Copeland*, 130 Wn. 2d 244, 270-71, 922 P.2d 1304 (1996)) (emphasis added). Unreliable testimony does not assist the trier of fact and is properly excluded under ER 702. *Anderson,* 172 Wn.2d at 600, 260 P.3d 857; *Cauthron,* 120 Wn.2d at 889-90, 846 P.2d 502.

When applying the *Frye* test, courts do not determine if the scientific theory underlying the proposed testimony is correct; rather, courts "must look to see whether the theory has achieved general acceptance in the appropriate scientific community." *Grant v. Boccia,* 133 Wash.App. 176, 179, 137 P.3d 20 (2006) (*quoting State v. Riker,* 123 Wn.2d 351, 359–60, 869 P.2d 43 (1994).

To determine whether a consensus of scientific opinion has been achieved, the reviewing court examines expert testimony, scientific writings that have been subject to peer review and publication, secondary

legal sources, and legal authority from other jurisdictions. However, the relevant inquiry is general acceptance by the scientists, not the courts. *Eakins v. Huber,* 154 Wash.App. 592, 599–600, 225 P.3d 1041 (2010). A trial court's decision concerning the admissibility of expert testimony under ER 702 is discretionary. *See State v. Yates,* 161 Wn.2d 714, 762, 168 P.3d 359 (2007). Generally, a trial court abuses its discretion by issuing manifestly unreasonable rulings or rulings based on untenable grounds, such as a ruling contrary to law. *Wash. State Physicians Ins. Exch. & Ass'n v. Fisons Corp.,* 122 Wn.2d 299, 339, 858 P.2d 1054 (1993). "It is an abuse of discretion to admit [expert] testimony if it lacks an adequate foundation." *Safeco Ins. Co. v. McGrath,* 63 Wash.App. 170, 179, 817 P.2d 861 (1991).

An expert must have a sufficient factual foundation for his or her opinion and must stay within his or her area of expertise. *Queen City Farms, Inc. v. Cent. Nat'l Ins. Co. of Omaha,* 126 Wn.2d 50, 103-04, 882 P.2d 703 (1994). Conclusory or speculative expert opinions that lack an adequate foundation are inadmissible. *Safeco Ins. Co. v. McGrath,* 63 Wash. App. at 177.

"In the context of a summary judgment motion, an expert must support his opinion with specific facts, and a court will disregard expert opinions where the factual basis for the opinion is found to be

inadequate." *Rothweiler v. Clark Cy.*, 108 Wash.App. 91, 100-01, 29 P.3d 758, 763 (2001).

ii. Ms. Gill's testimony regarding 0.5 COF as the threshold of safety fails ER 702

Ms. Gill did not support her 0.5 coefficient of friction theory with facts, peer-reviewed scientific studies, or other materials that support her position. Her statement that in her "opinion" and "experience" the standard is generally accepted in the scientific community is not enough to make it so. Rather, those are the types of conclusory expert statements that are insufficient in opposition to summary judgment. Ms. Gill has had many opportunities—she submitted six declarations below—to provide the court with published studies, but has only cited to self-published studies by Mr. English (he is not a doctor as alleged in the Kills' moving papers) and made the general assertion that her position is in accord with the approach taken in the larger scientific community. Again, experts have to do more than say that their opinions are in accord with the scientific community. That is particularly true where, as here, the opposing party has submitted published, peer-reviewed studies contrary to the expert's position.

Ms. Gill's opinion, that any surface that measures below a 0.5 Coefficient of Friction is dangerous, fails because: (1) the 0.5 number is

not based on any scientific studies addressing the proper technique for measuring utility covers, sidewalks or comparable surfaces; (2) tribometer readings are not interchangeable, as different tribometers do not measure on the same scale, and many non-slip surfaces fall below 0.5 COF on certain tribometers, including the English XL. "[A] tribometer can accurately determine whether one surface is more or less slippery than other surfaces *measured by that same tribometer*, but cannot give an objective measurement of a surface that can be compared to readings by other tribometers…."[59]

The results of a particular tribometer test are only meaningful if the tribometer used is from a class of tribometers that passed the "validation" test and the individual tribometer passed "calibration" test set forth in ASTM F2508 *before* the tribometer is used to take friction measurements. *Id.* at 4.2.

As illustrated above, English XL tribometers are not interchangeable, and do not take the same measurements as each other. Moreover, repeated testing on different English XL tribometers has shown that measurements below .5 obtained using an English XL tribometer do not indicate that the surface is unreasonably dangerous. Rather, such

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[59] CP 1210-11 (*Order Denying Motion for Reconsideration*).

measurements are only useful in that they allow comparison to other known surfaces, assuming that the tribometer in question was functioning properly. A tribometer COF test result of below 0.5 is meaningless absent additional information not provided by Ms. Gill.

Here, Ms. Gill does not attempt to relate her tribometer's readings to the human testing that forms the basis of the standard. Rather, she argues that the .5 standard is meaningful independent of how it relates to scientific studies, and that the analysis ends there. She is wrong. Given that some tribometers measure very slippery surfaces as above .5 and others measure surfaces that no one slips on well below 0.5, 0.5 COF does not withstand any scrutiny as a general standard. Ms. Gill's opinions are inadmissible.

iii. Ms. Gill's test results fail ER 702 because the record does not indicate that her tribometer was working properly on either occasion

At her deposition Ms. Gill admitted that calibration under ASTM F2508 was required for a tribometer to produce meaningful results:

> Q. So do tribometers have to be calibrated from time-to-time to ensure that they are working properly?
> A. Yes, sir. There's three levels of calibration. The first one is -- I don't know if you're familiar with the history of tribometers and the various standards – ASTM standards that were -- well, I'll just give you a thumbnail sketch. When tribometers were first developed, ASTM wrote a couple of standards that were specific to particular tribometers, and, basically, what they were were just the

> operating procedures for those particular tribometers. Well, then they realized that that went against their own protocols; in other words, they are not allowed by their own bylaws to endorse a particular piece of equipment. So those standards were subsequently withdrawn. And in their place, in order to come up with some way of having a -- the acceptance by ASTM for the use of a particular tribometer, they developed a new standard, and that standard number is -- I think it's in my notes – **ASTM 2508**, and it's entitled, "The Standard Practice for Validation and Calibration of Walkway Tribometers Using Test Standards." So in other words, **if you want your tribometer to be approved by ASTM for use, you have to meet all of the requirements that are set forth in the standard. The English XL tribometer has been subjected to all of those tests and does meet the requirement of that standard. That's the number one level of validation and calibration.** [60]

Given Ms. Gill's deposition testimony and ASTM committee membership in the committee that created the standard, it is not surprising that she generally accepts the ASTM F2508 standard. Similarly, Peter Widas offered the opinion that the machine satisfies ASTM F2508.[61] Notably, Mr. Widas opined that the machine satisfied the standard *once a substitute for the 95% confidence interval selected by his company was applied instead of the 95% requirement.*[62] Richard Gill also opines that the machine complied with ASTM F2508.[63] Their opinions are all flatly

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[60] CP 202-03 (*Second Declaration of Michael David Myers Ex.* 1) (emphasis added).
[61] CP 1114 (*Declaration of Peter Widas*, Ex. 1).
[62] *Id.*
[63] CP 934-936 (*Declaration of Richard Gill*).

contradicted by F2508 and the 95th Percentile Confidence Interval contained in the standard, as explained below.

Despite their acceptance of the standard, the Kills' experts end up arguing that the standard should not be applied as written, but in a manner that allows Ms. Gill's machine to satisfy it. Critically, they posit that the 95th percentile confidence interval need not be satisfied as stated in the standard and that tribometer operators may validate tribometers, even though the standard requires manufacturers to do that. The Kills further argue that ASTM F2508 contemplates that the same test tiles will be used for validation *and* calibration. However, the Kills fail to cite to any portion of ASTM F2508 that says that. Indeed, by its plain language, ASTM F2508 does not contemplate that the same test tiles must be used for validation and calibration. Rather, it provides that particular reference surfaces must be used.

The Kills argue that their expert's machine satisfied ASTM F2508 at the time of the second test. To be calibrated, her machine would have needed to satisfy the 95th percentile confidence interval set forth in the validation report for her class of tribometer. The Excel validation report for that model provides the following confidence intervals:[64]

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[64] CP 636. (*Fifth Declaration of Joellen Gill*, Exhibit C p. 3 (*Report of ASTM F2508 Validation of the English XL VIT with Sequencer Variable Incidence/Articulated Strut*

	RS-A Granite	RS-B Porcelain	RS-C Vinyl	RS-D Ceramic
Mean	0.080	0.134	0.177	0.611
Standard Deviation	0.007	0.008	0.011	0.019
Standard Error	0.001	0.001	0.002	0.003
95th Confidence Lower	0.078	0.132	0.173	0.605
95th Confidence Higher	0.082	0.137	0.180	0.616
Rank (1 = least slip resistant)	1	2	3	4

Mr. Widas, however, purports to establish different confidence intervals specific to Ms. Gill's tribometer:[65]

	RS-A Granite	RS-B Porcelain	RS-C Vinyl	RS-D Ceramic
Mean	0.066	0.116	0.165	0.576
Standard Deviation	0.005	0.010	0.010	0.018
Standard Error	0.001	0.002	0.002	0.003
Validation Confidence Lower*	0.050	0.104	0.138	0.561
Validation Confidence Upper*	0.110	0.164	0.198	0.661
Rank (1 = least slip resistant)	1	2	3	4

The asterisk behind the validation confidence lower and upper headings is in Mr. Widas's report. The Kills acknowledge that this margin of error is different than the 95th Percentile confidence interval set by ASTM F2508.[66] As noted above, under F2508 a tribometer is not calibrated if it fails to satisfy the 95th Percentile numbers. Whereas the 95th Confidence Intervals in Excel's validation report for the class of tribometers allow for ranges within .004, .005, .007 and .011 COF, respectively, the "Validation

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Tribometer with Standard XL VIT Non-Treaded Test Foot and Standard Test Foot Preparation Device)).

[65] CP 683-85. (*Declaration of Peter Widas,* Exhibit A).

[66] *See Kills' App. Brief* at p. 11-12.

Confidence" numbers created by Mr. Widas offer ranges of .06, .06, .06, and .10. In other words, the 95th percentile standard must be relaxed by a factor of roughly 10 in order for Ms. Gill's machine to satisfy it. This is what led to the Court asking the Kills' counsel whether they were arguing for a "fudge factor" at oral argument below.

> THE COURT: And no one is saying that there is that additional fudge factor but her [Ms. Gill]? Does anyone else say that the [95th Percentile] range doesn't really mean the range; it means the range plus fudge?
>
> MR. NUTE: According to her she talked to Peter Widas, who did the validation report for this tribometer and he said "Fudge is okay."[67]

Mr. Widas has documented his position that "[f]udge is okay" in Exhibit A to his declaration. However, he was never explained why a tenfold deviation from the confidence intervals set by ASTM F2508 somehow satisfies the standard. Indeed, such a deviation does not comply with the plain language of ASTM F2508. It appears he believes the standard set by ASTM F2508 is too exacting. If so, he must take the issue up with ASTM. He cannot substitute his own test for the 95th Percentile Confidence interval required by ASTM F2508. Although it is easy to understand why the vice president and chief operating officer for the company that manufactures Ms. Gill's tribometer would want that

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[67] RP 38:22-39:2.

tribometer to satisfy F2508, the plain language of F2508 does not support his assertions regarding Ms. Gill's tribometer. Mr. Widas's approach also contradicts the F2508 standard which provides: The published 95th percentile confidence interval is that found in the manufacturer's *validation* report. Mr. Widas offers a *calibration* report that does not reference the *validation* reports published by his company. Because the "calibration" report does not reference the published "validation" report, it does not comply with ASTM F2508.

The reason that his report ignores the published validation report is readily apparent: Ms. Gill's machine does not satisfy the confidence interval set by the validation report. Indeed, as discussed above laboratory testing of the English XL has indicated that it is an inconsistent instrument, and frequently to take consistent measurements. Mr. Widas's testing of Ms. Gill's machine measured a 0.066 on granite, .116 on porcelain, 0.165 on vinyl, and 0.576.[68] None of those numbers are within the confidence intervals published in the validation report for Ms. Gill's tribometer. Again, Mr. Widas's tests indicate that Ms. Gill's machine is entirely out of compliance with the published validation report for the class of tribometer used by Ms. Gill.

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[68] CP 1114 (*Declaration of Peter Widas*, Ex. 1)..

Ms. Gill offers an "opinion" that her machine was in calibration based on a variety of factors. However, her own testing and the testing by Mr. Widas reveals the opposite, it has never been in calibration. In her "validation" report, which ASTM prohibits her from performing, she reports measurements of 0.07 on granite, 0.1013 on porcelain, 0.1727 on vinyl and 0.8505 on ceramic.[69] Even if her "validation" report is considered it does not help the Kills. The 95th percentile confidence interval from Ms. Gill's report are .062-.078; .09 to .11; .16 to .19; and .84 to .87.[70] Again, the relevant confidence intervals from the suppliers' validation report are .078-.082; .132-.137; .173-.180 and .605-.616.[71] Accordingly, none of Ms. Gill's measurements were within the 95th percentile confidence interval published by the manufacturer. Moreover, in Mr. Widas' "calibration" testing following Ms. Gill's validation—which ASTM required to occur *before* Ms. Gill tested the rim, Mr. Widas came up with average measurements of .08, .1, .149 and .641.[72] A table readily demonstrates that even using the same tiles for both tests, Ms. Gill's machine does not function as required by ASTM F2508:

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[69] CP 645 (*Fifth Declaration of Joellen Gill,* Ex. B).
[70] *Id.*
[71] CP 630, 636 (*Fifth Declaration of Joellen Gill*, Ex. A).
[72] CP 678 (*Declaration of Peter Widas*, Ex. B).

Surface	Granite	Porcelain	Vinyl	Ceramic
Gill's "Validation" 95% interval	.062-.078	.09-.11	.16 to .19	.84 to .87
Widas's "Calibration" averages using Ms. Gill's tiles	.8	.1	.149	.641

Even in the last ditch attempt made by Ms. Gill and Mr. Widas to show that Ms. Gill's machine was capable of working properly and using the same set of tiles, her machine failed three of the four 95% confidence intervals. In sum, the Gills' theories that Ms. Gill's results are meaningful because her machine satisfied F2508 are ultimately based on Mr. Widas's substitute test, rather than the 95% confidence interval requirements of F2508, and therefore fail. Ms. Gill's machine has never been shown to be calibrated, even when the same tiles are used for both tests.

The Kills argue that in the absence of testimony from Mr. Flynn on the issue, the trial court erred when it determined that Ms. Gill's machine was not calibrated.[73] In doing so, they ignore the plain language of ASTM F2508, which clearly provides that both validation and calibration are required, and explains how the 95% confidence interval is to be calculated for purposes of the standard. In making the argument that "Excel is in a much better position than the City or the trial court to know about the

[73] Kill's Appellate Brief at 31.

interplay between the standard and the precision and calibration of its machine," the Kills infer that the City and trial court are incapable of reading and understanding the plain language in ASTM F2508. Again, Ms. Kill's machine has never been calibrated as required by the ASTM standard. The Kills' attempt to replace the 95% standard with a substitute standard offered by Mr. Widas is properly rejected.

iv. Any variability between different test tiles does not render Ms. Gill's opinion admissible

Irrespective of the tiles used to test Ms. Gill's machine, her machine has yet to satisfy the 95% confidence interval set by F2508. The record does not support the Kills' position. Even using different tiles, Ms. Kill's machine has not been shown to work in accordance with F2508. The tile problem noted by the Kills is just as easily explained by a problem with Excel tribometers, as opposed to variability in test tiles, and does not support the Kills' argument that Ms. Gill's opinions should go to the jury. Moreover, even if the tile argument is given some weight, it is not enough to overcome the other deficiencies with her opinion. She is mistaken as to the existence of 0.5 COF as the threshold of safety, failed to calibrate her machine prior to testing, fails to account for potential contaminants, fails to explain the difference between her different results, and fails to relate the measurements she did take to human studies.

v. Ms. Gill does not adequately address potential contaminants and the different results she obtained.

Ms. Gill's recent testing indicates over a .1 difference in COF between the rims of two adjoining handholes that appear very similar. Similarly, her first measurement of the handhole rim is .14 COF higher than her second measurement. Ms. Gill makes no attempt to explain the differences, other than to say they could be caused by contaminants. Had Ms. Gill made some effort to determine the relative slipperiness of the rim in a clean condition, we might have some baseline for assessing the potential effect of contaminants. Because she did not, we have no way of knowing whether the measurements taken by Ms. Gill, irrespective of other problems, were based on temporary contaminants. And, again, she has not and cannot demonstrate that .5 COF is the standard.

It is proper to exclude test results where the conditions at the time of an accident are not accounted for in a subsequent test. *Quinn v. McPherson*, 73 Wn.2d 194, 201, 437 P.2d 393 (1968) (excluding expert testimony where no similarity in time, in atmospheric conditions, or in any circumstance which would make the experiment comparable in any way to accident conditions). Here, Ms. Gill made no effort to determine whether contaminants might have played a role in Ms. Kill's fall. The potential presence of contaminants is important, because the City cannot be found

liable for temporary conditions on sidewalks that it did not create. *See* WPI 140.02. Ms. Gill's testimony regarding the conditions encountered by Ms. Gill is speculative because she never cleaned the rim in order to obtain a baseline Coefficient of Friction reading for a contaminant free rim. Accordingly, even putting the many other issues with her offered testimony aside, her test results cannot be said to reliably indicate the coefficient of friction at the time of Ms. Kill's fall. *Accord Michaels v. Taco Bell Corp.*, Not reported in F. Supp. 2d, 2012 WL 4507953, 9 (D. Or. 2012) (failure to account for effect of potential or actual contaminants renders coefficient of friction testing unreliable).[74]

vi. Because Ms. Gill's "scientific" testimony is inadmissible, her remaining opinions are also inadmissible as unhelpful to the jury

Ms. Gill's opinion that the rim is dangerous is based entirely on her measurements and interpretation of those measurements. Although it is known that some metal surfaces can be slippery when wet, it is beyond the lay person's ability to determine what degree of slipperiness is reasonably safe for ordinary walking. Ms. Gill contributes nothing to understanding how slippery the rim is because her results are not valid

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[74] *See also* RP 62:18-24. (Court: "[T]he idea that the presence or absence of contaminants has no impact on how slipperysomething is, I think was -- was addressed pretty effectively by that Michael's v. Taco Bell case where it seems clear that if this methodology is going to be reliable such that it should go to the jury, that it needs to be able to address the presence or absence of contaminants.)

because her test results are not valid. The factual basis for her opinion, her test results, are fatally flawed because her machine has not been shown to have been functioning properly during either test.

vii. The ER 702 cases cited by the Kills do not support the proposition that Ms. Gill's opinion is admissible

The Kills cite a number of cases for the proposition that Ms. Gill's error really was not that significant, and her testimony should be admissible. However, none of the cases cited are on point. Two cases cited by the Kills address FRE 702, but neither deal will a complete failure to satisfy part of an ASTM standard. In *Phelps v. Steinmart,* 2011 WL 1337362 (W.D. La. 2011), the court did not consider ASTM F2508, but entirely different standards dealing with flooring. (Dynamometer, not tribometer, used to test flooring material). The ASTM at issue authorized different types of materials to be used on dynamometers. On that basis, the Court rejected an FRE 702 argument that the tests of one expert who used a different type of test material than the other expert were inadmissible. *Rosenfeld v. Oceania Cruises, Inc.,* 654 F.3d 1190, 1194 (11th Cir. 2011) (noting that matters of slip resistance and surface friction are beyond the understanding and experience of the average lay citizen.) is also a flooring case. The issues in *Rosenfeld* went to the factual assumptions made and variables applied by the expert. The case does not

contain any discussion of how the coefficient of friction was measured or ASTM standards, and is of little use here.

F. ER 403 also requires exclusion of Ms. Gill's testimony

ER 403 provides that "Although relevant, evidence may be excluded if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by considerations of undue delay, waste of time, or needless presentation of cumulative evidence." Ms. Gill's testimony regarding her test results would confuse and mislead the jury. Her results do not mean what she says they mean. Indeed, they have no meaning at all, because her machine has not been shown to have been working properly during either test. Similarly, there is no .5 coefficient of friction standard that applies in this context. Ms. Gill's opinion that the rim is unreasonably slippery is without foundation, and was properly excluded.

G. No *Frye* hearing is required, as it would not alter the ruling under ER 702 that Ms. Gill's testimony is inadmissible

Given that the Court excluded the Kills' expert's testimony under ER 702, a *Frye* hearing would serve no purpose: even if the Court were to determine that the science underlying Ms. Gill's efforts was not novel, that would not affect the Court's conclusion that other problems with Ms.

Gill's proffered testimony render it inadmissible. The Court's ruling went beyond the application of F2508. Even if a *Frye* hearing were held, it would not affect the result, because it would not address the 0.5 COF issue, the contaminants issue, or Ms. Gill's failure to relate her test results to human studies. Although the Kills' correctly point out that the City made *Frye* arguments in moving for summary judgment, the problems with Ms. Gill's testimony beyond the application of F2508 moot any *Frye* issue regarding that standard.

The Kills suggest that a *Frye* hearing on the acceptance of F2508 is required. However, they do not offer another method of determining whether Ms. Gill took meaningful results. Moreover, they did not challenge the applicability of F2508 until reconsideration. Before then, they insisted that Ms. Gill had met the standard. They have waived the argument that Ms. Gill was not required to satisfy F2508.

V. CONCLUSION

Ms. Kill fell, but there is no admissible evidence in the record that would allow a jury to determine that the handhole cover she alleges she slipped on was not reasonably safe for ordinary travel. No Frye hearing in this matter is necessary, because Ms. Gill's testimony is properly excluded under ER 702. There is no fact issue regarding a key element of the Kills

claims—breach of duty—and the City respectfully requests that the Court affirm the trial court's grant of summary judgment.

DATED this 13th day of February, 2014.

PETER S. HOLMES
Seattle City Attorney

By: WSBA #32767 for
JOSEPH G. GROSHONG, WSBA #41593
Assistant City Attorney

Attorneys for Respondent, City of Seattle

Michaela M. Morrison certifies under penalty of perjury under the laws of the State of Washington that the following is true and correct.

I am employed as a Legal Assistant with the Seattle City Attorney's office.

On February 13, 2014, I sent via e-mail, per e-service agreement, a copy of the foregoing Brief of Respondent upon the following counsel:

Attorney for Plaintiffs:
Michael David Myers, WSBA #22486
1530 Eastlake Avenue E
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E-mail: mmyers@myers-company.com

and requested ABC-Legal Messengers, Inc., to deliver, by February 13, 2014 and file the original and one copy of said document with the Court of Appeals and to provide a courtesy copy to the Washington State Supreme Court.

DATED this 13th day of February, 2014.

MICHAELA M. MORRISON

APPENDIX

A. Declaration of James Flynn, P.E. in Support of The City of Seattle's Motion for Summary Judgment

- A.1. Validation of Walkway Tribometers: Establishing a Reference Standard
- A.2. Assessment of Walkway Tribometer Readings in Evaluating Slip Resistance: A Gait-Based Approach
- A.3. The Development of a universal approach to testing of walkway slip resistance in the U.S.
- A.4. Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces
- A.5. Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine

B. Second Declaration of James Flynn, P.E. in Support of The City of Seattle's Motion for Summary Judgment

- B.1. VIT Precision Study
- B.2. VIT Testing: USC 03-29-08

APPENDIX A

FILED
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KING COUNTY
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E-FILED
CASE NUMBER: 12-2-07790-8 SEA

The Honorable Kenneth Schubert

IN THE SUPERIOR COURT OF THE STATE OF WASHINGTON
FOR KING COUNTY

TWYLA KILL, and TERRY KILL, individually and the marital community comprised thereof, Plaintiffs, vs. CITY OF SEATTLE, a Washington municipal corporation, Defendant.	DECLARATION OF JAMES E. FLYNN, P.E., IN SUPPORT OF THE CITY OF SEATTLE'S MOTION FOR SUMMARY JUDGMENT No. 12-2-07790-8SEA

I, James E. Flynn, P.E. do declare as follows:

1. I am an engineer with J2 Engineering. I am the author or contributing author to a number of scientific studies analyzing slip and falls and the use of tribometers. I am Collaborative Researcher at the Musculoskeletal Biomechanics Research Laboratory (MBRL) at the University of Southern California. I am a registered mechanical engineer and safety engineer in California, and a registered mechanical engineer in Nevada.

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2. The representations I make in this declaration are based on scientific research, my years of training and experience in mechanical engineering and my familiarity with academic and peer-reviewed scientific works regarding slips.

3. I have been retained by the City of Seattle to provide expert witness services in the above captioned case. In particular, I have been asked to opine whether the opinion of Ms. Joellen Gill that the handhole involved in this case is unreasonably dangerous for ordinary travel because Ms. Gill measured the rim of the handhole as having a 0.35 average coefficient of friction when wet using an English XL tribometer. A tribometer is a device that can be used to obtain a coefficient of friction measurement.

4. It is my opinion that Ms. Gill's analysis is fatally flawed because she relies on a purported standard that has not been accepted or adopted by the scientific community. Her hypothesis that any coefficient of friction measurement below 0.5 -indicates that a surface is unreasonably dangerous for ordinary travel is not supported by current science.

5. Different types of tribometers and different models of the same tribometer will produce different coefficient of friction measurements, even when recently calibrated and tested under identical conditions. Research conducted at the Musculoskeletal Biomechanics Research Laboratory (MBRL) at the University of Southern California has shown that when several different types of tribometers are used to measure the coefficient of friction of identical surfaces, the results can be widely variable (Powers, et al. 2007, Powers, et al. 2010). This variability was also found when testing identical surfaces with several different tribometers of the same type. It was noted that with the variance in measurements obtained from different tribometers, it was not possible to relate the measurements to actual human ambulation nor was it possible to know which, if any, of the measurements should be used to predict the probability of a slip on a

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metered walking surface. If tribometer A measures the coefficient of friction of a surface to be 0.25 and tribometer B measures the same surface to be 0.50, additional data beyond a simple measurement is required to determine if the surface is safe or slippery. In the absence of this additional data, the use of a single "threshold" value cannot be supported. The articles cited in this paragraph are attached as Exhibits 1 and 2 to this declaration.

6. In 2007 and 2010 studies at the MBRL, the English XL failed to meet the requirements necessary to for tribometer validation. A research program was set up at the MBRL where 84 human subjects were walked across three different surfaces under wet and dry conditions. The human subjects were monitored with motion analysis equipment and the number of slips per surface was recorded. The surfaces were then ranked in order from most to least slippery. Nine different types of tribometers were then brought to the MBRL to test each of the surfaces. Each tribometer had a separate qualified operator. For the measurements obtained by a given tribometer to be considered valid, it was necessary for the tribometer to statistically differentiate between the surfaces and to rank the surfaces in the same order as the human subjects. The study was repeated using 80 subjects, four different wetted tiled surfaces and eleven different types of tribometers. In the first study the English XL was not able to rank the surfaces in the correct order. In the second study the English XL failed both criteria. The results of both studies were published in the Journal of Forensic Sciences (Powers, et al. 2007, Powers, et al. 2010).

7. The findings of the second Powers study were utilized in the creation of ASTM Standard Practice for Validation, Calibration and Certification of Walkway Tribometers Using Reference Surfaces. The F2508 Standard uses the four tiles from the second Powers study as an adjunct. The tiles and the F2508 Standard are available for purchase from ASTM. The tiles are

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used as reference surfaces along with protocols outlined in F2508 to validate a tribometer prior to its use in the field. Once a tribometer is shown to meet the criteria outlined in F2508, subsequent field measurements can be compared to measurements obtained from the reference tiles to determine the relative slip resistance of the field tested surface. If tribometer A measures the non-slip reference tile at 0.25 and in later field testing measures a site to be 0.25, it is readily apparent that the field tested site is a non-slip surface. If tribometer B measures the non slip reference tile at 0.50, a site measured in the field would need a reading of 0.50 from tribometer B to be classified as non-slip. There is no 'threshold" value. Having been shown to be valid per F2508 protocols, each tribometer can directly reference obtained readings back to published, peer reviewed human ambulation studies (Flynn, et al. 2012) (Attached as Exhibit 3).

8. Summarizing the above, a coefficient of friction measurement taken by a tribometer is meaningless absent comparison to other measurements taken by that tribometer in the manner required by ASTM 2508 (Attached as Exhibit 4). Because Ms. Gill has done no comparison between the 0.35 Coefficient of Friction measurement as required by ASTM F2508, the 0.35 number is of no guidance whatsoever in analyzing how slippery the measured surface was at the time of testing.

9. Ms. Gill's analysis is flawed in a number of other respects, some of which I detail in the following paragraphs.

10. At her deposition, Ms. Gill testified that a source for her use of the 0.5 "threshold" value was ASTM Standard D2047 "Test Method for Static Coefficient of Friction of Polish-Coated Surfaces as Measured by the James Machine" (105/6→11 and exhibit 10 to her deposition) (Parenthetical references to page and line numbers of Ms. Gill's deposition). It is apparent that Ms. Gill did not read D2047. (Attached as Exhibit 5) It was clear that until the time

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of her deposition, Ms. Gill incorrectly believed that the James Machine operated as a "drag sled" (106/4→11). Ms. Gill testified that she utilized the 0.5 criterion as set by D2047 when conducting her testing on the wetted surface upon which Ms. Kill reportedly fell (21/4→16). The Scope of the D2047 explicitly states that the "test method is not intended for use on wet surfaces." Section 1.2 of the standard states that "the test method is the only method appropriate for testing polishes for specification compliance with the floor polish static coefficient of friction criterion." The standard is not intended for use in testing the metallic rim of a utility cover.

11. Ms. Gill's use of the 0.5 threshold based upon D2047 is specifically addressed in the standard. Section 4.3 of D2047 states: "The 0.5 static coefficient of friction compliance criterion of this test method is only appropriate for polish coated surfaces tested in accordance with this machine and test method. The use of this compliance criterion with other test methods, other test instruments, and other surfaces is improper, because they are not a part of the body of experiential data upon which the conformance criterion is based."

12. Ms. Gill testifies that she relies on information from a book written by William English titled Pedestrian Slip Resistance which Ms. Gill states is a "very comprehensive treatise on the whole science of slip resistance." Ms. Gill cites the book as support for her use of the 0.5 "threshold" value (24/16→24). The book should not be used as support for a "science based" opinion as the book is a non peer reviewed manuscript which was self published in 2003 by Mr. English. The information in this book was published prior to any of the research conducted at the MBRL by Dr. Powers.

13. As support for her use of the 0.5 "threshold" value, Ms. Gill also cites ASTM F1679 "Standard Test Method for Using a Variable Incidence Tribometer" (105/6→15). This standard does not mention a 0.5 "threshold" value.

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14. In summary, Ms. Gill has conducted slip testing, presented opinions and claimed expertise in an area in which she is not current. Her test results are of no use in determining how slippery the metallic utility cover is and her conclusion that the rim is unreasonably dangerous to pedestrian travelers is entirely unsupported by her analysis.

I declare under penalty of perjury under the laws of the state of Washington that the foregoing is true and correct.

DATED this 7th day of May, 2013, at Fresno, Fresno County, California.

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APPENDIX A.1.

EXHIBIT 1

PAPER

ENGINEERING SCIENCES

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Validation of Walkway Tribometers: Establishing a Reference Standard*

ABSTRACT: Tribometers are mechanical devices used to measure walkway coefficient of friction (COF) for the purpose of assessing slip risk. The purpose of this study was to define a tribometer reference standard and use it to assess the performance of various tribometers. Eighty subjects were randomly assigned to walk across one of four wet walkway surfaces (polished black granite, porcelain, vinyl composition tile, and ceramic tile) to establish the relative slipperiness of each surface. Eleven tribometers were subsequently used to measure and rank the COF of all four surfaces. Our results revealed that only four of the 11 tribometers (Wessex pendulum, Sigler pendulum, Mark II, and Mark III) met our compliance criteria by both correctly ranking all four surfaces and differentiating between surfaces of varying degrees of slipperiness. Our protocol demonstrates that human gait-based measures of slipperiness can be used to create reference standards against which tribometer measurements can be validated.

KEYWORDS: forensic science, walkway safety, walkway tribometer, slips, coefficient of friction, reference standard

Tribometers are mechanical devices used by the safety community to measure walkway surface coefficient of friction (COF) for the purpose of assessing the risk of slipping. Tribometers also are used by the flooring and footwear industries to assess product performance. Currently, over 30 different tribometer models using a wide range of mechanical designs and COF calculation methods are being used by these various industries (1–3). To date, no tribometer model or mechanical test to measure COF relevant to human ambulation has been universally accepted. The fact that the measurement of friction is a function of both the material being tested and the measuring system itself explains why several studies have shown that different devices yield different COF measurements for the same surface (4–15). For example, a study of nine tribometers demonstrated an extremely wide range of COF values for the same surface when tested under wet conditions (0.06–0.69) (14).

Inconsistent measurement is one of the reasons why every measurement device should have a reference standard against which to validate and calibrate its performance; however, no such reference standard exists for tribometers. The consensus standards organizations that oversee footwear and walkway safety have recently recognized the importance of developing a protocol for validating tribometers to verify their ability to assess the safety of footwear, floor products, and walkway surfaces (16,17).

In a previous publication, we introduced the concept of using human subject slip risk to create a reference standard against which tribometer measurements could be validated (14). In this prior study, human subjects ($N = 84$) walked across three different surfaces with and without a contaminant (six conditions). The number of slips recorded on each surface was used to establish the relative slipperiness of each surface condition. We then proposed two objective criteria to establish the validity of a given tribometer. First, a tribometer had to correctly rank the COF of the different surfaces in the order of slip risk as determined by the human subject walking trials. Second, the COF of the surfaces of varying slipperiness had to be statistically different from each other. Results revealed that only two of the nine tribometers tested (Tortus II and the Mark III) met the compliance criteria by both correctly ranking all six conditions and differentiating between surfaces of differing degrees of slipperiness. However, a criticism of this study was that two of the three surfaces were not standard walkway surfaces. Establishing a reference standard using atypical materials could preclude its use for the validation of tribometers normally used to measure the COF of flooring materials commonly encountered by pedestrians. A second limitation of our previous study was that both wet and dry surface conditions were used. Typically, slips do not occur under dry conditions. Using a protocol similar to our previous study (14), the current investigation sought to address the aforementioned limitations and define a walkway tribometer reference standard and assess its use by various tribometers.

Methods

Human Subject Testing

Subjects—Eighty subjects (23 males, 57 females) between the ages of 20 and 39 years (mean age 26.3 ± 4.8 years) were recruited

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for this portion of the study. All subjects were healthy and capable of independent ambulation. Subjects who reported any orthopedic injury, medical condition, or pregnancy were excluded from participation. Prior to testing, each subject signed an informed consent approved by the Institutional Review Board of the University of Southern California.

Floor Surfaces and Conditions—Four flat smooth surfaces were tested: polished black granite, porcelain, ceramic tile, and vinyl composition tile (VCT). Each surface consisted of a 0.6 × 1.2 m rectangle embedded in the center of a 10-m walkway. A sufficient amount of distilled water was applied to each surface to create a continuous film. For the black granite surface, Triton X-100 nonionic surfactant (Gallade Chemical, Santa Ana, CA) was mixed into the water (200-μL/500-mL) to avoid beading and improve wetting.

Procedures—All testing (tribometer and human subject) was performed at the Musculoskeletal Biomechanics Research Laboratory at the University of Southern California. The temperature and humidity in the laboratory during testing were 70°F and 34%, respectively. To rank the slipperiness of the different surfaces, subjects were randomly assigned to walk across one of the four floor surfaces (20 subjects per group). Several studies have shown that awareness of a potential slip condition and prior slip experience can lead to alterations in gait (18–20). Therefore, to limit gait adjustments that may have affected the slip trial outcome, subjects only were exposed to one surface. The four groups were similar in terms of age, height, and weight (Table 1).

To control for the influence of footwear, subjects were provided with a pair of Oxford-style shoes in their size. The soles of these shoes consisted of a smooth styrene butadiene rubber with a 75 Shore A hardness (Quabaug Corp., North Brookfield, MA). The soles represented the most common shoe bottom material used globally in the year 2001 (William Ells, Quabaug Corp., pers. comm.). Before each test session, the floor was swept for dust and both the floor panel and shoe soles were cleaned with 70% isopropyl alcohol.

During all walking trials, subjects were required to wear a fall-arresting harness attached to an overhead low-friction trolley that extended the length of the walkway. Subjects first performed several walking trials on a dry, nonslippery floor condition. These trials were used to adjust the subjects' starting position to ensure a clean foot strike on the target surface. The mean walking velocity for all trials was 2.09 ± 0.15-m/sec as determined via photoelectric triggers placed at both ends of the walkway.

To reduce awareness of which trial contained the test surface, subjects left the room for a similar period of time between each trial (c. 2 min). Subjects also wore goggles with the lower half blacked out and were instructed to look at a spot on the far wall as they traversed the walkway. Lighting was dimmed to minimize reflections from the wet surfaces, and a "spotter" at the far end of the laboratory gave the appearance that the test surface was near the end rather than the middle of the walkway. To eliminate the effect of prior experience, subjects were exposed to their assigned test surface for only one trial.

TABLE 1—*Subject characteristics mean (SD).*

	Black Granite	Porcelain	Ceramic	Vinyl Composition Tile
	$N = 20$	$N = 20$	$N = 20$	$N = 20$
Females/males	16/4	15/5	14/6	12/8
Age (years)	28.3 (5.7)	26.0 (5.2)	25.4 (3.7)	25.7 (4.1)
Height (cm)	167.8 (11.0)	165.0 (9.5)	169.3 (7.9)	170.8 (7.3)
Weight (kg)	63.5 (13.7)	62.5 (12.2)	67.5 (13.9)	70.6 (13.8)
Walking speed (m/sec)	2.05 (0.16)	2.15 (0.15)	2.05 (0.12)	2.12 (0.17)

Slip Definition During Walking—To confirm whether a slip occurred on a given surface, an 8-camera motion analysis system (Vicon; Oxford Metric Ltd., Oxford, U.K.) was used to capture human subject motion data at 120-Hz. Reflective markers were placed on the heel and second metatarsal head area on subjects' shoes. Heel slips were defined as a minimum 4 cm anterior displacement of the heel marker following the initial contact phase of gait (21). Toe slips were defined as any negative (posterior-directed) velocity of the toe marker before toe-off phase of gait (14). In all cases, digital video was used to confirm the presence of a slip.

Tribometer Testing

Tribometers—Eleven tribometers were used to measure the COF of the four surfaces (Table 2). One tribometer (BOT 3000) was tested using static and dynamic modes. Each tribometer was operated by an experienced user of that device, and testing followed protocols provided by the manufacturer or as set forth in applicable standards from ASTM International (West Conshohocken, PA). A second individual recorded the tribometer results, while a third individual monitored the testing protocol to ensure consistent technique and correct recording. The value measured by each tribometer was assumed to represent the COF measured by that tribometer unless the manufacturer specified the required use of a conversion factor.

Procedures—COF testing with the tribometers was performed on the four floor surfaces under the same laboratory conditions present at the time of the walking trials. The tribometer test order for measuring the four surfaces was randomly designated. The surface wetting protocol was the same as that used for the human subject portion of the study. Prior to testing, the test foot of each tribometer was cleaned and prepared according to manufacturer specifications. This procedure was repeated prior to the testing of each surface. The independent observer ensured that a continuous wet film was present on the test surface. The COF of each surface was measured four times, once in each orthogonal direction (i.e., 0°, 90°, 180°, and 270°) relative to the longitudinal axis of the walkway.

Data Analysis—Each human subject walking trial was classified as a no slip, toe slip, or heel slip. To test for differences in the type of slip that occurred on the four surfaces, a chi-squared test for homogeneity was performed on a 4 × 3 (floor surface × slip type) contingency table at a significance level of $\alpha = 0.05$.

To test for differences between the measured COF values for each surface, the mean and standard deviations of the COF values for each tribometer/surface combination were first calculated. For each tribometer, a one-way analysis of variance (ANOVA) was used to determine whether significant differences were present between the four surfaces. *Post hoc* tests were conducted using a Fischer least significant difference. The significance level for each ANOVA was $\alpha = 0.05$ and was not adjusted for multiple comparisons because the number of tribometers chosen for the study should not influence whether or not a specific tribometer identified the slipperiness of a specific pair of surfaces as significantly different.

TABLE 2—*Tribometer characteristics: tribometer name, type, and test foot material.*

Device	Operating Principle	Test Foot (Material/Size)
English XL*	Inclinable mast (pneumatic driven)	Neolite® (13 mm diameter)
BOT 3000†	Drag sled—motor driven	Leather (27.9 × 27.9 mm)
C1028‡	Drag sled—manually pulled	Neolite® (76 × 76 mm)
Tortus II§	Drag sled—motor driven	4S rubber (9.5 mm diameter)
Tortus III‖	Drag sled—motor driven	4S rubber (9 mm diameter)
Horizontal Pull Slipmeter*	Drag sled—motor pulled	Neolite® (13 mm diameter)
Wessex Pendulum**	Pendulum	4S rubber (76 × 2 mm)
Sigler Pendulum††	Pendulum	Neolite® (38 × 38 mm)
Mark I‡‡	Inclinable mast (gravity driven)	Neolite® (76 × 76 mm; nongrooved)
Mark II§§	Inclinable mast (gravity driven)	Neolite® (76 × 76 mm; grooved)
Mark III‖‖	Inclinable mast (spring activated)	Neolite® (76 × 76 mm; grooved)

*William English Inc., Alva, FL.
†Regan Scientific Instruments, Southlake, TX.
‡Smithers Scientific Services, Akron, OH.
§Severn Science Limited, Bristol, U.K.
‖Developed by Irvine/Liberty Mutual, no longer manufactured.
**Wessex Engineering Ltd., U.K.
††Developed by Percy Sigler and National Bureau of Standards, no current manufacturer.
‡‡No specific manufacturer.
§§Slip-Test, Spring Lake, NJ.

Comparison of Human Subject and Tribometer Ranking—As reported previously (14), the slipperiness ranking determined from the walking trials was considered the reference against which the tribometer-determined ranking was compared. The tribometer measurements were compared to the gait-based ranking using two criteria. Criterion #1: did a given tribometer rank the COF of the different surfaces in the same order indicated by the human subject results? Criterion #2: did a given tribometer statistically differentiate between surfaces with significantly different levels of slip risk?

Results

The results of the human subject walking trials are presented in Table 3. All four surface conditions were significantly different from each other with respect to levels of slipperiness ($p < 0.05$). Black granite had the largest number of slips ($N = 19$), the majority of which were heel slips ($N = 13$). Porcelain produced a mixture of heel slips ($N = 4$), toe slips ($N = 11$), and no slips ($N = 5$). VCT induced several toe slips ($N = 7$) but no heel slips. Ceramic tile did not produce any slips. Using these results, the surfaces were characterized as most slippery (black granite), moderately slippery (porcelain), less slippery (VCT), and least slippery (ceramic tile).

The distinction between the most slippery surface containing primarily heel slips and the moderately slippery surface containing primarily toe slips was based on the premise that toe slips are not hazardous for the walker because of where they occur in the gait cycle. Toe slips take place in late stance as weight is being transferred off the slipping limb to the support limb. In contrast, heel slips occur in early stance when weight is being transferred onto the slipping limb which increases the risk of a fall compared to a toe slip (14).

TABLE 3—*Slip results: walking trials.*

Surfaces	No Slips	Toe Slips	Heel Slips	Ranking
Black granite	1	6	13	Most slippery
Porcelain	5	11	4	Moderately slippery
VCT	13	7	0	Less slippery
Ceramic	20	0	0	Least slippery

VCT, Vinyl composition tile.

Across all tribometers and surfaces, COF measurements varied from a low of 0.05 ± 0.01 for the Wessex pendulum on black granite to a high of 0.94 ± 0.03 for the BOT 3000 (static mode) on ceramic tile. Within each surface, the most consistent range of COF values was observed on black granite (0.05–0.35) whereas the most varied range of COF values was observed on ceramic (0.24–0.94). Although all 11 tribometers were able to statistically differentiate levels of slipperiness between some of the surfaces, only six tribometers (Tortus III, Horizontal Pull Slipmeter [HPS], Wessex, Sigler, Mark II, and Mark III) were able to significantly differentiate all four surfaces (Criterion #2 in Table 4).

A comparison of the tribometer COF measurements to the gait-based ranking of surface slipperiness revealed that only four tribometers (Wessex, Sigler, Mark II, and Mark III) satisfied our validation criteria by both ranking the surfaces in the correct order (Criterion #1) and statistically differentiating the differing degrees of slipperiness between each of the four surfaces (Criterion #2). The remaining seven tribometers failed Criterion #1, Criterion #2, or both.

Two tribometers (BOT 3000 and Mark I) were able to rank the surfaces in the correct order of slipperiness but failed to statistically differentiate among them (Table 4). The BOT 3000 (static mode) was unable to differentiate between VCT and ceramic tile. In dynamic mode, the BOT 3000 could not statistically differentiate black granite and porcelain. The Mark I could not differentiate between porcelain and VCT. Two tribometers (Tortus III and HPS) passed Criterion #2 but failed Criterion #1 (Table 4). Both tribometers failed Criterion #1 by incorrectly ranking ceramic as being more slippery than VCT.

Three tribometers (English XL, C1028, and Tortus II) failed both validation criteria (Table 4). The English XL incorrectly ranked VCT as more slippery than porcelain thereby failing Criterion #1. Additionally, the English XL did not differentiate between these surfaces, thus failing Criterion #2. The C1028 incorrectly ranked ceramic tile as more slippery than VCT and also failed to differentiate between the two surfaces thereby failing both validation criteria. The Tortus II failed Criterion #1 by incorrectly ranking ceramic tile as more slippery than VCT. The Tortus II failed Criterion #2 by not differentiating between ceramic tile and VCT.

TABLE 4—*Coefficient of friction for the four surfaces assessed and the criteria met by the 11 tribometers mean (SD).*

Slipperiness	Surface	English XL	BOT 3000 (Static)	BOT 3000 (Dynamic)	C1028	Tortus:II	Tortus III	Horizontal Pull Slipmeter	Wessex	Sigler	Mark I	Mark II	Mark III
Most	Black granite	0.18 (0.01)	0.30 (0.06)	0.20 (0.01)*	0.22 (0.05)	0.35 (0.02)	0.14 (0.01)	0.32 (0.05)	0.05 (0.01)	0.13 (0.01)	0.21 (0.10)	0.18 (0.00)	0.20 (0.00)
Moderate	Porcelain		0.62 (0.09)	0.23 (0.02)*	0.44 (0.02)	0.47 (0.04)	0.21 (0.02)	0.61 (0.03)	0.19 (0.01)	0.16 (0.02)	0.42 (0.11)*	0.22 (0.00)	0.32 (0.02)
Less	VCT		0.85 (0.08)*	0.38 (0.05)					0.24 (0.01)	0.20 (0.02)	0.48 (0.06)*	0.31 (0.02)	0.37 (0.01)
Least	Ceramic	0.49 (0.01)	0.94 (0.03)*	0.74 (0.02)					0.49 (0.04)	0.42 (0.01)	0.67 (0.01)	0.69 (0.01)	0.63 (0.01)
	Criteria failed	1,2	2	2	1,2	1,2	1	1			2		

Criterion #1 = correct surface ranking; Criterion #2 = statistical differentiation between all surfaces.
Shaded areas denote incorrect ranking of surfaces for a given tribometer.
*Denotes failure to statistically differentiate surfaces.
VCT, Vinyl composition tile.

Discussion

The results of our tribometer testing are consistent with prior studies that have demonstrated that different tribometers give different COF values for the same surface (4–15). In the current study, wet porcelain was categorized as "moderately slippery" as 15 of 20 subjects slipped when walking across it; yet the range of COF measurements from the 11 tribometers spanned from 0.19 to 0.62 for this surface. This variability represents a problem to those in the walkway safety community who ascribe to the common approach of relating tribometer COF measurements to the required minimum (i.e., 0.21–0.26) for walking speeds in the range of 0.97–2.17-m/sec (22). As a result, the user of the tribometer that measured the wet porcelain COF as 0.19 would likely categorize the surface as very slippery because the surface supplies less friction than the pedestrian demand. The user of the tribometer that measured a COF of 0.62 might categorize that same surface as slip resistant as the measured COF far exceeds the required pedestrian demand. The wide range of tribometer COF readings underscores not only the need for a tribometer reference standard to be used for validation and calibration, but also the difficulty in ascribing a single safe threshold COF to a given floor surface to indicate the floor's potential for causing a slip.

The ability of the four surfaces used in the current study to statistically differentiate human subject slip risk on a continuum from most to least slippery demonstrates that this suite of materials can provide a means by which tribometer measurements can be compared and validated. Even after the criticisms directed at our earlier study were used in the design of the present investigation, very few of the tribometers tested produced acceptable results. Only four tribometers (Wessex, Sigler, Mark II, and Mark III) met our compliance criteria by correctly ranking all four surface conditions and differentiating between surfaces of differing degrees of slipperiness as established by the human subject walking trials.

The tribometers that passed our compliance criteria represent two different operating principles. The Sigler and Wessex are pendulum devices that measure the energy loss of a swinging test foot to derive COF values. The Mark II and Mark III are inclinable-mast tribometers designed such that the test foot strikes the surface at a known angle and speed. The devices are of similar design with the main difference being that the Mark II is gravity driven whereas the Mark III is spring activated. In addition, one distinguishing characteristic of the Mark II and Mark III is that they use grooved test feet (as recommended by the manufacturer). The grooves cut into the test foot (a 3 mm deep by 1.5 mm wide and spaced 5 mm apart) may better replicate the dynamics of a shoe heel with a tread pattern landing on a wet walkway surface compared to a smooth test foot. Additionally, a previous study has shown that the Mark II better approximates the peak impact force underfoot early in the gait cycle when slips are most likely to occur (15).

Contrary to our previous testing (14), the Tortus II did not pass either criterion in the current study. This motor-driven tribometer has a small test foot (9.5-mm diameter) that is held in contact with the surface under a fixed load as it slides across the surface. Other investigators have implicated the drag sleds' prolonged surface residence time as a cause of adhesion, leading to COF measurements on wet surfaces that are greater than or equal to slip resistant dry surfaces (9,12,23). This adhesion may account for the poor results of the other drag sled tribometers evaluated in our study (BOT 3000, Tortus III, HPS, and C1028).

As stated earlier, the statistically differentiated slip risk demonstrated by the four walkway surfaces used in the current study provides an objective foundation for the validation and calibration of tribometers. We believe that these four surfaces could define a reference standard that tribometer manufacturers could use to validate their devices by demonstrating that the instrument's COF measurements properly rank and statistically differentiate these surfaces. The tribometer supplier also could use the reference surfaces to establish reference COF values to be provided to tribometer users so that users could independently calibrate their instruments by verifying consistent results.

Because only one tribometer of each model was included in the current study, our results do not necessarily invalidate all the instruments of a particular model. For instance, while the English XL used in this study failed to pass both compliance criteria, subsequent testing of 15 English XL tribometers revealed that five passed both criteria (J. Flynn, unpublished data). This illustrates the importance of using a reference standard to assess the validity and accuracy of each individual instrument.

Summary

The results of the current study are consistent with previous studies in that different tribometers yield different COF values for a given surface. Our results reinforce the need for objective criteria to ascertain which tribometers accurately evaluate floor slipperiness and a pedestrian's risk of slipping. Our protocol demonstrates that human gait-based measures of slipperiness can be used to create reference standards against which tribometer measurements can be validated. Given that only four of 11 tribometers passed our validation criteria, care should be taken in the interpretation of tribometer measurements in determining the safety of various walkway surfaces.

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APPENDIX A.2.

EXHIBIT 2

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Assessment of Walkway Tribometer Readings in Evaluating 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 reference standard against which tribometer readings could be compared. First, human subjects ($N = 84$) were used to rank objectively the slipperiness of three different surfaces with and without a contaminant (six conditions). Second, nine tribometers were used to independently measure and rank surface slipperiness for all six conditions. The slipperiness ranking determined from the walking trials was considered the reference against which the tribometer measurements were compared. Our results revealed that only two of the nine tribometers tested (Tortus II and Mark III) met our compliance criteria by both correctly ranking all six conditions and differentiating between surfaces of differing degrees of slipperiness. These findings reinforce the need for objective criteria to ascertain which tribometers effectively evaluate floor slipperiness and a pedestrian's risk of slipping.

KEYWORDS: forensic science, tribometer, walkway safety, coefficient of friction, slip resistance

Tribometers are mechanical instruments that purport to measure the slip resistance of walkway surfaces. These devices are used in many industries including flooring, floor coating, and shoe to test product safety. In addition, tribometers are used in the property insurance and forensic-science communities to identify the causes and interventions for slip-and-fall events and claims. Currently, eight ASTM standards exist for six different tribometers and about 30 portable tribometers are available commercially (1–3). These tribometers operate using a range of mechanical designs from simple nonimpact drag sleds to more complex dynamic devices that attempt to simulate foot contact.

While many manufacturers claim that their tribometers can predict the probability of safe human ambulation on a walkway surface, numerous studies have shown that different tribometers yield different measurements of friction for the same flooring material (4–14). These friction differences approach an order of magnitude in some cases (5,9) and are often pronounced in the presence of a contaminant (15). These large intertribometer differences suggest that the value obtained from a given tribometer may or may not represent a measure of a pedestrian's risk of slip: a fact that potentially undermines the validity of all tribometers. Thus, objective criteria are needed to ascertain which tribometers effectively evaluate floor slipperiness and a pedestrian's risk of slipping.

In addition to having properties such as high repeatability (precision between device measurements with the same operator) and reproducibility (precision between device measurements from different operators), a tribometer should be able to rank correctly the slipperiness of different surfaces (Criteria 1) and differentiate between surfaces of differing degrees of slipperiness (Criteria 2). If a tribometer satisfies these compliance criteria, then a threshold slipperiness value for that tribometer has meaning, even if its absolute slipperiness value is not equal to or even linearly correlated to friction.

To determine whether a tribometer meets the above criteria, a series of surfaces of known slipperiness are required to function as reference standards against which tribometer readings can be compared. Unfortunately, no mechanical test to compute surface slipperiness relevant to human ambulation has been universally accepted. To resolve this problem, some researchers have used humans to evaluate subjectively the slipperiness of various combinations of floors, footwear, and contaminants by rubbing their shoe over a set of surfaces (16–21). Other researchers have recommended that dynamic human subject tests be used (22–24). As tribometers are ultimately tools to assess surface slipperiness for human locomotion, there is face validity to using the incidence of slip from human subject walking trials to quantify the relative slipperiness of different surfaces. Although this method does not quantify absolute slipperiness, it provides a potential means of validating tribometer readings over a range of slipperiness levels associated with slip events.

To date, only two studies have attempted to relate tribometer measurements to actual risk of slipping. Hanson et al. (23) created a gradient of available coefficient of friction (COF) to evaluate the relationship between tribometer measurements and actual slips with human subjects while descending a ramp. To create a gradient of slip resistance, the ramp angle and the application of contaminants to the walking surface were varied. While these authors were able to demonstrate that friction values obtained from a programmable slip resistance tester (PSRT) could be used to predict slip events, it should be noted that gait biomechanics while descending a ramp differs significantly from level walking (25).

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Therefore, the results of this study are difficult to extrapolate to slips on level surfaces. Similarly, Kulakowski et al. (12) correlated the measurements of one tribometer (NBS-Brungraber) to the results of human walking slip trials. These authors reported that 79% of slip events could be predicted based on knowledge of the subjects' utilized friction during walking and the friction values from the tribometer. A limitation of the studies conducted by Hanson et al. (23) and Kulakowski et al. (12) is that small sample sizes were utilized in each ($N = 5$), thereby limiting the generalizability of the results to the entire population.

Given the need for additional research in this area, the goal of this study was to assess the viability of using slip risk (as quantified during human subject walking trials) to create a reference standard against which tribometer readings could be compared. To achieve this goal, we conducted a two-part study. First, human subject slip events during walking were used to rank objectively the slipperiness of a suite of three different surfaces with and without a contaminant (six conditions). Second, nine tribometers independently measured and ranked the surface slipperiness for all six surface conditions. The human subject and tribometer rankings were then compared using the two criteria described above.

Methods

Human Subject Testing

Subjects—Eighty-four subjects (42 males, 42 females) between the ages of 22 and 38 years (mean age 25.9 ± 3.8 years) were recruited for this portion of the study. All subjects were healthy and capable of independent ambulation. Subjects who reported any orthopedic injury, medical condition, or pregnancy were excluded. Before testing, each subject signed an informed consent approved by the Institutional Review Board of the University of Southern California.

Floor Surfaces and Conditions—Three flat smooth surfaces were tested in both a dry and wet condition: a high-pressure laminate (HPL), which is a common high-density fiberboard flooring material; polytetraflouroethylene, which is a low-friction plastic polymer more commonly known as Teflon® (DuPont, Wilmington, DE); and an acetal material, which is a low-friction plastic polymer commonly referred to as Delrin® (DuPont). Each surface consisted of a 2′ × 4′ rectangular section embedded near the middle of a 10 m walkway. For the wet condition, sufficient water was applied to the surface to create a continuous film. A nonionic surfactant, Triton X-100 (Gallade Chemical, Santa Ana, CA), was mixed into the water (five drops/250 mL) to improve wetting and minimize the amount of water needed.

Procedures—All testing was performed at the Musculoskeletal Biomechanics Research Laboratory at the University of Southern California. The temperature and humidity in the laboratory at the time of testing were 70°F and 34%, respectively.

To rank the slipperiness of the different surfaces objectively, subjects were randomly assigned to walk across one of the six floor surface conditions (14 subjects per group). To ensure a balanced gender distribution within each group, males and females were randomized separately. The six groups were similar in terms of age, height, and weight (Table 1).

To control for the influence of footwear, subjects were provided a pair of Oxford-style shoes in their size. The soles of these shoes consisted of a smooth styrene butadiene rubber (SBR) with shore A hardness of 75 (mid-range). This soling represented the most common shoe bottom material used globally in the year 2001 (William Ells, Quabaug Corp., personal communication). Before each test session, the floor was swept for dust and both the floor panel and shoe soles were cleaned with 70% ethanol solution.

All subjects wore a fall-arresting body harness attached to an overhead low-friction trolley that extended along the length of the walkway. Subjects first performed three to six nonslip walking trials, followed by a single trial in which the floor panel of interest was inserted into the walkway. Subjects were instructed to walk briskly for all trials. The average walking velocity for all subjects was 2.18 ± 0.13 m/sec as determined by photoelectric light switches. Walking speed did not vary between the six groups (Table 1).

As awareness of a potential slip and prior slip experience can generate alterations in human gait (26–28), special attention was paid to minimizing these effects. To reduce awareness of which trial contained the test surface, subjects left the room for a similar period of time between all trials (*c.* 2 min). Subjects also wore goggles with the lower half blacked out and were instructed to look at a spot on the far wall as they traversed the walkway. Lighting in the laboratory was decreased to minimize reflections from the wet surfaces, and a "spotter" at the far end of the walkway gave the appearance that the test surface was near the end rather than the middle of the walkway. To eliminate the effect of prior experience, subjects were exposed to their assigned test surface only once.

Slip Definition During Walking—Immediately following each walking trial, subjects were asked whether they perceived a slip. If so, they were then asked whether it was a heel or toe slip, and where along the walkway the slip occurred. To confirm objectively whether a slip occurred, an eight-camera (120 Hz) Vicon Motion Analysis System (Oxford Metrics Ltd., Oxford, UK) was used to record the position of reflective markers (25 mm spheres) placed on the heel and the second metatarsal head regions of the shoes. Heel slips were defined as 10 mm or more of anterior translation of the heel marker during the loading or early midstance phase of the gait cycle. A toe slip was defined as the presence of a negative (posterior) velocity of the toe marker before toe off. In all cases, the video data agreed with the subject's perception of a slip.

Tribometer Testing

Tribometers—Nine tribometers were used to measure the COF of the six surfaces (Table 2). Each tribometer was operated by an

TABLE 1—*Subject characteristics/mean (SD).*

Surfaces	Dry HPL	Dry Delrin®	Dry Teflon®	Wet HPL	Wet Delrin®	Wet Teflon®	Average
N	14	14	14	14	14	14	84
Age (years)	27.7 (4.0)	25.4 (2.6)	25.4 (2.8)	24.5 (2.5)	26.9 (5.0)	24.6 (2.3)	25.8 (3.5)
Height (cm)	171.1 (6.9)	171.2 (9.6)	171.1 (10.3)	168.3 (6.3)	170.4 (5.8)	170.8 (8.2)	170.5 (7.8)
Weight (kg)	69.9 (11.1)	65.5 (12.0)	71.8 (17.5)	67.5 (14.4)	67.4 (12.5)	68.3 (10.3)	68.4 (13.0)
Velocity (min/sec)	2.19 (0.08)	2.19 (0.19)	2.16 (0.18)	2.20 (0.11)	2.16 (0.12)	2.20 (0.11)	2.18 (0.13)

HPL, high-pressure laminate.

TABLE 2—*Tribometer name, type, and test foot material.*

Device	Operating Principle	Test Foot Material/Size
Horizontal pull slipmeter* (HPS)	Drag sled—motor pulled	Neolite® Test Liner† (NTL) (3) 13 mm diameter
C 1028‡	Drag sled—manually pulled	NTL 76 mm × 76 mm
Tortus II§	Drag sled—motor driven	Four S rubber¶ 9.5 mm diameter
Universal walkway tester‖ (UWT)	Drag sled—motor driven	NTL 28 mm × 28 mm
Sigler Pendulum**	Pendulum	NTL 38 mm × 38 mm
Wessex Pendulum††	Pendulum	Four S rubber 76 mm wide
Mark II‡‡	Articulated strut—gravity driven	NTL 76 mm × 76 mm grooved§§
Mark III‡‡	Articulated strut—spring activated	NTL 76 mm × 76 mm grooved§§
English XL¶¶	Variable incidence—pneumatically driven	NTL 32 mm diameter

*Developed by Irvine/Liberty Mutual, no longer manufactured.
†Smithers Scientific Services, Akron, OH.
‡No specific manufacturer.
§Severn Science Limited, Bristol, UK.
¶Standard simulated shoe sole, developed by Rubber & Plastics Research Association UK.
‖National Floor Safety Institute, Southlake, TX.
**Developed by Percy Sigler and National Bureau of Standards, no current manufacturer.
††Wessex Engineering Ltd., UK.
‡‡Slip-Test, Spring Lake, NJ.
§§Based on manufacturer's recommendations grooves were cut into test foot approximately 3 mm deep, 1.5 mm wide with lands 5 mm across.
¶¶William English Inc., Alva, FL.

experienced user of that device, and testing was performed according to the manufacturer's instructions or applicable standard. A second individual recorded the tribometer test results, while a third individual oversaw the testing protocol to ensure consistent technique and correct recording. The value measured by each tribometer was assumed to represent the COF measured by that tribometer and no distinction was made between measurements of static, transitional, and dynamic COF.

Procedures—Tribometer testing was conducted first on the three dry surfaces and then on the three wet surfaces. Test order was randomized separately within the dry and wet surfaces. 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 COF was measured four times: once in each of four orthogonal directions, i.e., at 0, 90, 180, and 270° relative to the longitudinal axis of the walkway.

Data Analysis

Each human walking trial over one of the six test surfaces was classified as a No Slip, Toe Slip, or Heel Slip. To test for differences in the type of slip (no, toe, or heel) that occurred on the six surfaces, a χ^2-test for homogeneity was performed on the 6 × 3 (floor condition × slip type) contingency table. *Post hoc* analyses were then performed using simple 2 × 3 χ^2 comparisons to identify homogeneous groups of surfaces (i.e., surfaces that the walking tests did not identify as being significantly different).

To test for differences between the measured friction values for each surface, the mean and standard deviation of the friction values for each tribometer/surface combination were first calculated. For each tribometer, a one-way analysis of variance (ANOVA) was used to determine whether significant differences were present between the six surfaces. *Post hoc* tests were run using a Fischer least significant difference (LSD) test to identify both homogeneous groups of surfaces and surfaces that were significantly different from one another according to that tribometer.

The omnibus χ^2 analyses was evaluated nondirectionally at a significance level of $\alpha = 0.05$. The significance levels for the nondirectional *post hoc* χ^2-tests were adjusted for the number of *post hoc* comparisons using a Bonferroni adjustment. The significance level for each ANOVA was $\alpha = 0.05$ and was not adjusted because the number of tribometers chosen for the study should not influence whether or not a specific tribometer identified the slipperiness of a specific pair of surfaces as significantly different.

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 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? Criteria 2 could only be applied to surface conditions that generated a combination of no, toe, and/or heel slips. It could not be applied to distinguish between surfaces that generate either no slips or all heel slips.

Results

The results of the human subject walking trials are presented in Table 3. Dry HPL, dry Delrin®, and wet HPL did not produce any slips and were characterized as being "not slippery" (not slippery group). Although wet Delrin® and wet Teflon® produced 10 and 13 heels slips, respectively, one was not more slippery than the other ($p = 0.77$) and thus both were characterized as being "very slippery" (very slippery group). Dry Teflon®'s mix of no slips and toe slips was more slippery than the three surfaces in the not slippery group ($p < 0.0001$) and less slippery than the two surfaces in the very slippery group ($p < 0.005$). The intermediate level of slipperiness demonstrated by dry Teflon® was therefore designated "slippery" (slippery group).

The distinction between the very slippery category containing primarily heel slips and the slippery category containing primarily toe slips was based on the fact that toe slips were interpreted as less ominous for the walker because of where they occur in the gait cycle. For example, toe slips take place in late stance as weight is being transferred to the contralateral (i.e., forward) limb. In contrast, heel slips occur in early stance when weight is be transferred to the lead limb. Therefore, a heel slip results in forward acceleration of the weight-bearing limb, which results in a

TABLE 3—*Number of slip events on the six surfaces.*

Surfaces	No Slips	Toe Slips	Heel Slips	Group
Dry HPL	14	0	0	Not slippery
Dry Delrin®	14	0	0	
Wet HPL	14	0	0	
Dry Teflon®	6	8	0	Slippery
Wet Delrin®	2	2	10	Very slippery
Wet Teflon®	0	1	13	
Total	50	11	23	$N=84$

HPL, high-pressure laminate.

more unstable situation (i.e., the base of support is moving away from the body center of mass).

All nine tribometers measured significantly different friction values between at least some of the surfaces ($p<0.0001$; Table 4). *Post hoc* testing revealed that the English XL discriminated all six surfaces, whereas the Wessex, Sigler, horizontal pull slipmeter (HPS), and universal walkway tester (UWT) resolved only four distinct friction levels among the six surfaces (Table 4). Across all tribometers and surfaces, friction measurements varied from a low of 0.06 ± 0.02 for the English XL on wet Delrin® to a high of 2.06 ± 0.28 for the Tortus II on dry HPL. Within the six surfaces, the most consistent range of friction values (0.26–0.48) was observed on dry Teflon® and the most varied range of friction values (0.66–2.06) was observed on dry HPL. A comparison of the tribometer measurements of friction to the gait-based ranking of surface slipperiness showed that two tribometers (Tortus II and Mark III) met our two criteria by correctly ranking the surfaces and being able to differentiate between surfaces of different degrees of slipperiness (Table 4). Four tribometers (Mark II, English XL, Wessex, and Sigler) satisfied criteria 2 and missed fulfilling criteria 1 by reversing the ranking order of two surfaces (Table 4).

Three tribometers (C 1028, HPS, and UWT) were unable to distinguish a difference between wet HPL and wet Delrin®, which were two surfaces that demonstrated significant differences in the risk of slip in the walking trials. These three tribometers did not meet either of the compliance criteria (Table 4).

Discussion

Tribometers are routinely used to assess the safety of pedestrian walkway surfaces. The importance and need for developing a biomechanical-based test method for evaluating the validity of tribometers has been recognized previously by investigators and has been gaining momentum within consensus standards organizations with an interest in walkway and footwear safety (23,29,30). Our experimental protocol demonstrated that a gait-based system can be used to create reference standards against which tribometer measurements can be compared.

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 (4–14). For example, wet Delrin® was categorized as being very slippery because of its ability to cause 12 of 14 subjects to slip; yet, the tribometers measured a range of COF from 0.06–0.69 for this surface. This extremely wide range underscores the impossibility of ascribing to a floor surface a single number to indicate its potential for causing a slip, a practice all too common in the standards writing process in the field of walkway and product safety. Unless all tribometers mimic the critical biomechanical parameters between the sole bottom, contaminant, and floor at heel strike, COF values will continue to be highly dependent on the test method used.

The wide range of COF values is no surprise, given the various operational principles for the selected tribometers (Table 1), not to mention, no tribometer has yet been developed that accurately models the kinematics and kinetics of the foot–floor interaction. The "classic" laws of friction formulated in the 17th century stated that COF is independent of contact area and velocity; however, these laws are not obeyed by either rubber polymers from which most tribometer test feet are constructed or the materials commonly used in flooring (31). In addition, the magnitude of the load, loading rate, pressure, and time of contact between two surfaces also influence COF results in the presence of rubber and plastic polymers. Chang et al. (32) provide an excellent review of such friction mechanisms during the measurement of slipperiness.

In the current study, only two of the nine tribometers tested (the Tortus II and Mark III) met our compliance criteria by correctly ranking all six conditions and differentiating between surfaces of differing degrees of slipperiness as established by the walking trials. The Tortus II is a drag sled-type tribometer whose friction slider is held in contact with the floor surface under a fixed load. The self-propelled machine moves forward at a constant velocity and the deflection of the friction slider is measured by a strain gauge. The device averages the surface's COF over a 20-cm distance. One noteworthy exception to the Tortus' ability to meet our compliance criteria was the high COF (2.06) and standard deviation (0.28) computed from its four measurements on the dry HPL. High COF results are not unusual with this device on certain dry surfaces. The phenomenon is likely explained by an affinity or adhesion between the device's test foot made of 4S rubber (Rubber & Plastics Research Association, UK) and the dry HPL tile.

The overall performance of the Tortus II was in direct contrast to the performance of the three other drag-sled tribometers (HPS, UWT, and C 1028), which failed to meet either of our criteria for a

TABLE 4—*Coefficient of friction for the six surfaces measured and the criteria met by the nine tribometers.*

Group	Surface	Tortus II	Mark III	Mark II	English XL	Wessex	Sigler	C 1028	HPS	UWT
Not slippery*	Dry HPL	2.06 (0.28)	0.67 (0.03)	0.80 (0.01)	0.86 (0.03)	0.71 (0.04)	0.66 (0.02)	0.76 (0.04)	0.79 (0.03)	1.00 (0.00)
	Dry Delrin®	1.10 (0.13)	0.69 (0.04)	0.84 (0.08)	0.51 (0.09)	0.70 (0.04)	0.60 (0.07)	0.84 (0.01)	0.52 (0.03)	1.00 (0.00)
	Wet HPL	0.56 (0.03)	0.59 (0.02)	0.52 (0.01)	0.21 (0.01)	0.30 (0.01)	0.20 (0.02)	0.64 (0.03)	0.57 (0.03)	0.72 (0.08)
Slippery	Dry Teflon®	0.47 (0.03)	0.30 (0.02)	0.26 (0.01)	0.27 (0.02)	0.40 (0.01)	0.33 (0.01)	0.48 (0.03)	0.40 (0.05)	0.36 (0.03)
Very slippery	Wet Delrin®	0.32 (0.01)	0.25 (0.00)	0.33 (0.02)	0.06 (0.02)	0.19 (0.01)	0.12 (0.01)	0.59 (0.05)	0.52 (0.03)	0.69 (0.04)
	Wet Teflon®	0.31 (0.01)	0.19 (0.02)	0.19 (0.02)	0.12 (0.02)	0.19 (0.03)	0.12 (0.03)	0.42 (0.02)	0.31 (0.02)	0.30 (0.01)
	Criteria met	1,2	1,2	2	2	2	2	—	—	—

*No determination could be made from the walking trials as to the relative slip resistance between dry HPL, dry Delrin®, and wet HPL as no slips were recorded on these surfaces. The ordering of these three surfaces in column #2 is one of convenience.

Column #2 shows the rank order of the surfaces from most to least slip resistance as determined by the walking trials.

Combined and connected boxes highlight homogeneous groups.

HPL, high-pressure laminate; HPS, horizontal pull slipmeter; UWT, universal walkway tester.

compliant tribometer. In particular, these three tribometers failed to differentiate between wet and dry Delrin®, which were widely divergent in creating risk of slip based on the walking trials. This finding is consistent with the observations of other investigators who have implicated drag sleds' prolonged surface residence time in creating the phenomenon of sticktion (i.e., surface-tension adhesion) (11,12,33). In the presence of sticktion, tribometers often measure a wet slippery surface as having the same or greater COF compared with a dry slip-resistant surface. Determining why the Tortus II did not appear to experience the sticktion phenomenon is beyond the scope of this research.

Three of the tribometers (English XL, Wessex, and Sigler) failed the first criteria by incorrectly ranking the wet HPL surface as being more slippery than dry Teflon®. It is possible that the effective mass of the test feet on these three devices at surface impact may be too low, thus allowing hydroplaning of the test feet in the presence of a liquid contaminant (wet HPL) compared with the dry Teflon® condition. The Mark II experienced a similar problem in meeting the first criteria in that it incorrectly ranked dry Teflon® as being more slippery than wet Delrin®.

The selection of tribometers for this study was one of convenience and availability. While we believe that the study includes the most commonly used portable tribometers in the United States, we had no usage data to support this premise. We also made no attempt to establish the reproducibility or accuracy of the tribometers. The selection of surface materials was based on our aim of developing a suite of materials that not only spanned a wide range of slip resistance during walking but could also be easily obtained and modified for use within a gait laboratory.

Direction of Future Research

The plastics (Teflon® and Delrin®) utilized in this study are not typical walkway surfaces and their material properties may diverge from those of surfaces more typically encountered. Consequently, future research should include more frequently used walkway materials if controlled manufacturing processes and continuous supply can be secured.

In order to formulate a material suite with a continuum of slip resistance (as opposed to a binary slip/no slip system), future experiments should incorporate more intermediate surfaces that, when presented to walking human subjects, may or may not cause a slip. Dry Teflon® with its ability to cause toe slips in the walking trials functioned as such a surface in the current study. Because the utilized COF at toe off is slightly higher than at heel strike during normal ambulation, we believe the toe slips recorded on dry Teflon® defined that surface as having a slip resistance in between the very slippery surfaces that caused primarily heel slips and the not slippery surfaces that caused no slips. The challenge is to identify more surfaces with and without contaminants that perform in this intermediate range in order to expand and refine a gait-based system for future tribometer validation.

This study investigated the biofidelity of tribometers under walking conditions only. As many slips and falls occur during more strenuous actions such as pushing a load or running, future research should incorporate tasks with a higher friction demand in order to evaluate a tribometer's ability to assess safety over a broader range of activities.

Conclusions

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 two of the nine tribometers tested (the Tortus II and Mark III) met our compliance criteria by both correctly ranking all six 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. This experimental protocol demonstrates that gait-based measures of slipperiness can be used to create reference standards against which the output of tribometers can be compared.

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APPENDIX A.3.

EXHIBIT 3

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The development of a universal approach to testing of walkway slip resistance in the U.S.

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Abstract. The measurement of walkway slip resistance is required to assess the risk of slipping. Unlike other countries, the U.S. has not decided upon a single approach to the measurement of slip resistance. Several types of tribometers are available to measure slip resistance however, the measured value of the slip resistance of a given surface has been found to be tribometer specific. The introduction of ASTM International Standard F2508 Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces, has produced a method which allows validation of each type of tribometer and the values generated during testing.

Keywords: Tribometer, Slip, Walkway safety, Slip resistance

1. Introduction

The measurement of walkway slip resistance is necessary to assess the risk of slipping. In the U.S., there has been considerable discussion, debate, and controversy regarding the selection of a definitive test method and apparatus for determining walkway slip resistance. Unlike several other countries, there has never been a single approach to such measurement and many different types of tribometers are used. No tribometer has been accepted which is able to measure slip resistance such that the measurements can be definitively related to human ambulation. The use of several different types of tribometers is problematic in that, when metering a walkway surface, the measurements generated have been found to vary with the tribometer used. This is not unexpected as the measurements are a function of the material being tested, the test foot material and the specific tribometer[2-9].

Over the past 10 years, ASTM International, a consensus standards making organization, has worked to develop a slip resistance test standard for walkway surfaces that can be used to validate the use of any tribometer. In 2011, ASTM International published F-2508 Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces[1]. This standard practice is accompanied by an adjunct consisting of four tiles. The tiles are reference surfaces with surface slip resistance properties defined by human ambulation studies. Through the use of the F-2508 Standard Practice and the reference tiles, it can be determined whether or not a specific tribometer can produce valid measurements of the slip resistance of a walkway surface. At the same time, a method is provided by which the values of slip resistance generated from tribometric-testing of a walkway surface can be related to human ambulation[5,9].

2. Methods

With the acceptance of the use of several types of tribometers, it was necessary to develop a method for

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an objective evaluation of tribometer performance. To that end, reference surfaces were selected for tribometer testing. Four types of tiles were selected for testing. The tiles were polished black granite, porcelain, ceramic and vinyl composition tile (VCT). To rank the tiles in order of slip resistance, testing was conducted at the University of Southern California Musculoskeletal Biomechanics Laboratory. Eighty subjects were recruited to walk across the tiles and the subjects were monitored using an 8-camera Vicon motion analysis system. The tiles were wetted prior to each trial. All slips were recorded and using the number of slips per tile, the tiles were ranked in order of slip resistance. The polished black granite was most slippery and was followed in decreasing order by porcelain, VCT and ceramic[9].

With the availability of the reference surfaces, ASTM International Committee F-13 Pedestrian Walkway Safety and Footwear, created ASTM International Standard Practice F-2508. The standard involves using the reference tiles to validate tribometer performance. In order for the performance of a tribometer to be considered valid, the tribometer must satisfy two criteria. It must be able to statistically differentiate between the surfaces of the four reference tiles. The tribometer must also be able to rank the slip resistance of the tiles in the same order as that generated by the human subject testing at the USC Musculoskeletal Biomechanics Laboratory.

If the tribometer can differentiate between the tiles and rank the surfaces in the correct order, the testing of the reference tiles can provide tribometer specific slip resistance values for the four different reference surfaces. The values for slip resistance generated during testing of the reference surfaces can be used as benchmarks for the testing of an unknown surface as the validity of the values can be traced back to the human subject testing. If a surface is measured and is found to have a slip resistance value of 0.4, the value only has meaning with respect to the results obtained from testing the reference tiles. If, when testing the reference tiles, values from the polished black granite were close to 0.4, then 0.4 would indicate a slippery surface. If however, testing the non-slip surface of the ceramic tile generated a value of 0.4, a value of 0.4 would indicate a non-slippery surface. It is possible that two tribometers testing the same reference tiles will get very different values. The values obtained from the testing of the reference tiles and the interpretation of those values are tribometer specific [3,9].

The F-2508 Standard Practice is intended for the use of the manufacturer of each type of tribometer as well as the end user. The manufacturer conducts Walkway Tribometer Validation Testing while the end user conducts Walkway Tribometer Calibration Testing.

When conducting the Walkway Tribometer Validation Testing, forty tests are conducted on each tile. Prior to testing, each tile is wetted. The tiles are tested in four orthogonal directions. The results of testing are used to calculate the mean, standard deviation, standard error of the mean and the 95th percentile confidence interval. The results of the analysis should show that the tribometer was able to produce significantly different results when measuring the slip resistance of the each of the surfaces. Significant difference is determined through the use of paired *t*-tests ($p < 0.05$) for all adjacently ranked reference surfaces.

When the end user is conducting Tribometer Calibration Testing, sixteen tests are to be conducted on each reference surface. The results of the testing are used to calculate the mean. Calibration requires the mean to be inside the 95th percentile confidence interval as reported by the tribometer manufacturer.

End user results are reported based upon a specific tribometer and test foot combination. Calibration is therefore required whenever a new test foot is employed. Calibration is also required on an annual basis or whenever the tribometer is repaired[1].

3. Discussion

The human subject testing at the USC Musculoskeletal Biomechanics Laboratory and the resultant creation of the ASTM International standard F-2508 are a significant movement in the direction of validation of tribometers and the measurements of walkway slip resistance. It must be noted that the standard does not state that the validation will hold for all combinations of walkway surfaces and test foot materials.

The ASTM F-13 Committee continues to move forward in the area of tribometry. The Committee is currently working on a new standard and a new guide. The first is the Standard Practice for Certifying Walkway Tribometers while the second is the Standard Guide to Walkway Auditor Qualifications.

The Standard Practice for Certifying Walkway Tribometers requires a Walkway Tribometer Validation Report as defined in Standard F-2508. It also requires the manufacturer to conduct a precision study through the ASTM International Interlaborato-

ry Study office (ILS). The precision study looks at both tribometer repeatability and reproducibility. The repeatability is determined through the use of a single tribometer and single operator. The tribometer is used to test the reference tiles and focuses on the repeatability of the measurements from each specific reference tile.

Reproducibility involves the use of a minimum of six tribometer/operator combinations. Each tribometer/operator measures the slip resistance on the same group of four reference tiles. The data is used to determine the expected data spread between tribometer operators.

The precision study has no required minimum range for either repeatability or reproducibility. It simply provides a confidence level for those looking at data from different tribometers of the same type.

The Standard Guide to Walkway Auditor Qualifications is intended to provide an overview of the materials to be included in any program used to certify walkway auditors. The guide is designed to define a minimum competence level for those involved in walkway auditing.

4. Summary

ASTM International has created Standard F-2508 and a program within Committee F-13 which can be used to validate the use of a specific tribometer or tribometer type. The standard further can provide meaning to the values of slip resistance measurements when using a validated tribometer and the associated reference tiles.

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APPENDIX A.4.

EXHIBIT 4

Designation: F2508 – 11

Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces[1]

This standard is issued under the fixed designation F2508; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice is intended to establish the parameters for validation and calibration of walkway tribometers.

1.2 This practice provides a walkway tribometer supplier with a procedure and suite of reference surfaces to validate his walkway tribometer by properly ranking and differentiating the surfaces.

1.3 This practice provides the user of a walkway tribometer with a procedure and suite of reference surfaces to test calibration of his instrument.

1.4 This practice describes the necessary materials, specifications, and the cleaning process for reference materials, as well as the requirements for the validation of a supplier's walkway tribometer and calibration of a user's walkway tribometer.

1.5 This practice applies to walkway tribometers without reference to the nature of the scale of the readings produced by them. The scale used in the reports of validation and calibration must be the same, and are to be those of the instrument or defined for the instrument.

1.6 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only and are not considered standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1349 Practice for Rubber—Standard Temperatures for Testing

D3244 Practice for Utilization of Test Data to Determine Conformance with Specifications

F1646 Terminology Relating to Safety and Traction for Footwear

3. Terminology

3.1 *Definitions*—For terms used in this practice not identified herein, refer to Terminology F1646.

3.1.1 *paired t-test, n*—a test of statistical significance based on the use of student's *t*-distribution and used to compare two sample means (see Appendix X2).

3.1.2 *supplier, n*—any individual, agent, company, manufacturer, or organization responsible for the walkway tribometer prior to receipt by the user. **D3244**

3.1.3 *test foot, n*—shoe bottom material or surrogate mounted on the walkway tribometer that comes into contact with the surface being tested.

3.1.4 *walkway tribometer, n*—any apparatus used to measure the frictional forces acting at an interface between a walkway surface and shoe material.

3.1.4.1 *Discussion*—A judgement of the adequacy of these frictional forces acting on a walkway surface/shoe surface interface is the basis for an assessment of slip properties relative to human locomotion.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration, n*—the set of operations that establishes, under specified conditions, the relationship between the values obtained by a walkway tribometer and the corresponding supplier reference values.

3.2.2 *reference surfaces (RS's), n*—specified materials, identified in Section 7, that have an experimentally demonstrated slip properties for a select population of pedestrians and serve as references for walkway tribometer measurements.

3.2.3 *validation, n*—the set of operations that establishes, under specified conditions, the proper ranking and differentiation of reference surfaces by a walkway tribometer.

[1] This practice is under the jurisdiction of ASTM Committee F13 on Pedestrian/Walkway Safety and Footwear and is the direct responsibility of Subcommittee F13.10 on Traction.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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4. Summary of Practice

4.1 This practice establishes a procedure to: *(1)* validate walkway tribometer models against a human gait-based reference system, and *(2)* calibrate each individual walkway tribometers of a validated model against published suppliers' reference values (as defined in 9.1, Eq 4).

4.2 This practice provides for validation and calibration of walkway tribometers as a means of verifying their relationship to reference surfaces and verifying a particular device continues to produce consistent results.

4.3 The method of ranking walkway surface slip properties using a limited population of ambulating human subjects is supported by a peer-reviewed study.[3]

4.4 Validation consists of a series of 40 tests on each reference surface from this practice. A walkway tribometer model is considered valid if it ranks the four reference surfaces from this practice in the proper order with statistically significant differentiation between results obtained for each surface. Validation is intended to be accomplished for each walkway tribometer model when it is initially introduced and is to be accomplished by or on behalf of the supplier and made available to each user.

4.5 Calibration for a specific walkway tribometer requires a series of 16 tests on each of the reference surfaces from this practice. A specific walkway tribometer is considered within calibration if the bias of the mean test values for each surface falls within the 95 % confidence interval for the walkway tribometer model as established by the validation tests (as defined in 9.1, Eq 4).

5. Significance and Use

5.1 To be meaningful, walkway tribometer results must correlate the slip characteristics of a surface or contaminant, or both, to the actual propensity for human slips. To achieve this goal, walkway tribometer models must be validated against a standard with relevance to human ambulation.

5.2 This practice prescribes a series of reference surfaces with known relative slip potential ranging from very high to low (as defined by laboratory conditions only) upon which walkway tribometer models can be validated. The relative slip potential of each reference surface was established from human subject walking trials.[3]

5.3 The following should be considered in applying the validation and calibration obtained by this practice:

5.3.1 The scientific study upon which the validation process is based was conducted with a select population of young adults (mean age 26 years) who were free from gait deviations while walking in a straight path on a level surface with a mean walking velocity of 2.18 m/s. This walking velocity is faster than the average walking velocity for the general population which includes a much wider age range with greater variability; thus, the study sample population of pedestrians and conditions is not representative of the larger general population of pedestrians.

5.3.2 All subjects walked in Oxford-style shoes whose soles were constructed of smooth styrene butadiene rubber (SBR) with 75A Shore hardness. The shoe style and sole material is not representative of all combinations available in the marketplace.

5.3.3 The reference surfaces defined in this practice are not representative of all walkway surfaces. The outcome of the validation practice reflects performance on the type of reference surfaces and surface conditions defined in this practice only. Validation and calibration of a walkway tribometer as defined by this practice does not imply validation and calibration under all combinations of test foot materials and walkway surfaces.

5.3.4 The validation and calibration procedure defined by this practice is not intended to establish a "safe threshold" value for any walkway surface.

6. Apparatus

6.1 The walkway tribometer shall be free of defects and operational throughout its range. Refer to the walkway tribometer instruction manual to ensure proper operation and instrument condition before the validation and calibration process.

6.2 *Test Foot Designation and Condition*:

6.2.1 The supplier must provide test foot material, dimension, storage, and service life specifications. The specifications shall be sufficient to permit procurement of an exemplar test foot.

6.2.2 A uniquely numbered test foot, meeting the supplier's material and dimensional specifications shall be provided with the walkway tribometer being tested.

6.2.2.1 The calibration results shall apply only to the walkway tribometer/test foot combination tested.

6.2.3 Prepare the test foot as prescribed by the walkway tribometer supplier or by a fully documented procedure included in the validation or calibration report.

7. Reference Surfaces (RS's)[4]

7.1 *Reference Surfaces*:

7.1.1 *RS A*—Polished black granite whose surface beneath the test foot is covered with a continuous film of 0.04 % by volume solution of Triton X-100[5] (nonionic surfactant) in distilled water (that is, 200 µL of Triton X-100 per 500 mL of distilled water).

7.1.2 *RS B*—Porcelain whose surface beneath the test foot is covered with a continuous film of distilled water.

7.1.3 *RS C*—Vinyl composition tile whose surface beneath the test foot is covered with a continuous film of distilled water.

7.1.4 *RS D*—Ceramic whose surface beneath the test foot is covered with a continuous film of distilled water.

7.2 Each RS shall be permanently marked to designate its reference class (that is, "A", "B", "C", "D").

[3] Powers, C. M., Blanchette, M. G., Brault, J. R., Flynn, J., and Siegmund, G. P., "Validation of Walkway Tribometers: Establishing a Reference Standard," *Journal of Forensic Sciences*, Vol. 55, No. 2, March 2010, pp. 366–370.

[4] Available from ASTM International Headquarters. Order Adjunct No. ADJF2508. Original adjunct produced in 2011.

[5] The sole source of supply of the apparatus known to the committee at this time is Gallade Chemical, Santa Ana, CA. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

7.3 Reference surfaces shall be stored in a manner that prevents deformation and contamination.

7.4 Reference surfaces should not be used for validation or calibration testing after 5 years from date of purchase.

8. Procedure

8.1 *Environment*—The validation and calibration test shall be performed at a humidity level of 50 ± 5 % and a temperature range of 23 ± 2°C (73.4 ± 3.6°F) (derived from Practice D1349).

8.2 *Reference Surface Preparation*—The reference surface shall be free from visible dents, cracks, voids, or other significant blemishes.

8.2.1 *Cleaning*:

8.2.1.1 No surface treatment except as specified in this section is permitted.

8.2.1.2 Prepare a 0.05 % by volume solution of liquid sodium lauryl sulfate in distilled water (that is, 250 µL of sodium lauryl sulfate per 500 mL of distilled water).

8.2.1.3 Dip a clean soft-bristled nylon brush in the cleaning solution and gently scrub in a circular pattern the entire reference surface for a minimum of 10 s. Reapply the cleaning solution and repeat the minimum 10-s scrubbing two times.

8.2.1.4 Rinse the surface thoroughly with distilled water, ensuring that no visible suds or soap residues remain.

8.2.1.5 Dry the surface with dry and oil-free compressed air or air dry if compressed air is not available. The reference surface shall exhibit no visible moisture film or droplets.

8.2.1.6 Prepare an ethanol solution containing equal parts denatured ethanol in distilled water.

8.2.1.7 Dip a clean soft-bristled nylon brush, different from that used in 8.2.1.3, in the ethanol solution and gently scrub the reference surface for 10 s.

8.2.1.8 Dry the reference surface with dry and oil-free compressed air or air dry if compressed air is not available. Any visible contamination remaining after this step will disqualify the reference surface for use.

8.2.1.9 Ensure that handling of the reference surface does not introduce contaminants to the surfaces, including exposing the surfaces to contact of human skin.

8.2.1.10 The cleaning procedure should be performed before each testing session.

8.3 *Reference Surface Mounting*—Mount the reference surface onto a flat and rigid substrate that prevents movement of the reference surface parallel to the test plane of the walkway tribometer during testing. Select a substrate that will not deform during wet testing.

8.4 *Walkway Tribometer Validation Testing*—Using the walkway tribometer being validated and the test foot prepared in 6.2.3, perform 40 tests in accordance with a uniquely identifiable version of the walkway tribometer supplier's operating instructions or any other formal procedure in the test area of each of the four reference surfaces that have been prepared in accordance with 8.2. Of the 40 tests, perform 10 in each of 4 orthogonal directions, that is, at 0, 90, 180, and 270° relative to an arbitrarily defined direction on the reference surface. Record the results of all tests as specified in Section 10.

9. Analysis of Results and Walkway Tribometer Validation

9.1 For the 40 tests on each reference surface, calculate the mean ($\bar{X}$), standard deviation (*SD*), standard error (*SE*) of the mean, and 95th percentile confidence interval (*CI*) for the walkway tribometer test results for each reference surface using Eq 1 through Eq 4, respectively:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n}(x_i) \tag{1}$$

where:

n = number of measurements (40), and

x_i = test result

$$SD = \sqrt{\frac{1}{n-1}\cdot\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{2}$$

$$SE = \frac{SD}{\sqrt{n}} \tag{3}$$

$$\begin{aligned}\text{95th percentile } CI &= \bar{X} \pm (1.96 \times SE)\\ &= \bar{X} - (1.96 \times SE) \text{ to } \bar{X} + (1.96 \times SE)\end{aligned} \tag{4}$$

9.2 A valid walkway tribometer must properly rank the friction between the test foot and reference surfaces and provide a statistically unique slip resistance measure for each surface. A valid walkway tribometer model shall satisfy the following two compliance criteria:

9.2.1 *Rank Order*—The rank order of the mean walkway tribometer results for each reference surface shall be the same as shown in Appendix X1.

9.2.2 *Differentiation*—Using the mean and standard deviation, paired *t*-tests as described in Appendix X2 shall produce significantly different results ($p < 0.05$) for all adjacently ranked reference surfaces (that is, between RS A and RS B, RS B and RS C, and RS C and RS D).

9.3 Failure to meet the two validation criteria shall be considered an unsatisfactory result. The supplier's guidelines for troubleshooting shall be followed, and the walkway tribometer validation repeated. If the results are still not satisfactory, the walkway tribometer fails the validation.

10. Walkway Tribometer Validation Report

10.1 The report shall include information about the walkway tribometer, test foot, reference surfaces, test procedure, and analysis method to allow the validation testing to be reproduced. The report shall include the following minimum information:

10.1.1 Operator, test address, company, and contact information;

10.1.2 Source of reference surfaces and date acquired;

10.1.3 Validation test date;

10.1.4 Validation temperature and humidity;

10.1.5 Walkway tribometer supplier, model number, and serial number;

10.1.6 Test foot number, material, age, preparation procedure, and dimensions;

10.1.7 The supplier's published version of the walkway tribometer operating instructions, test foot preparation, and test procedure. If a different procedure is used, attach a full description to the report;

10.1.8 *Test Results*—Mean, standard deviation, standard error of the mean, and 95th percentile confidence intervals for each reference surface (see Section 9);

10.1.9 Results of the rank order of reference surfaces and a statement of whether the walkway tribometer complies (see 9.3);

10.1.10 Results of the differentiation of reference surfaces and a statement of whether the walkway tribometer complies (see 9.3);

10.1.11 Comments on any aspect of the validation process that the operator judged to be noteworthy or that may have affected the test results; and

10.1.12 Statement that validation has been performed in accordance with this practice.

11. Validation Schedule

11.1 Validation shall be performed by walkway tribometer suppliers or independent testing facility:

11.1.1 When the walkway tribometer model is first certified to comply with this practice; and

11.1.2 Whenever the design of a walkway tribometer model is changed.

12. Walkway Tribometer Calibration Testing

12.1 Using the walkway tribometer being calibrated and the test foot prepared in 6.2.3, use supplier's instructions or any other formal procedure to perform 16 tests on each reference surface (defined in Section 7) in the test area that has been prepared by 8.2. Of the 16 tests, perform four in each of four orthogonal directions, that is, at 0, 90, 180, and 270° relative to an arbitrarily defined direction on the reference surface. Record the results for all tests as specified in Section 10.

13. Analysis of Results and Walkway Tribometer Calibration

13.1 Compute the mean for each reference surface using Eq 1 (see 9.1).

13.2 To be considered a calibrated walkway tribometer, the mean for each reference surface shall lie within the supplier's reported 95th percentile confidence interval.

13.3 Failure to meet this calibration criterion shall be considered an unsatisfactory result. The walkway tribometer shall be recalibrated or adjusted, or both, in accordance with the supplier's instructions and the walkway tribometer calibration repeated. If the result is still not satisfactory, the walkway tribometer fails calibration.

14. Walkway Tribometer Calibration Report

14.1 The report shall include sufficient information about the walkway tribometer, test foot, test foot preparation, reference surfaces, test procedure, and analysis method to allow the calibration testing to be reproduced. The report shall include the following minimum information:

14.1.1 Operator, test address, company, and contact information;

14.1.2 Source of reference surfaces and date acquired;

14.1.3 Calibration test date;

14.1.4 Calibration temperature and humidity;

14.1.5 Walkway tribometer supplier, model type, and serial number;

14.1.6 Test foot number, material, age, preparation procedure, and dimensions;

14.1.6.1 The calibration results shall apply only to the unique walkway tribometer/test foot combination tested.

14.1.7 The supplier's published version of walkway tribometer operating instructions, test foot preparation, and test procedure. If a different procedure is used, attach a complete description to the report;

14.1.8 *Test Results*—Mean of each reference surface;

14.1.9 Comparison of mean to supplier's reported 95th percentile confidence interval;

14.1.10 Statement addressing walkway tribometer's compliance or noncompliance with criterion;

14.1.11 Comments on any aspect of the calibration process that the operator judged to be noteworthy or that may have affected the test results; and

14.1.12 Statement that the calibration has been performed in accordance with this practice.

15. Calibration Schedule

15.1 Calibration shall be performed:

15.1.1 Following initial manufacture and before delivery to the initial end user;

15.1.2 Following introduction of a new test foot;

15.1.3 After any repair of the walkway tribometer; and

15.1.4 At intervals not to exceed one year.

16. Keywords

16.1 slip properties; walkway tribometer

APPENDIXES

(Nonmandatory Information)

X1. RANK ORDER OF REFERENCE SURFACES

X1.1 Reference surfaces from left to right ranked from least to most slip resistant in Table X1.1.

TABLE X1.1 Rank Order of Reference Surfaces

Least Slip Resistant			Most Slip Resistant
RS – A	RS – B	RS – C	RS – D

X2. PAIRED *t* TEST

X2.1 *Formula for Calculation of t:*

$$t = \frac{d_m}{SD/\sqrt{N}} \quad \text{(X2.1)}$$

where:

d_m = the mean difference, that is, the sum of the differences of all the data points (RS A measurement 1 – RS B measurement 1, ...) divided by the number of pairs (40),

SD = the standard deviation of the differences between all the pairs (calculate using Eq 2, see 9.1), and

N = the number of pairs (40).

NOTE X2.1—Use the absolute value of t (that is, assume that t is positive).

X2.2 *Calculation of Statistical Significance between Reference Surfaces:*

X2.2.1 If the calculated t value is greater than 1.694 (critical value), then a statistically significant difference exists between reference surfaces.

X2.2.2 If the calculated t value is less than 1.694 (see Note X2.2), then no statistically significant difference exists between reference surfaces.

NOTE X2.2—The selection of this critical value assumes: *(1)* one-tailed t test (used when there is an expectation of a significant difference between groups), *(2)* 39 degrees of freedom (number of pairs – 1), and *(3)* 0.05 level of significance.

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APPENDIX A.5.

EXHIBIT 5

Designation: D2047 – 11

Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine[1]

This standard is issued under the fixed designation D2047; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This laboratory test method covers the use of the James Machine for the measurement of the static coefficient of friction of polish-coated flooring surfaces with respect to human locomotion safety. Further, this test method also establishes a compliance criterion to meet the requirement for a nonhazardous polished walkway surface. The test method is not intended for use on "wet" surfaces or on surfaces wherein the texture, projections, profile or clearance between the sculptured pattern of the surface does not permit adequate contact between the machine foot and the test surface.

1.2 This test method is the only method appropriate for testing polishes for specification compliance with the floor polish static coefficient of friction criterion.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C1028 Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method

D1436 Test Methods for Application of Emulsion Floor Polishes to Substrates for Testing Purposes

D1630 Test Method for Rubber Property—Abrasion Resistance (Footwear Abrader)

D2825 Terminology Relating to Polishes and Related Materials

D4103 Practice for Preparation of Substrate Surfaces for Coefficient of Friction Testing

D6205 Practice for Calibration of the James Static Coefficient of Friction Machine

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E456 Terminology Relating to Quality and Statistics

2.2 *Federal Specification:*

KK-L-165C Leather, Cattlehide, Vegetable Tanned and Chrome Retanned, Impregnated, and Soles.[3] Type 1–Factory (for Shoe Making), Class 6–Strips

3. Terminology

3.1 *Definitions*—See also Teminologies D1436 and D2825.

3.1.1 *friction, n*—the resistance to relative motion developed between two solid contacting bodies at, and parallel to, the sliding plane.

3.1.2 *coefficient of friction, n*—the ratio of the horizontal (shear) component of force required to overcome friction, to the vertical (normal) component of force applied.

3.1.3 *static coefficient of friction, n*—the ratio of the horizontal component of force applied to a body that just overcomes the friction or resistance to sliding, to the vertical component of force applied.

3.1.4 *dynamic coefficient of friction, n*—the ratio of the horizontal component of force required to cause a body to continue to slide at a constant velocity, to the vertical component of force applied.

3.1.5 *slip resistance, n*—the frictional force opposing movement of an object across its surface, usually with reference to the sole or heel of a shoe on a floor. A surface having a static coefficient of friction of 0.5 or greater as measured by this test method is considered to have adequate slip resistance. That is, it will provide the required traction for preventing or markedly reducing the probability of slipping while walking.

[1] This test method is under the jurisdiction of ASTM Committee D21 on Polishes and is the direct responsibility of Subcommittee D21.06 on Slip Resistance.

Current edition approved Oct. 1, 2011. Published November 2011. Originally approved in 1964 as D2047–64T. Last previous edition approved in 2004 as D2047 – 04. DOI: 10.1520/D2047-11.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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4. Significance and Use

4.1 Test Method D2047 establishes a compliance criterion relating static coefficient of friction measurements of flooring surfaces with human locomotion safety. The compliance criterion is based on extensive experiential data from residential, commercial, industrial and institutional walkway surfaces since 1942.

4.2 Polishes and other floor maintenance coatings having a static coefficient of friction of not less than 0.5, as measured by this test method, have been recognized as providing nonhazardous walkways.

NOTE 1—The value of 0.5 meets the requirements for compliance with Rule 5 on "The use of terms slip retardant, slip resistant, or terms of similar import," of the Proposed Trade Practice Rules for the Floor Wax and Floor Polish Industry as issued by the Federal Trade Commission on March 17, 1953.

4.3 The 0.5 static coefficient of friction compliance criterion of this test method is only appropriate for polish-coated surfaces tested in accordance with this machine and test method. The use of this compliance criterion with other test methods, other test instruments, and other surfaces is improper, because they are not a part of the body of experiential data upon which the conformance criterion is based.

NOTE 2—The conformance criteria of this test method may be valid for other surfaces and surface coatings tested by this test method, but this has not been substantiated by correlation with experiential data.

5. Apparatus

5.1 *James Machine*[4]—See Fig. 1.

5.2 *Shoe Material*[5]—For interlaboratory and specification testing the shoe material shall be leather, conforming to Federal Specification KK-L-165C. Other materials commonly employed as footwear sole or heel material may be used. However, it should be understood that the 0.5 static coefficient of friction compliance criterion value is not relevant when such materials are substituted for the specification leather (Notes 2 and 3). To date, compliance criterion values for polish interfaces with other shoe materials have not been determined with respect to establishing minimum requirements for nonhazardous walkways. If a standard rubber shoe material is required, the test rubber should be in accordance with Test Method D1630.

NOTE 3—The static coefficient of friction measured with elastomeric compositions are frequently as much as 0.3 to 0.5 higher than leather.

5.3 *Substrate*—For interlaboratory and specification testing, OVCT[6], wood panels[7], or standard ceramic tiles[8] shall be used.

5.3.1 If substrates other than the above standards are to be used, they should be of uniform porosity and free of surface irregularities which would interlock the shoe material with the surface or otherwise impede smooth sliding of the shoe over the film surface.

6. Test Surface

6.1 For interlaboratory and specification testing of floor polishes, films on OVCT, wood panels, or ceramic tiles shall be prepared in accordance with Practice D4103 or Test Method C1028, respectively.

7. Test Shoe Material

7.1 The size of the shoe material used by the apparatus is 3 by 3 in. square by 0.25 in. thick (76.2 by 76.2 by 6.4 mm).

7.2 For interlaboratory and specification testing, the shoe material shall be leather manufactured in accordance with Federal Specification KK-L-165C. Cut the 3 by 3-in. (76.2 by 76.2 mm) specimen from the center portion of the hide by any suitable method. Mark the direction of the grain fibers for later reference. The alignment of the sides of the test specimen shall be along the length and width of the hide. Do not compress the leather during cutting. Dress the edges square.[5]

7.3 Before use, the specification leather should be equilibrated at 50 %(±5 %) relative humidity for one week. Between uses, the leather shoe material should be stored under these same constant humidity conditions.

7.4 Other shoe materials may be used for individual and specific testing purposes. If rubber is used, a standard rubber compound conforming to Test Method D1630, Section 7.1, is recommended. It is further recommended that the thickness of the shoe material not be greater than 0.25 in. (6.4 mm) or less than 0.20 in. (5.1 mm).

7.5 Gently sand the inside (flesh) surface of the leather to produce a uniform thickness. The final sanding in this process should be done by using 400 grit waterproof silicon carbide paper[9] affixed to a flat surface to produce a uniform surface for mating with the shoe holder. The inside (flesh) and outside (grain) faces of the leather should be parallel to within 0.01 in. (0.25 mm). The inside surface should be free of loose shreds of leather, grit, and dust.

7.6 Cement the flesh side of the leather to the metal shoe (3-in. square flat steel plate) using any suitable adhesive or double-sided tape. Orient the leather on the shoe so that the original grain of the leather is parallel to the direction of shoe travel.

7.7 To prepare the face of the leather-shoe for interlaboratory and specification testing, sand the grain face of the leather with 400 grit paper using four passes, two parallel to the direction of shoe travel followed by two perpendicular to the

[4] Assembled, motorized machines are available from Michelman, Inc., 9080 Shell Road, Cincinnati, OH 45236–1229. Assembled, non-motorized machines are available from Quadra, Inc., 1833 Oakdale Ave., Racine, WI 53405. Engineering/machinist drawings are available from Consumer Specialty Products Association, 900 17th Street NW, Washington, DC 20006.

[5] Precut specification leather material is available from Consumer Specialty Products Association , 900 17th Street NW, Washington DC 20006.

[6] OVCT, Official Vinyl Composition Tile, is available from Consumer Specialty Products Association, 900 17th Street NW, Washington, DC 20006.

[7] Wood panels may be constructed from assembled Rock Maple shorts (Second Grade, or better), available from Robbins, Inc., 4777 Eastern Ave., Cincinnati, OH 45226, or from local distributors for Bruce Hardwood Floors, or Harris-Tarkett Floors. Alternatively, panels may be cut from 3/4 in. (19.1 mm) furniture grade maple veneer plywood, available from local lumberyards or millworks.

[8] Available from the Tile Council of America, P.O. Box 1787, Clemson, SC 29633. The tiles should be prepared for coating in accordance with the procedure in Test Method C1028.

[9] 3M-413Q, available from 3M Co., St. Paul, MN; C414W, available from Carborundum Abrasives Co., Niagara Falls, NY; T421, available from Norton Co., Stephenville, TX.

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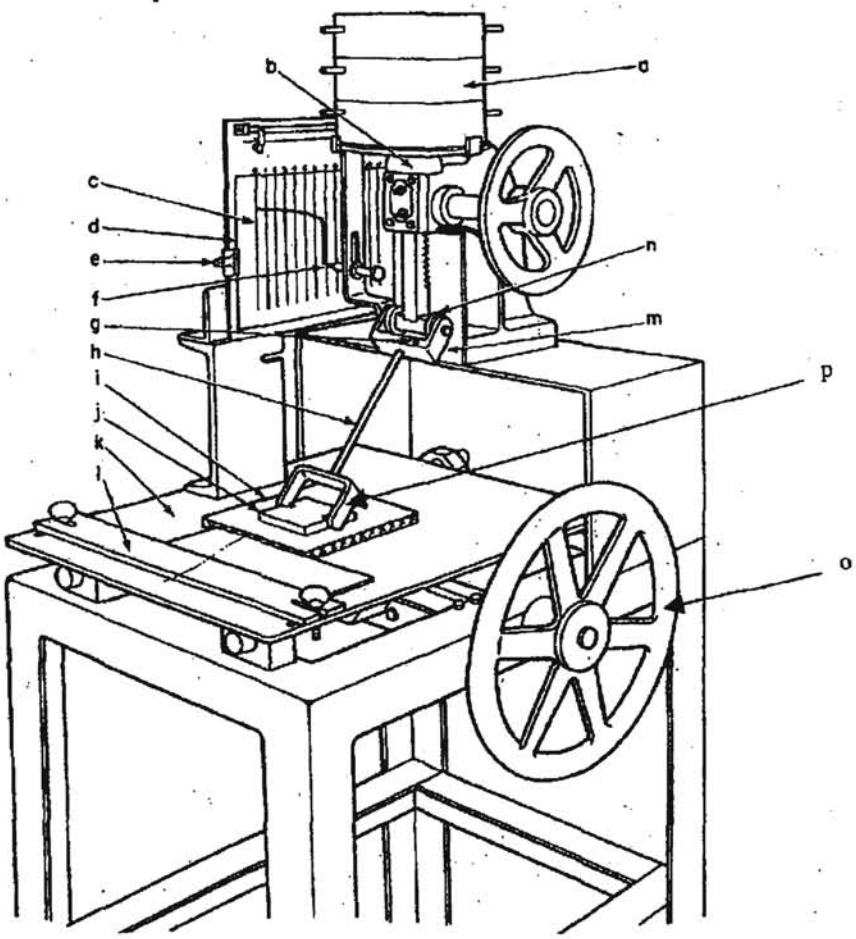
NOTE—The schematic is of a hand driven model. Motorized models do not have a table transport hand wheel (o). For clarity, this depiction of the James Machine does not show guards in place; pinch points should be guarded in accordance with recognized safety engineering standards.



a—Weights
b—Cushion
c—Chart
d—Chart Board
e—Spring Clip
f—Recording Pencil
g—Set Screw
h—Strut
i—Specimen
j—Shoe
k—Test Table
l—Retaining Bar
m—Back Plate
n—Ball Bearing Rollers
o—Table Transport wheel
p—Shoe holder

FIG. 1 James Machine

direction of shoe travel. Remove all dust from the leather surface using a brush, vacuum, blower, or woodworking "tack" cloth. Test the surface to be certain it is free of dust by wiping with green felt cloth and observing the cloth for dust.

7.8 Lightly sand the grain face of the leather shoe with the 400-grit paper before each reading, as described in 7.7.

NOTE 4—Discontinue use of the leather material when sanding has reduced the thickness by 0.05 in. (1.3 mm).

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8. Procedure (See Fig. 1)

8.1 Thoroughly check the James Machine is level in all directions, and correct any mechanical malfunctions to ensure reliable results (see Practice D6205).

8.2 Attach the chart[10] to the chart board.

8.3 Raise the weights until the strut is perpendicular to the table and attach the prepared test shoe in the shoe holder.

8.4 Before starting the actual test, make a test run in four mutually perpendicular directions using a panel of known coefficient of friction. Follow the procedure in 8.8. The test results shall differ by no more than 5 % from the known coefficient of friction. A greater deviation indicates the necessity to check the alignment of the machine (Practice D6205). Repeat this process until specified results are obtained.

NOTE 5—Finishes of known coefficient of friction are those which have undergone repeated evaluation by this test method, including round robin tests, and which have amassed considerable exposure to pedestrian traffic. Most commerical finishes meet these requirements. Samples and corresponding coefficient of friction values are available from many formulating manufacturers, polymer manufacturers, and other floor finish raw material suppliers.

8.5 Use three tiles or panels for each test, obtaining four readings on each panel. Rotate the panels 90° between each of the four readings so that a fresh surface is tested each time and directional effects, if any, are cancelled. If there is insufficient floor finish to coat three panels, tests on one or two panels may be run, though with the expectation of reduced precision.

8.6 Place the panel on the test table in firm contact with the retaining bar. Lightly dust the test panel to remove any extraneous matter.

8.7 Carefully place the leather-shoe into the strut yoke and gently lower the entire assembly into contact with the test panel. Disengage the small hand wheel.

8.8 Release the recording pen, making sure it is on the zero line of the chart.

8.9 Move the test table forward at a uniform rate of 60 in./min (1524 mm/min), ± 3 in./min (±76 mm/min), until the shoe slips and the vertical column drops.The table movement should be started within 5 s after the contact in 8.7 has been made.

8.10 After each determination, lift the strut and return the test table to the start position. Rotate the test panel 90°, sand the leather shoe material in accordance with 7.8, vertically offset the recording pen, and repeat steps 8.6 through 8.9.

8.11 Record as the static coefficient of friction the point at which the horizontal curve made on the chart by the recording pen changes to a vertical line. If this point is not sharply defined at the top of the vertical line, it may be necessary to draw a standard curve with the shoe braced to prevent slippage. Overlay the standard curve on the test curve, and record the point at which the test curve first deviates from the standard curve. Estimate the readings to the nearest 0.01

NOTE 6—If panels thicker than 0.5 in. (12.7 mm) are to be tested (for example, concrete or terrazzo slabs), a shim may be required underneath the gear box frame. The shim shall be cut to the contours of the frame and horizontal support and may be of any thickness necesary to accommodate the panel. When in position it shall maintain the strut and weights perpendicular to the test table and shall not impede the free fall of the weighted vertical gear through the gear box. Holes should be cut in the shim to accomodate bolts so that the unit may be bolted down before operation.

9. Report

9.1 The completed CSPA chart shall constitute the report of testing. It shall include the following:

9.1.1 The static coefficient of friction as the arithmetic average of all twelve readings obtained on the three panels. For interlaboratory testing or external reporting, round off the average to one significant digit using the rounding-off method of Practice E29. For intralaboratory data analysis, two significant digits may be retained.

9.1.2 The calculated standard deviation from the mean of the readings, or the range (lowest and highest) readings in the test.

9.1.3 The name or other identifier of the polish, and the date tested.

9.1.4 If other than the standard leather, identity and specifications for the test foot material used.

9.1.5 The temperature and humidity under which the tests were conducted.

9.1.6 If other than two coats of polish were applied, report the number of coats and the application procedure used (see Test Method D1436 and Practice D4103).

9.1.7 The polish substrate, if other than the standard OVCT tile, wood, or ceramic tile.

9.1.8 Name of the operator.

10. Precision [11]

10.1 The following criteria should be used for judging the acceptability of results (95 % confidence):

10.1.1 *Repeatability*—Duplicate determinations of the mean static coefficient of friction of a polish film, by the same operator and on the same James machine, should be considered suspect if they differ by more than 0.02.

10.1.2 *Reproducibility*—The mean static coefficient of friction of films from a liquid polish determined by two laboratories should be considered suspect if they differ by more than 0.07.

11. Bias

11.1 The procedure in Test Method D2047 for measuring the static coefficient of friction of polish-coated surfaces by the James Machine has no bias because the value of the static coefficient of friction of polish-coated surfaces is defined only in terms of this test method.

12. Keywords

12.1 coefficient of friction; finishes; flooring; footwear; heel; James Machine; polishes; sole

[10] Suitable charts are available from the Consumer Specialty Proucts Association, 900 17th Street NW, Washington DC 20006. Only use originals of these charts, not copies. Even the best copying machines will not duplicate exactly, and small deviations in the distance between coefficient of friction lines on the chart could lead to inaccurate results.

[11] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D21-1000.

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APPENDIX B

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The Honorable Kenneth Schubert

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CASE NUMBER: 12-2-07790-8 SEA

IN THE SUPERIOR COURT OF THE STATE OF WASHINGTON
FOR KING COUNTY

TWYLA KILL, and TERRY KILL, individually and the marital community comprised thereof, Plaintiffs, vs. CITY OF SEATTLE, a Washington municipal corporation, Defendant.	SECOND DECLARATION OF JAMES E. FLYNN, P.E., IN SUPPORT OF THE CITY OF SEATTLE'S MOTION FOR SUMMARY JUDGMENT No. 12-2-07790-8SEA

I, James E. Flynn, P.E. do declare as follows:

1. I am an engineer with J2 Engineering. I am the author or contributing author to a number of scientific studies analyzing slip and falls and the use of tribometers. I am a Collaborative Researcher at the Musculoskeletal Biomechanics Research Laboratory (MBRL) at the University of Southern California. I am a registered mechanical engineer and safety engineer in California, and a registered mechanical engineer in Nevada.

2. The representations I make in this declaration are based on scientific research, my years of training and experience in mechanical and safety engineering and my familiarity with

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academic and peer-reviewed scientific works regarding slips. I make these representations as a response to the Second Declaration of Joellen Gill and to supplement my prior declaration in this matter. Based on the materials I have reviewed to date, plaintiff's expert's tribometer has never been calibrated as required by ASTM F2508. Although Ms. Gill recognizes that ASTM F2508 sets the required method for validation and calibration, she offers an interpretation of the standard that does not match its plain language. Ms. Gill suggests that only validation is required, not both validation and calibration. Had her machine been calibrated, she would have a report demonstrating as much pursuant to ASTM F2508 section 14. Every time Ms. Gill replaces the test foot on her machine and at least once every year, her tribometer must undergo the required calibration testing.

3. Although it appears from the Excel Tribometers website that the class of English XL tribometers was *validated* by the manufacturer, ASTM 2508 makes clear that both validation of the class of tribometers *and* calibration of the individual tribometer used by a tester is required. Without the calibration required by ASTM 2508, the results of a tribometer test are of no use whatsoever.

4. A brief review of the text of ASTM 2508, an exhibit to my prior declaration, demonstrates that calibration is required, in addition to validation:

> 1.1 This practice is intended to establish the parameters for validation and calibration of walkway tribometers.
> 1.2 This practice provides a walkway tribometer supplier with a procedure and a suite of reference surfaces to validate his walkway tribometer by properly ranking and differentiating the surfaces.
> 1.3 This practice provides the user of a walkway tribometer with a procedure and a suite of reference surfaces to test calibration of his instrument."
> * * * * *
> 3.1.1 *calibration, n*—the set of operations that establishes, under specified conditions, the relationship between the values obtained by a walkway tribometer and the corresponding supplier reference values.

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3.2.3 *validation, n*—the set of operations that establishes, under specified conditions, the proper ranking and differentiation of reference surfaces by a walkway tribometer.

* * * * *

4.1 This practice establishes a procedure to: (1) validate walkway tribometer models against a human gait-based reference system, and (2) calibrate each individual walkway tribometers of a validated model against published suppliers' reference values (as defined in 9.1, Eq 4)"

* * * * *

4.4 Validation consists of a series of 40 tests on each reference surface from this practice. A walkway tribometer model is considered valid if it ranks the four reference surfaces from this practice in the proper order with statistically significant differentiation between results obtained for each surface. Validation is intended to be accomplished for each walkway tribometer model when it is initially introduced and is to be accomplished by or on behalf of the supplier and made available to the user.

4.5 Calibration for a specific walkway tribometer requires a series of 16 tests on each of the reference surfaces from this practice. A specific walkway tribometer is considered within calibration if the bias of the mean test values for each surface falls within the 95% confidence interval for the walkway tribometer model as established by the validation tests (as defined in 9.1 Eq 4).

* * * * *

12. Walkway Tribometer Calibration Testing

12.1 Using the walkway tribometer being calibrated and the test foot prepared in 6.2.3, use suppliers' instructions or any other formal procedure to perform 16 tests on each reference surface (defined in Section 7) in the test area that has been prepared by 8.2. Of the 16 tests, perform 4 in each of four orthogonal directions, that is, at 0, 90, 180, 270° relative to an arbitrarily defined direction on the reference surface. Record the results for all tests specified in Section 10.

13. Analysis of Results and Walkway Tribometer Calibration

13.1 Compute the mean for each reference surface using Eq 1 (See 9.1).

13.2 To be considered a calibrated walkway tribometer, the mean for each reference surface shall lie within the supplier's reported 95th percentile confidence interval.

13.3 Failure to meet this calibration criteria shall be considered an unsatisfactory result. The walkway tribometer should be recalibrated or adjusted, or both, in accordance with the supplier's instructions and the walkway tribometer calibration repeated. If the result is still not satisfactory, the walkway tribometer fails calibration.

5. The validation report from Excel Tribometer's website that is cited as an attachment to the declaration of Ms. Gill also indicates that calibration is required:

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An F2508 Calibration procedure shall be performed following initial manufacture and before delivery to the initial end user of each XL VIT base-model who so requests. Verification of the F2508 Validation of the XL VIT base-model shall otherwise be accomplished through an F2508 Calibration procedure following introduction of a new test foot; after any repair of the walkway tribometer that could affect the performance of the tribometer; and at intervals not to exceed one year.

The F2508 Calibration procedure consists of a series of 16 tests on each of the reference surfaces, four (4) tests in each of four (4) orthogonal directions, that is, at 0, 90, 180, and 270 degrees relative to an arbitrarily defined direction on the reference surface, all in accordance with specifications and procedures defined herein and defined in the ASTM F2508-11 Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces.

The XL VIT base-model is considered within calibration if the bias of the mean test values for each surface falls within the 95th percentile confidence interval herein defined for the XL VIT base-model, as established by the validation tests, and as established by Excel Tribometers LLC. Failure to meet this calibration criterion shall be considered an unsatisfactory result, and shall require the XL VIT base-model be recalibrated or adjusted, or both, by Excel tribometers LLC, and the F2508 Calibration procedure repeated.

An F2508 Calibration Report shall be prepared and include sufficient information about the XL VIT base-model, test foot, test foot preparation, reference surfaces, test procedure, and analysis method to allow the calibration testing to be reproduced. The F2508 Calibration Report shall include at the minimum: 1.) Operator, test address, company, and contact information; 2.) Source of reference surfaces and date acquired; 3.) Calibration test date; 4.) Calibration temperature and humidity; 5.) Walkway tribometer supplier, model type, and serial number; 6.) Test foot number, material, age, preparation procedure, and dimensions; 7.) The Excel Tribometers LLC version of the XL VIT User Guide, test foot preparation, and test procedure used; 8.) Test Results: Mean of each reference surface; 9.) Comparison of mean to Excel Tribometers LLC reported 95th percentile confidence interval; 10.) Statement addressing compliance or noncompliance with criterion; 11.) Comments on any aspect of the calibration process that the operator judged to be noteworthy or that may have affected the test results; and 12.) Statement that the calibration has been performed in accordance with ASTM F2508-11 Standard Practice for Validation and Calibration of Walkway Tribometers Using Reference Surfaces.

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The calibration results shall apply only to the unique XL VIT base-model/XL VIT and F2508 treaded-model test foot combination tested."

Second Declaration of Joellen Gill, Exhibit C, p. 3. (Report of ASTM F2508 Validation of the English XL VIT Base-Model Variable Incidence/Articulated Strut Tribometer (undated, testing performed August 2011)(emphasis added)).

6. The tribometer tested for the validation report cited by Ms. Gill came up with the following average measurements for the four reference tiles:

	RS-A Granite	RS-B Porcelain	RS-C Vinyl	RS-D Ceramic
Mean	0.125	0.259	0.359	0.858
Standard Deviation	0.006	0.013	0.025	0.014
Standard Error	0.001	0.002	0.004	0.002
95th Confidence Lower	0.123	0.255	0.351	0.854
95th Confidence Higher	0.126	0.263	0.367	0.863
Rank (1 = least slip resistant)	1	2	3	4

7. By comparison, the validation test of another base model tribometer using a different method to prepare the test foot came up with the following results:

	RS-A Granite	RS-B Porcelain	RS-C Vinyl	RS-D Ceramic
Mean	0.083	0.112	0.168	0.557
Standard Deviation	0.007	0.009	0.013	0.028
Standard Error	0.001	0.001	0.002	0.004
95th Confidence Lower	0.081	0.109	0.164	0.549
95th Confidence Higher	0.085	0.115	0.172	0.566
Rank (1 = least slip resistant)	1	2	3	4

Report of ASTM F2508 Validation of the English XL VIT Base-Model Variable Incidence/Articulated Strut Tribometer with Standard XL VIT Non-Threaded Test Foot and Standardized Test Foot Preparation Device, June 19, 2012 (available at:

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http://www.exceltribometers.com/uploads/download/XL%20VIT%20Base-Model%20F2508%20Std%20Foot%20Validation%20Report.pdf Last visited May 21, 2013).

8. To provide an example of the significance of calibration relative to the two validation reports: On the third reference surface, vinyl composition tile, the difference between .359 and .168 is significant. During human testing of wet vinyl tile, 7 of 20 subjects experienced a toe slip on that surface, but none experienced a heel slip. A noted in the published report that is exhibit 1 to my initial declaration,

> The distinction between the most slippery surface containing primarily heel slips and the moderately slippery surface containing primarily toe slips was based on the premise that toe slips are not hazardous for the walker because of where they occur in the gait cycle. Toe slips take place in late stance as weight is being transferred off the slipping limb to the support limb. In contrast, heel slips occur in early stance when weight is being transferred onto the slipping limb which increases the risk of a fall compared to a toe slip (14).

9. If Ms. Gill's machine had been calibrated pursuant to ASTM F 2508, we would have some basis for saying that the tested surface is roughly equivalent to Vinyl Composition tile, or much more slip resistant than such tile. But because the machine was not calibrated, we cannot draw any conclusions regarding her test results.

10. In her Second Declaration, Ms. Gill purports to be "very familiar" with ASTM F2508. ¶ 3. She misunderstands or ignores parts of the standard. ASTM F2508 required that her tribometer be calibrated per the standard. It never has been. Rather, it has only been "calibrated" by testing it on a single tile specified by the manufacturer of her machine.

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11. I have spent a significant amount of time analyzing and studying tribometers. Indeed, Ms. Gill relies on some of my prior publications in support of her arguments. However, Ms. Gill does not appear to understand current research in the field. Research that I and others conducted between 2007 and 2010 led to the development of ASTM F2508. That research demonstrated that tribometers do not all operate on the same scale of measurement. Meaning that one tribometer might measure a surface as having a coefficient of friction dramatically different from that measured by a different tribometer, or even another tribometer of the same model.

12. As indicated by the Excel validation tests cited above, how the test foot is prepared can have a dramatic effect on results. I have discussed this issue with the current owners of Excel Tribometers, and they have developed a new test-foot preparation device, "The Sander," in the hopes of developing more uniform results between XL machines. "The Sander" was not commercially available in 2011 and I understand that it has not yet been brought to market. However, because of my ongoing work in this area, I have been provided a test model for evaluation. Given that Ms. Gill did not use "The Sander" to prepare her test foot, I will not delve further into the issue here.

13. I will note, however, an example of my past research that indicates why the calibration of a device as required by ASTM F2508 is so critical. In addition to the 2007 and 2010 studies cited in my previous declaration, I also performed testing of the English XL tribometer in 2008. In that test, 8 XL tribometers were tested under laboratory conditions by their respective owners using the factory-proscribed test foot preparation method. Within two weeks prior to testing, 6 of the 8 tribometers had been calibrated by the manufacturer. Even after further onsite-calibration of the machines, the measurements obtained by the different

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tribometers was off by orders of magnitude when measuring the four different test tiles that are now part of ASTM F2508.[1]

14. I shared the results of the 2008 testing I describe above with the ASTM F13 committee. The ASTM F2508 standard was developed based on my and other's research during a time period that included my chairmanship of the F13 committee responsible for the standard. The four reference tiles in the studies I cited in my declaration are the same four tiles used in ASTM F2508.

15. Had Ms. Gill calibrated her machine, it would allow us to compare her measurements to those obtained by the manufacturer during the validation test. It is through validation *and* calibration that the results of a particular test can be related back to human testing and analyses. Only through that process can we relate the coefficient of friction measured by a machine to a meaningful human measurement of slipperiness.

16. In sum, Ms. Gill's continued confusion of the difference between *validation* and *calibration* mean that her test results are useless. Ms. Gill is not up-to-date on current science, which shows that there can be no single "safe" coefficient of friction because different tribometers operate on different scales of measurement, and cannot be said to be operating with any degree of reasonable accuracy without validation *and* calibration.

I declare under penalty of perjury under the laws of the state of Washington that the foregoing is true and correct.

DATED this 23 day of May, 2013, at Fresno, Fresno County, California.

James Flynn, P.E.

[1] The test protocols and results are attached as exhibits 1 and 2 to this declaration.

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APPENDIX B.1.

EXHIBIT 1

1. The study was conducted at the Musculoskeletal Biomechanics Laboratory of the University of Southern California.

2. The test design was reviewed and approved by William English who is the manufacturer of the VIT.

3. Eight operators with eight different tribometers were selected for participation.

4. Seven of the eight operators had participated in the CXLT program which provided instruction in the use of the VIT. The CXLT course was taught by William English.

5. Six of the eight operators sent their tribometers to the manufacturer within two weeks prior to the precision study.

6. All tribometers were calibrated prior to testing. Calibration was conducted using a calibration test tile provided by Mr. English. Test tile readings were widely variable. Obtaining acceptable calibration required test foot replacement on five of the eight tribometers. The new test feet had been provided prior to the test date by Mr. English.

7. Sanding and test protocols were provided by Mr. English. All protocols were followed without deviation.

8. Four different test tiles were utilized:
    a. Polished Granite
    b. Porcelain
    c. Vinyl Composition Tile (VCT)
    d. Ceramic Tile.

9. Each tile was tested in four orthogonal directions. All tribometers tested the same spot on each tile.

10. The tiles were wetted prior to testing. The porcelain, VCT and ceramic tiles were wetted with distilled water. The polished granite was wetted with a solution of water and Triton X-100 surfactant (200μL/500mL) to avoid beading and improve wetting.

APPENDIX B.2.

EXHIBIT 2

VIT Testing: USC 03-29-08

	Reference Tile	Granite	Average	Porcelain	Average	Vinyl	Average	Ceramic	Average
Page Edkridge	0.15	0.12	0.120	0.14	0.128	0.14	0.165	0.40	0.463
Calib. Date: 03-17-08		0.12		0.14		0.14		0.49	
		0.12		0.11		0.18		0.37	
		0.12		0.12		0.20		0.59	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
Dean Ahlberg	0.14	0.05	0.050	0.08	0.075	0.08	0.113	0.26	0.238
Calib. Date: 03-18-08		0.06		0.09		0.14		0.24	
		0.05		0.06		0.11		0.22	
		0.04		0.07		0.12		0.23	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
Mike Stapleford	N/A	0.10	0.100	0.16	0.148	0.14	0.163	0.55	0.543
Calib. Date: 03-22-08		0.10		0.15		0.16		0.54	
		0.10		0.14		0.20		0.46	
		0.10		0.14		0.15		0.62	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
David Dainty	0.15	0.06	0.060	0.07	0.070	0.09	0.150	0.26	0.305
Calib. Date: 03-21-08		0.06		0.07		0.10		0.30	
		0.06		0.08		0.22		0.27	
		0.06		0.06		0.19		0.39	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
Bill Newman	0.16	0.14	0.148	0.20	0.190	0.22	0.258	0.35	0.378
Calib. Date: 03-17-08		0.15		0.18		0.22		0.35	
		0.15		0.20		0.28		0.30	
		0.15		0.18		0.31		0.51	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
Al Ferrari	0.14	0.17	0.165	0.14	0.158	0.19	0.185	0.33	0.368
Calib. Date: 03-25-08		0.17		0.19		0.19		0.36	
		0.16		0.18		0.16		0.27	
		0.16		0.12		0.20		0.51	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
Martin Balaban	0.11	0.06	0.063	0.10	0.098	0.14	0.130	0.33	0.320
Calib. Date: 05-14-07		0.07		0.11		0.11		0.35	
		0.07		0.10		0.13		0.30	
		0.05		0.08		0.14		0.30	
	Reference Tile	**Granite**	Average	**Porcelain**	Average	**Vinyl**	Average	**Ceramic**	Average
Richard Warner	0.14	0.12	0.118	0.13	0.128	0.11	0.130	0.29	0.325
not calibrated		0.12		0.14		0.16		0.28	
		0.12		0.11		0.12		0.25	
		0.11		0.13		0.13		0.48	