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Research Article

Slip Resistance Evaluation of 10 Indoor Floor Surfaces

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Abstract

Slip and fall injuries and fatalities continue to be a significant problem at work and in the community. Water is the most common contaminant that reduces traction on floors and other walkway surfaces resulting in a slip and fall event. This project investigated 10 common flooring surfaces to assess their slip resistance when dry vs wet and coated vs uncoated. Investigators used the English XL Variable Incidence Tribometer to measure slip resistance under all conditions. Results revealed a significant (p - value < 0.05) loss of slip resistance when wet vs dry. Investigators also found significant (p - value < 0.05) increases in traction when using a coating under wet conditions. Researchers support the use of coatings for floors and walkway surfaces that increase traction and reduce the chances of slip and fall events under all conditions.

Introduction

Slips and falls are a major cause of injury among the general public, senior citizens, and in the workplace [1]. The National Safety Council reported that 44,686 people died as a result of falls at home and work in 2021 [2]. Falls are the number one reason for emergency room visits in the US. Fall-related injury constitutes 26% of all emergency room visits and totaled more than 10,500,000 in 2010 [3]. Seniors are especially vulnerable to falls, the CDC [4] reported that 1 in 4 older adults fall each year.

In the workplace, slip and fall injuries represent the highest or second highest type of workers' compensation claims depending on the industry [5]. There were 227,760 documented falls at work in 2017 with 887 resulting in fatality [6]. Socias-Morales, et al. [7] examined 9,517 workers' compensation claims associated with slip trips and fall injuries experienced by Ohio construction workers from 2010 through 2017. The investigative team found that 17% of claims were entirely slip events without fall. They also found that 39% of claims experienced lost time from work. Falls at the same level were examined closely for causation and identified causes that included floor irregularities, and contaminants such as mud, gravel, water, dirt, oil, and grease [7]. Slip and fall injuries comprised 11% of all workers' compensation claims and 13% of claims costs.

Slips and falls are often due to two major causes: Extrinsic *vs*. Intrinsic. Extrinsic causes are those factors associated with the environment such as slippery floor finish or coating, uneven surfaces, worn walkway surface asperities, poor lighting, heavy awkward loads, improper footwear, and the most common being walkway contaminants such as water, dirt, grease, or oil. Intrinsic factors include poor health, gait abnormalities, weakness of the lower extremities, balance problems, poor eyesight, fatigue, lack of sleep, lack of anticipation, lack of experience, poor work practices, and high work demands to name a few [6].

Fall prevention begins with understanding the hazards present in the workplace or community. Workplace safety and health professionals are advised to measure and evaluate slip resistance (SR) at their place of employment to characterize risk and identify appropriate interventions to reduce the chances of slip and fall injuries [1]. Walkways and floors are made of a variety of materials including ceramic tile, prefinished woods, vinyl composites, decking made of plastics, and other polymers as well as concrete, asphalt, and gravel [8]. Researchers have concluded that fall prevention in the workplace is mandatory [6].

Fall prevention includes a variety of strategies to reduce the chances of slip and fall events. It is recommended to practice basic safety principles that include identifying hazards, evaluating risks, implementing and maintaining controls, re-evaluating to assess effectiveness, and documentation [1]. A written program should include frequent inspection and monitoring, housekeeping, immediate reporting of hazards, warning signs, barricades, trash containers close to points of generation, floor mats, appropriate walkway surfaces, walkway treatments, appropriate footwear, employee training, and documentation.

Many standards exist to guide employers, property owners, occupants, safety professionals, and others interested in or responsible for safe walkways and walking surfaces [8]. The ASTM International, American Standards Institute (ANSI), Americans with Disabilities Act (CFR 28 Chapter 1 Part 36), and OSHA (Federal Register 68:23527-23568) have published standards for walkway safety [8]. Walkway surface factors play an important role in the safety related to walkway surfaces such as surface roughness, asperity shape, distribution, and height to ensure traction between the shoe and the walkway surface [8]. Walkway surface conditions and characteristics may all effect the SR of the surface and must be measured and evaluated [1].

Hazard assessment involves inspection of the walkway for basic design, construction, maintenance, material composition, irregularities, and/or contaminants [1]. Measurement and evaluation of SR is essential to determine if risk is acceptable or must be mitigated [1]. Slip resistance is a complex phenomenon related to three primary factors: 1) the type of footwear, 2) the conditions of the walking surface, and 3) the presence of contaminants [8]. Intrinsic factors also play a role but are not controlled by the parties responsible for walkway safety. Slip resistance is defined by the ASTM F1646 standard as, “the relative force that resists the tendency of the shoe or foot to slide along the walkway surface” [8]. An SR or static coefficient of friction (SCOF) of 0.50 or greater is recommended to reduce the chances of walkway slip and fall injuries [8,9]. The National Floor Safety Institute (NFSI) ranks SCOF > 0.60 as having high traction, > 0.04 < 0.60 as having moderate traction, and, < 0.40 as having minimal traction. Measuring SR on walkway surfaces is achieved using a tribometer [8,10-12](. It has been stated that over 60 tribometers have been invented [11]. Basic types of tribometers include the pendulum tester, the drag sled design, the roller coaster design, and the articulated strut-type with a movable mast [13].

The English XL™ Variable Incidence Tribometer (VIT) was invented by William English in the early 1990s [12,14]. The device was adopted by the ASTM in standard F1679 and recognized as a valid measuring device. The standard was later withdrawn in 2006 but continues to be used by safety professionals and provided by ASTM [13]. The English XL VIT passed the ASTM F2508 standard for accuracy and precision. The ASTM F2508 standard requires tribometers to correctly rank the SR of test tiles in the correct order of slipperiness. The English XL™ VIT passed this requirement. The English XL™ VIT is a portable, biofidelic instrument that simulates the human gate leg angle, ankle function, and heel strike making it particularly useful in SR testing on walkway surfaces [14]. The English XL™ VIT is an articulated strut design tribometer with an adjustable mast that can be declined from vertical to more than 40 degrees [15]. The unit is powered by a CO2 cartridge regulated to 25 psi while in use. The activation switch allows a release of gas that powers the system and discharges the piston leg and Neolite foot. The 1¼” (31mm) Neolite test foot travels at 13”/second and strikes the walking surface similar to a shoe heel strike [14]. Neolite has a rated hardness of 92 +/- 1 shore A. The mast is then progressively declined until the Neolite foot slips on the surface being evaluated and the slip reading is taken and read to the 100ths. The tangent of the angle is the SR or SCOF. Prior research has been carried out measuring slip resistance on concrete and wood surfaces using the English XL™ VIT [16]. The researchers evaluated slip resistance on different surfaces, applied anti-slip coatings, and retested to assess the reduction in slip propensity. The project by Grieser and Frantz [16] was similar in design to the current project.

This investigation tested SR on 10 common floor surfaces including tile and laminate using the English XL™ VIT both wet and dry, then a coating was applied according to the manufacturer’s instructions, and the surfaces were retested. The first hypothesis was that there would be no difference in SR values of dry and wet surfaces. Hypothesis two was that no difference would be seen in SR values of uncoated surfaces compared to coated surfaces. This project aimed to investigate SR on common surfaces under different conditions.

Methods

The lead researcher obtained tribometer certification with Excel Tribometry (CXLT) and trained all team members. The investigative team members demonstrated competency using the English™ XL VIT with the calibration tile provided by Excel Tribometers. Team members were required to obtain measurements no greater than +/- 0.03 variance to demonstrate correct use. Ten different floor surface samples were randomly selected and obtained from a local floor covering supplier in Butte, MT; six ceramic and five laminate. The floor covering facility had an extensive display room with approximately 50 different flooring surface examples. The facility management suggested that we randomly select 10 samples of our choosing and evaluate slip resistance. We surveyed the selection and randomly selected 10 samples as we walked through the display room with no preconceived intention or process. All tiles were cleaned with a citrus floor cleaner purchased from the Slip Doctors as recommended before applying Tuff Grip floor coating. Tiles were placed on a 1/8" cork surface to enhance stability and ease of testing. Temperature and humidity readings were recorded on all testing days. The project was carried out at the Safety and Ergonomics Lab at Montana Technological University in Butte, MT.

Adhering to the protocols for use outlined in the User's Manual [15], the team members generated SR measurements with the English™ XL VIT for each of the 10 floor surfaces dry and wet in four directions moving in a clockwise, NESW rotation. Values were summed and divided by four to obtain an average SR estimate under each condition [15]. Measurements were obtained initially for dry conditions followed by wetting the surfaces with tap water and retesting. Water was applied with a plastic spray bottle to create a uniform film before each measurement attempt. The 10 floor surfaces were then cleaned with the Citrus cleaner as recommended by the supplier coated with Dura Grip according to the manufacturer's recommendations and retested in both dry and wet conditions for SR. Data collected included temperature, humidity, and SR readings in four directions for each of the 10 floor surfaces in all conditions. Data were recorded in MS Excel and moved to Minitab for analysis. Descriptive statistics were generated and relationships between conditions were evaluated using paired T-test.

Results

The temperature and humidity were monitored during each test session and found to be 68° to 70 °F and 16% over the seven testing periods. The SR readings were greatest with dry conditions with and without coating ranging from 0.52 to 0.66 (Table 1). Uncoated wet conditions revealed considerably lower SR readings ranging from 0.21 without the Tuff Grip slip-resistant coating to 0.66 with Tuff Grip coating, see Table 1. Very little variance was seen in SR readings of coated surfaces either dry or wet, all measures were above 0.05 with only one tile showing a significant difference (Table 1). Greater variance was seen in uncoated tiles when comparing dry to wet with dry readings all above 0.5 and most above 0.60. Wet uncoated tiles had lower readings except for three tiles, 2, 6, and 8 respectively. Tile 4 showed an increase in SR wet compared to dry, see Table 1. ANOVA GLM was used to evaluate the best-fit model.

Table 1: Slip Resistance Measurements in All Conditions.

Tiles	Dry NoCoat Mean(SD)	Wet NoCoat Mean(SD)	*p* - value	CoatedDry Mean(SD)	CoatedWet Mean(SD)	*p* - value
1	0.66(0.00)	0.30(0.02)	< 0.00*	0.64(0.02)	0.60(0.01)	0.19
2	0.66(0.02)	0.52(0.03)	0.01*	0.64(0.02)	0.69(0.01)	0.05*
3	0.66(0.01)	0.65(0.00)	0.76	0.66(0.01)	0.65(0.01)	0.76
4	0.52(0.01)	0.58(0.02)	0.54	0.61(0.01)	0.57(0.02)	0.02*
5	0.69(0.02)	0.46(0.02)	< 0.00*	0.66(0.01)	0.54(0.02)	< 0.00*
6	0.56(0.01)	0.51(0.00)	0.03*	0.65(0.00)	0.59(0.04)	0.04*
7	0.60(0.01)	0.21(0.00)	< 0.00*	0.64(0.02)	0.56(0.00)	< 0.00*
8	0.61(0.01)	0.55(0.03)	0.03*	0.64(0.01)	0.65(0.04)	0.73
9	0.63(0.02)	0.19(0.01)	< 0.00*	0.64(0.01)	0.65(0.04)	0.74
10	0.64(0.01)	0.38(0.02)	< 0.00*	0.66(0.01)	0.66(0.03)	0.77

Tiles dry with and without coating and wet with and without coating - *Significant difference, p - value < 0.05.

Looking at the means seen on an interval plot, one can see the dry SR measurements were well above the 0.50 safety threshold for both coated and uncoated surfaces, Figure 1. Whereas, looking at the wet conditions the SR measurements of the uncoated tiles were below the recommended 0.50 SR level.

The data were skewed to the right. The GLM provided a best-fit model yielding normality plots, fitted values, residuals, and observation orders, see Figure 1. Data conform to a straight line on the residual normality plot. The versus fits plot identifies the random nature of the distribution of data points with a right skewness. The histogram of residuals shows a more normal distribution of data points. The versus order plots confirm the independence of data points, see Figure 1.

Discussion

This study examined the SR on 10 common floor surfaces under differing conditions, dry vs wet and coated vs uncoated to investigate the effect of water contamination followed by treatment with a slip-resistant coating. Slip and fall injuries continue to be a major problem for businesses, industry, and the community [1]. Water is the most common contaminant associated with slip and fall events. Water is a lubricant that may be from a spill, rain, or melting snow and ice. In most cases, water significantly reduces slip resistance by lubricating the walkway surface. We found significantly reduced traction in eight of 10-floor surfaces with the application of water. Only tiles #3 & #4 demonstrated consistency in the safe traction levels > 0.50 when wet or dry. Furthermore, the application of a slip-resistant coating enhanced traction to a safe level on the same eight of 10 tiles that lost traction when wetted. The potential effects of water must be mitigated to assure walkway safety in wet conditions.

The National Floor Safety Institute (NFSI) is presently circulating a petition that requests the Consumer Product Safety Commission mandate testing and labeling of SR of commercial and residential grade floor coverings, coatings, and treatments [3]. Great concern exists to ensure floor and walkway surfaces are safe, 50% of all same-level slips and falls, occur as the result of a hazardous (slippery) walkway

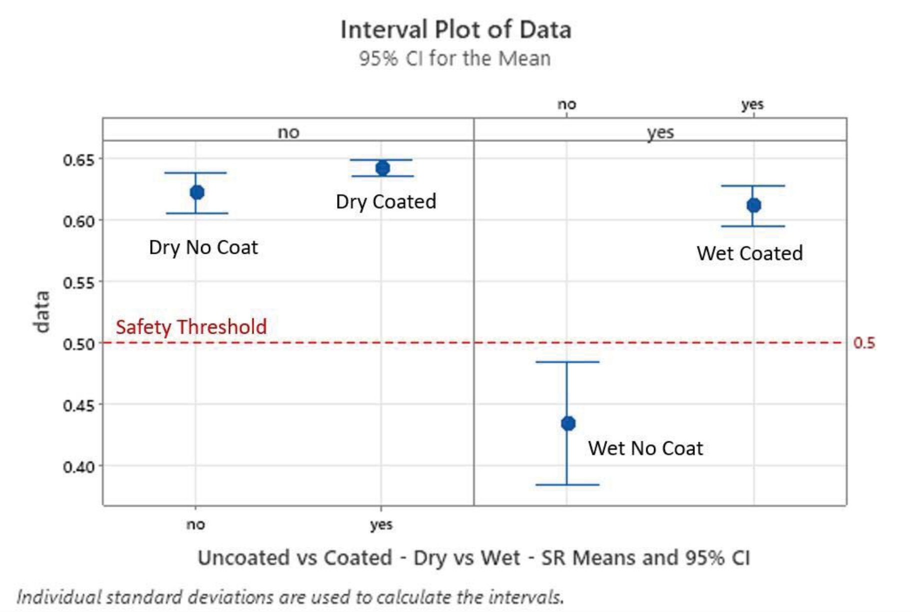

Figure 1: Interval Plot of Dry vs. Wet and Uncoated vs. Coated Mean SR w/95% CI.
Significant Differences – p - values < 0.05 in Uncoated Dry vs. Wet.

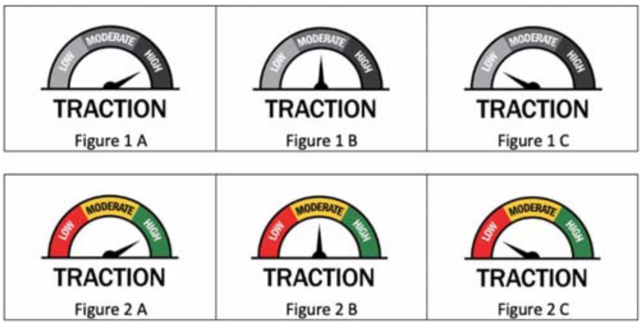

Figure 2: Proposed NFSI Labeling Exemplars.

Table 2: NSFI Definitions of Low, Moderate, and High Traction SR.

Wet DCOF Value (μ)	Available Traction	Action
≥ 0.50 (ramp) ≥ 0.45 (level surfaces)	High	None required. Monitor and test DCOF regularly.
0.30 - 0.44	Moderate	Monitor and test DCOF regularly. Consider using traction-enhancing products and practices where applicable for intended use and maintain walking surfaces in dry conditions.
< 0.30	Low	Seek professional intervention. Consider replacing flooring or treating it with traction-enhancing products.

or floor [3]. Falls are the third leading cause of unintentional fatality among the general population and #1 for those over 70 years of age [3]. Falls disproportionately adversely impact our seniors with 20% to 30% suffering moderate to severe injury due to fall events [3]. The overall lifetime risk for death due to a fall is 1 in 102. Assessing SR and informing users is a sound strategy to reduce slips and falls. The NFSI has provided some exemplar figures, see Figure 2, that represent low, moderate, and high traction [3].

The NSFI provided specific definitions for low, moderate, and high resistance (Table 2). The exemplars seen in Figure 2 were designed and developed to assist the residential and commercial consumer in selecting products not only for functional and aesthetic appeal but also for safety reasons. The exemplars were created to convey the meaningful slip resistance values listed in Table 2 [3]. The arrows pointing to the classifications of traction are consistent with prior NFSI standards adopted in 2015 for recommended slip resistance categories [3]. The expectation is that manufacturers would provide the information using the exemplars at the point of purchase with the product to fully inform purchasers. The NSFI supports the CSPC adoption of proposed standards and labeling to improve walkway safety and consumer understanding of potential risks associated with low-traction walkway flooring purchased by residential and commercial consumers. The actions further inform the purchaser that ongoing monitoring and evaluations are necessary to assure safety. The actions also make the purchaser aware that slip resistance enhancing applications are available that can improve traction when slip resistance measures indicate loss of traction due to wear. The overall strategy supports consumer safety and is expected to reduce the incidence of slip and fall-related injuries and fatalities.

Many authors have published definitions for the classification ranges of SR [1]. Most sources identify 0.50 SR as the safe level [14]. Others have identified SRs of 0.45 through 0.58 as safe and above 0.58 as very safe. The same authors identified 0.33 through 0.45 as conditional safe.

They also identified SRs of 0.20 through 0.33 as unsafe and below 0.20 as very dangerous. The researchers evaluated several wet floor surfaces in a variety of businesses including a state agency, hospital, school, university, and pharmacy, and found results as low as ranging from 0.17 to 0.45. Wet surface evaluations revealed that 29 of 60 were in the unsafe and dangerous ranges. Dry surface evaluation ranged from a low of 0.29 to a high of 0.52 with 22 of 60 in the conditional safe and safe ranges. Grieser and Frantz [17] evaluated 10 different walking surfaces both wet and dry using five different brands of coatings. The researchers evaluated painted concrete and wood floor surfaces. They also found significant reductions, p - value < 0.05, in SR for wet surfaces compared to dry for both concrete and wood. The investigators found dry SR on concrete was 0.80 or higher for all painted surfaces and wet testing revealed SR values significantly lower but above 0.70. Whereas, testing of wood floor material with five different coatings had a much greater drop in SR when wetted. Dry SR values were all above 0.70 followed by a precipitous drop when wetted, p - value < 0.05, with three of five values being 0.40 or lower however, two were above 0.50 even when wet [18-24].

Our results are consistent with other researchers' findings. We did not test multiple coatings and preferentially used the single Dura Grip coating on all types of flooring surfaces. It becomes clear that wetted surfaces significantly decrease the SR. The adoption of uniform standards would help all stakeholders. The NFSI is attempting to accrue support for the CPSC to move forward with standardized labeling of floor and walkway surfaces and bring consistency to SR ranges. We reject both our hypotheses, there were significant (p - value < 0.05) differences seen in measurements when comparing dry to wet surfaces and non-coated to coated. We are reminded that multiple factors may play a role in the occurrence of a slip and fall event not just the SR of the walkway surface. However, intrinsic factors and shoe types cannot be controlled in most circumstances. Walkway safety requires planning and execution of best practices, diligence, and effort to maintain safety on the part of property owners, establishments, and occupants. Measuring SR is an important first step in assessing risk and should not be overlooked. If SR measures are below 0.50, one option is to consider anti-slip coatings such as Dura Grip or an equivalent. Despite the application of coatings, repeated evaluation remains necessary as the use of the walkway surface may wear away the coating or reduce and/or eliminate asperities over time.

Limitations

All measurements have a margin of error. The English XL VIT requires operators to be within +/-0.03 when using the device. All operators established competency with the device to this limit and demonstrated consistency on the calibration tile under the supervision of a CXLT. Measurements taken should have no more variance than 0.03. Operators followed all procedures outlined in the operations manual but could have made an undetectable error.

The room temperature and humidity were monitored during each test session. Very little variance was seen in the temperature, however; the 2° difference between testing sessions seen may have affected our results. The humidity was consistent at 16%. Our electronic equipment may have had some small margin of error.

The floor surfaces were randomly selected from a much larger group of floor surface samples at the establishment and do not represent all floor and walkway surfaces. We attempted to follow all manufacturer's procedures for tile coating preparation and application. We used the citrus cleaner as instructed by the supplier but recognized that other investigators used alcohol for cleaning and time preparation. The citrus cleaner may have altered the measurements in some way. We applied the Dura Grip per the manufacturers' instructions and waited 36 hours before testing SR. We may have made an error in the application process. Based on these limitations, we can't establish their effect on the investigation process nor differential bias toward or away from the null hypothesis.

Conclusion

This research project demonstrated the effect of walking surface contamination with tap water. Water remains the most common contaminant associated with slip and fall events. The investigation also demonstrated that non-slip coatings such as Dura Grip may significantly increase SR and improve the safety of flooring and walkway surfaces. Our research confirms what others have found in various research studies. We identified significant decreases in SR measures on most surfaces when contaminated with tap water and that the application of a non-slip coating increased SR in all cases. Future research should include the evaluation of more coatings for walkways and floor surfaces. We also support the adoption of standardized labeling and definitions of SR ranges for consumers as recommended by the NFSI. We also advocate for due diligence with a comprehensive walkway safety program to ensure user safety by reducing controllable risks. The challenge is great thus, the burden of slip and fall-related injuries should be a priority.

Declarations

Contributions: Cal Snow was a senior student working on the team to complete his senior project. Cal was involved in all phases of the study. He demonstrated competency using the English XL VIT and completed several measurements on floor surfaces. He participated in the development and review of the manuscript.

Cody Hays is a senior student working on the team to complete his senior project. Cody was involved in all phases of the study. He demonstrated competency using the English XL VIT and completed several measurements on floor surfaces. He participated in the development and review of the manuscript.

Sara Girard was a senior student working on the team to complete his senior project. Sara was involved in all phases of the study. He demonstrated competency using the English XL VIT and completed several measurements on floor surfaces. He participated in the development and review of the manuscript.

Lorri Birkenbuel is a professor in the department and was a co-primary faculty for the Senior Projects class. She was involved in all phases of the study and helped supervise students. Lorri assisted in the development and review of the manuscript.

Dan Autenrieth is a professor in the department and was a co-primary faculty for the Senior Projects class. Dr. Autenrieth was involved in all phases of the study and helped supervise students. Dr. Autenrieth led the analysis strategies and assisted in the development and review of the manuscript.

David Gilkey is a professor in the department and assisted the Senior Projects class. He was the CXLT for the project. Dr. Gilkey was involved in all phases of the study and was the primary supervisor for students on the project and assisted in the development and review of the manuscript.

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