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Generalizability of Footwear Traction Performance across Flooring and Contaminant Conditions

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Abstract

Background: To prevent slip and fall events at the workplace, mechanical slip testing is conducted on shoes. Such experiments may involve redundant testing across floorings and contaminant conditions, causing wasted time and effort.

Purpose: Quantify the correlations between shoe traction across different contaminant-flooring conditions to reduce redundant slip testing efforts.

Methods: The available coefficient-of-friction (ACOF) was quantified for 17 shoes across five floorings and three contaminant conditions. Redundant testing conditions were identified when the shoe ACOF values for one floor-contaminant condition were highly correlated with a second floor-contaminant condition.

Results: High correlations were observed among quarry floorings across different contaminants and among vinyl (composite tile) floorings with the same contaminant. However, vinyl floorings exhibited low correlations with quarry floorings. Low correlations were also observed across contaminants within vinyl tiles.

Conclusions: This study was able to determine the generalizability of traction performance of shoes across vinyl and quarry floorings. This information is anticipated to reduce redundant traction testing of shoes across vinyl and quarry floorings.

Keywords

Slip; Traction; Coefficient of Friction; Vinyl; Quarry; Footwear

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Conflict of Interest
The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

1. Introduction

Human feet and the shoes that protect them are highly used and go through an average of 5000-7000 steps a day (Bassett Jr, Wyatt, Thompson, Peters, & Hill, 2010). Exposure to different surfaces commonly leads to slips and falls at the workplace, causing numerous injuries. The National Safety Council (NSC) has estimated the frequency of falls as being over 25,000 daily in the US and costing over $70 billion in annual medical costs and compensations (Di Pilla, 2016). The US Department of Labor-Bureau of Labor Statistics (BLS) (2016) estimated that 27% of reported workplace injuries are due to slips and falls. A majority of the falling events initiate with slipping (W.-R. Chang et al., 2001). Therefore, better slip prevention strategies are an imperative component for injury prevention strategies.

Slipping is significantly influenced by the friction or traction condition at the interface of the shoe and the floor (Strandberg & Lanshammar, 1981). To quantify shoe-floor friction, the available coefficient of friction (ACOF) is measured using mechanical slip testers (Beschorner, Redfern, Porter, & Debski, 2007; W.-R. Chang et al., 2001; W.-R. Chang, Leclercq, Lockhart, & Haslam, 2016; W. Chang, Courtney, Gronqvist, & Redfern, 2003). Previous experimental studies have indicated that the difference between the ACOF and required coefficient-of-friction (RCOF) for walking is a good predictor of slips (Beschorner, Albert, & Redfern, 2016; Burnfield & Powers, 2006; Hanson, Redfern, & Mazumdar, 1999). Hanson et al. (1999) investigated the probability of slips based on RCOF and ACOF measurements. It was concluded that the chances of slipping increased as the difference between ACOF and RCOF decreased. The proportion of exposures resulting in a slip approached 1 as ACOF-RCOF approaches negative infinity. Recently, Jones et al. (2018) evaluated the ACOF values of standard slip-resistant shoes (SR) in the market. Twelve shoe designs were tested with three contaminants and five different flooring materials using a biofidelic slip tester, and the rate of slipping was evaluated with a human-subjects study. This study concluded that important variability existed across slip resistant shoes, indicating the need for testing of these shoes.

To date, a wide range of mechanical slip testing devices have been used to measure friction at the shoe-floor interface (W.-R. Chang et al., 2001). Two important aspects of testing include “biofidelity” (i.e., the ability to mimic the under-shoe dynamics of a human slip) and “environmental fidelity” (i.e. the ability to mimic the walkway surfaces and contaminant conditions common to slip and fall accidents) (W. Chang et al., 2003). However, due to design and reproducibility issues (W.-R. Chang et al., 2016), shoe movements have been simplified from what is observed in an actual slipping experiment with human subjects (Cham & Redfern, 2002; Perkins, 1978; Strandberg, 1983). More drastic simplifications were made with portable slip testers due to weight and portability constraints, leading to limited fidelity with the actual shoe-floor interface (W.-R. Chang et al., 2016). Substantial differences are present between ACOF results quantified across slip meters (W.-R. Chang et al., 2001). A range of ACOF values have also been found for a particular shoe across different floor-contaminant test conditions (Grönqvist, 1995).

To better understand the complexities associated with friction measurements, Chang et al. (2003) suggested testing shoes on realistic floors and contaminant conditions. Current footwear traction testing reports are typically limited to a few flooring and contaminant conditions, leading to questions about the footwear's performance on other floor-contaminant conditions (Blanchette & Powers, 2015; Li, Wu, & Lin, 2006). Increasing the number of shoes, contaminants, or floorings, can greatly expand the number of test conditions. An example is data reported data by the UK Health and Safety Laboratory (2009) of 63 shoes on three floorings and two contaminant conditions. This study resulted in over 250 test conditions, which still only represents a small fraction of the tests needed to assess the shoes on all relevant floor-contaminant conditions.

Therefore, the need to test across different flooring materials and contaminant conditions must be balanced against practical constraints. It is not possible to anticipate and test all of the walking surfaces that a footwear might experience. Ideally, testing should be done on surfaces that are representative of a range of floor-contaminant conditions. Unfortunately, a paucity of information exists regarding the correlations of the footwear traction across floor and contaminant conditions. Thus, it is unclear whether shoe traction performance on one surface and with one contaminant can be used to estimate that shoe's performance on another surface. In the current work, the slip resistance of 17 different shoes was tested on five different floors and with three different contaminants. An analysis was conducted to characterize the correlations between ACOF across various contaminant and flooring conditions. The main purpose of the study was to understand the generalizability of shoe slip resistance across common floorings and contaminant conditions.

2. Materials and Methods

2.1 Shoes, floor materials and contaminants tested

Shoes labeled as slip-resistant (SR) as well as those that did not include this label (NSR) were procured from 10 different brands. Footwear selection aimed at having a wide variation across those which are worn in indoor work settings, including the ones labeled as SR, and those which are commonly worn as an alternative to SR (Jones et al., 2018). A total of 17 shoes (Six Oxford-style work shoes, three clogs, seven comfort shoes, and one athletic shoe) were tested (Table 1). The NSR shoes chosen for the study were selected as potential shoe designs commonly purchased as an alternative to SR shoes for indoor work environments. The shoes were U.S. Men's size 9 or Women's size 10 (J2 in Table 1) right shoes. Shoe codes were assigned using a letter (A-K) corresponding to a specific brand, followed by a number (1-4) referring to a certain style within a shoe brand.

ACOF values were measured on five different floors including two polymer designs (both were vinyl composite tiles, or "vinyl"), and three quarry designs (one labeled as ceramic and two labeled as quarry). The ceramic tile and one of the vinyl tiles ("ref vinyl") were reference tiles from the ASTM F2508 standard (2012). The second vinyl tile was used because it was installed in a gait laboratory for a human validation analysis, which is described in Jones et al. (2018). The quarry tiles were chosen to simulate common flooring used in the food industry (W.-R. Chang, Li, Filiaggi, Huang, & Courtney, 2008). One tile (Quarry 2) included abrasive particles, while the other (Quarry 1) did not. The mean surface roughness deviations of the floor surfaces (R_a) was measured using a 2D contact profilometer (Surtronic S-100, Taylor-Hobson, AMETEK, Leicester, England) (Table 2). Each measurement was recorded at three different locations and orientations.

Three contaminants were tested, including water, a mixture of sodium laurel sulfate (SLS) (0.5% by volume) and water (99.5% by volume), and canola oil. The viscosities of these contaminants were measured using a rheometer (Brookfield AMETEK LVDVE115 with spindle UL/Y, Middleboro, MA). Canola oil was applied to represent a high viscosity contaminant that is commonly found in kitchens. SLS is a reference contaminant from the ASTM F2913-17 standard (2017) and has been used in previous work (Jones et al., 2018) to simulate a detergent aqueous solution. Water is the most common low viscosity contaminant used in traction testing (A. Iraqi, Cham, Redfern, Vidic, & Beschorner, 2018; Jones et al., 2018) and is ubiquitous in work and living environments.

2.2 Slip testing Experiments

A portable, biofidelic slip simulator, based on the design by Aschan et al. (2005), was used in our study to quantify ACOF values (Figure 1 A). The normal and shear forces were measured using a force plate (Bertec FP4060, Columbus, OH). Three parallel linear servomotors (LinMot PS01-37X240, Elkhorn, WI, USA) were used to generate vertical forces. One similar motor (LinMot PS01-48X240, Elkhorn, WI, USA) was placed horizontally to apply horizontal forces and generate the sliding movement (Figure 1 A). The slip tester had a mechanism for altering the shoe-floor angle (Figure 1 A), in order to maintain the same angle across different shoe designs. A sufficient amount of contaminant was applied to the floor to simulate a flooded condition (Jones et al., 2018). A shoe-floor angle of 17 ± 1° was set, and a normal force of 250 ± 25 N was applied along with a sliding speed of 0.5 m/s. The normal force value was maintained for 200 ms. The normal and frictional shear force measurements were obtained by the force plate during this time interval. ACOF was estimated as the mean ratio of frictional shear and normal forces recorded over 200 ms (Figure 1 B) (Jones et al., 2018). The mean normal force across this period was 250 ± 10 N. For each test condition, five trials were conducted, and the mean ACOF results were obtained across the five trials. The contaminant on the floor was cleaned between contaminant conditions with a mixture of water and detergent, rinsed and dried. With a few of the shoe-floor-contaminant conditions, specifically E1 shoe with SLS on Ref Vinyl, and A2, D1, D2, E1 and E2 shoes with SLS on vinyl, slip stick was observed. The slip stick phenomenon occurs when the shoe alternates between sticking to the flooring and sliding across the flooring, with a corresponding change in the vertical and shear forces. This occurrence altered the applied normal force, outside of the 250 ± 25 N range. The loading conditions used in this study were selected because they are consistent with the heel dynamics during slip initiation (Jones et al., 2018), are predictive of slipping (A. Iraqi, Cham, R., Redfern, M.S., Beschorner, K.E., 2018), and are part of a draft standard for shoe friction that is currently being considered (ANSI/NFSI B101.7-2018).

2.3 Data analysis

Bi-variate correlation analyses were performed for the shoe ACOF values across each combination of floor and contaminant, and the level of correspondence between any two contaminant-flooring conditions was described using r^2. An r^2 threshold of 0.5 was used to qualitatively differentiate between good (or high) and poor (or low) levels of correspondence ((Morris, Smith, Cowen, Friston, & Dolan, 1999)). Specifically, the ACOF from all 17 shoes for one floor and one contaminant (e.g., ceramic with canola oil) were compared against the ACOF from all shoes for another floor and contaminant (e.g., vinyl with water). For every correlation, two-sided *t*-tests were used to assess the null hypothesis that the slope of the best fit line was zero. All analyses were conducted with a significance level (α) of 0.05. Statistical comparisons of ACOF across shoes were not performed here, as this information has been reported previously (Beschorner, Jones, & Iraqi, 2017; Jones et al., 2018).

3. Results

3.1 Traction of shoes across different floorings with the same contaminant

Correlations across floors were highly variable even when the same contaminant was used. With water contamination, good correlations in the ACOF values were observed when the two flooring materials were ceramic and/or the two quarry tiles (r^2>0.88, p<0.001), and when the two vinyl tiles were compared (r^2>0.70, p<0.001) (Figure 2). However, poor correlations (r^2<0.21) were observed between the ACOF of one of the two vinyl tiles and one of the other flooring tiles (ceramic, quarry 1 and quarry 2). An example of poor correlation (r^2=0.07, p=0.30, t=1.07) of ACOF was between the ceramic floor and ref vinyl floor (Figure 3A). An example of a good correlation (r^2=0.88, p<0.001, t=10.48) was between the ACOF of quarry 1 and the ceramic floor (Figure 3B). The highest correlations were observed for ceramic and quarry 2 floorings (r^2=0.94, p<0.001), followed by the quarry 1 and quarry 2 floorings (r^2=0.91, p<0.001). The lowest correlation values reported were for ref vinyl and ceramic (r^2=0.04, p=0.46); vinyl and ceramic (r^2=0.07, p=0.30); and ref vinyl and quarry 2 (r^2=0.07, p=0.30).

Testing of shoes on different floorings with SLS indicated similar results to the water contamination (Figure 4). With SLS, strong correlations (r^2>0.85, p<0.001) were observed across ceramic, quarry 1 and quarry 2 floorings. The two vinyl tiles were correlated but not as strongly as in the water condition (r^2=0.50, p<0.001). The ceramic, quarry 1 and quarry 2 tiles exhibited low correlations with ref vinyl tile and the other vinyl tile, but not as low as was observed for water.

Testing of shoes on different floorings with canola oil exhibited generally higher correlations than water or SLS (Figure 5). The highest correlation (r^2=0.91, p<0.001) was estimated for the ceramic and quarry 2 floorings, followed by the correlation between the ref vinyl and vinyl floorings (r^2=0.82, p<0.001). Overall, the ceramic, quarry 1 and quarry 2 floorings correlated well (r^2>0.72, p<0.001). The correlations between the vinyl floorings and the ceramic, quarry 1 and quarry 2 were recorded in the range 0.53<r^2<0.82 and with significance p<0.001.

3.2 Traction of shoes across different contaminants

Correlations across contaminants within a floor surface condition were variable (Figure 6). For ref vinyl and vinyl floorings, low correlations were observed between water and SLS contaminants (0.22<r^2<0.25), and between water and canola oil contaminants

(0.26<r^2<0.34). However, comparatively higher correlations (0.47<r^2<0.57, p<0.001) were observed between SLS and canola oil contaminations. For ceramic, quarry 1 and quarry 2 floorings, higher correlations were observed across all contaminants than for the vinyl tiles (r^2>0.56, p<0.001). The highest correlations were observed for water and SLS contaminants (r^2>0.81). Correlations between water and canola oil were between 0.56 and 0.76, and between SLS and canola oil were between 0.58 and 0.70.

3.3 Traction of shoes across different floorings and different contaminants

The traction or ACOF were correlated for certain cases when changing both the floor and contaminant conditions (Table 3). ACOF estimated with Ref vinyl and any contaminant exhibited generally low correlation with ACOF of the other vinyl when the contaminant was also different (r^2<0.50 for 5 out of 6 cases). Between a vinyl tile and a quarry tile with a different contaminant, low correlations were generally observed (r^2<0.50 for 32 out of 36 cases). Generally, higher correlations were observed within the quarry tiles (ceramic, quarry1 or quarry 2) with a different contaminant (0.5<r^2<0.92, p<0.001).

4. Discussion

This study generated novel findings on the generalizability of traction (measured in terms of ACOF) of shoes across common flooring and contaminant conditions. Testing across different floorings revealed strong correlations among ref vinyl and vinyl tiles, and among ceramic and quarry tiles, for all three contaminations. Weaker correlations were observed between vinyl tiles and the ceramic or quarry tiles. Stronger correlations were observed across all floorings with the canola oil contamination compared to water and SLS contaminations. Across different contaminants for ref vinyl and vinyl floorings, comparatively higher ACOF correlations were observed between SLS and canola oil contaminations, than across water and SLS, and water and canola oil. For the ceramic and quarry floorings, strong correlations were quantified across all contaminants. When flooring and contaminants were both changed, low correlations were observed between either the ref vinyl or vinyl floorings and ceramic, quarry 1 or quarry 2 floorings. Higher correlations were observed among the ceramic, quarry 1 and quarry 2 floorings when both flooring and contaminant were changed. Thus, shoe performance on any quarry tile with any contaminant can be generally applied to other quarry tiles but not to vinyl tiles. Results from vinyl tiles can be generalized to other vinyl tiles but may not be applicable when the contaminant is also different. These results clarify the generalizability of traction for different shoe-contaminant-floor conditions, and also could help reduce redundant test conditions.

The correlation results across floorings and contaminants in the present study are somewhat similar to ACOF correlations across floorings and contaminants estimated using traction testing data that has been reported by other groups. To make this comparison, correlations were performed across 63 shoes using reported data by the UK Health and Safety Laboratory (2009) across different floorings and contaminants (Figure 7). It was observed that with water contaminant, low ACOF correlations were observed across floorings (e.g. r^2=0.18 between steel and chequer plate). However, higher correlations (0.34<r^2<0.53) were quantified across floorings with glycerol contamination. Our study findings are consistent with these observations of higher ACOF correlation across floorings for a more viscous contaminant (e.g. oil or glycerol) over a less viscous contaminant (e.g. water). For any particular flooring, testing across different contaminants (Laboratory, 2009) exhibited moderately low correlations ($0.36<r^2<0.41$). The correlations for these floorings were similar (i.e. Steel and chequer plate) to those observed with the vinyl floorings used in this study (i.e. Ref vinyl and vinyl) where moderately low correlations ($0.22<r^2<0.47$) were observed across contaminants. It should be noted that a different device for testing ACOF and the different floorings may account for the differences in correlation magnitudes between this prior study and the present study (the previous study used the SATRA STM 603 whereas this study used the portable slip simulator).

Some of the current results can be explained based on the tribology mechanisms relevant to shoe-floor friction. Since the shoes included here contained treads, the predominant lubrication regime was likely boundary lubrication with minimal hydrodynamic pressures (Hemler & Beschorner, 2017; Singh & Beschorner, 2014). The two primary friction mechanisms in boundary lubrication are adhesion and hysteresis (W.-R. Chang et al., 2001; S. R. M. Moghaddam, Redfern, & Beschorner, 2015; Strobel, Menezes, Lovell, & Beschorner, 2012). Adhesion friction is highly dependent on the contaminant and can be substantially reduced by detergents (e.g., SLS) and canola oil (Cowap, Moghaddam, Menezes, & Beschorner, 2015; Strobel et al., 2012). Thus, hysteresis tends to be the dominant mechanism in the presence of contaminants that reduce adhesion friction. Hysteresis is a mechanical interaction that is highly sensitive to contact pressures, and therefore, the design of the shoe tread (Jones et al., 2018; S. R. Moghaddam et al., 2017). Shoes are expected to deform similarly across different floor surfaces leading to similar contact pressures, explaining the strong correlations in the presence of hysteresis friction. However, adhesion is dependent on several mechanical and chemical phenomena that lead to forces formed at the contact regions between two contacting surfaces (e.g., shoe and flooring). These forces are dependent on the combination of surfaces and the adhesion forces can be substantially different when changing either of the contacting substrates (Zeng, 2013). For a specific shoe, the adhesion on one floor surface is not necessarily translatable to another floor surface. Given that adhesion forces are higher for water than SLS or canola oil (Cowap et al., 2015; Strobel et al., 2012), this may explain the poor correlations across floor surfaces in the presence of water and the low correlations between water and SLS or canola oil. Thus, this study suggests that friction due to hysteresis may be more generalizable across contaminants and flooring than friction due to adhesion.

This study has two major implications with respect to traction testing of shoes. First, the ACOF of quarry floorings was generally applicable across different types of quarry within the same contaminant. Also, ACOF of shoes on one type of quarry tile with any contaminant was found to be highly correlated with another type of quarry tile with a different contaminant. Thus, future traction performance testing of shoes on only one type of quarry flooring with any one contaminant condition can provide an estimation for that shoe's performance on other quarry tiles, even in the presence of different contaminants. Second, ACOF of shoes on vinyl floorings was observed to be reasonably representative ($r^2 > 0.5$) of their performance on another vinyl flooring for the same contaminant.

This study has a few limitations which should be acknowledged. Out of a large number of possible flooring and contaminant conditions, only a few designs were considered. Specifically, some common floorings and contaminants observed in indoor spaces such as in offices, restaurants, and hospitals were tested. Caution should be utilized when extrapolating these results beyond the types of flooring considered in this study. Considering additional flooring and contaminant conditions (including the ones encountered outdoors such as in mining environments) may further our understanding on generalization of traction across surfaces. With respect to the slip testing device, using a different slip tester (with different slip testing parameters: normal force, sliding speed, and shoe angle) operating within the boundary lubrication regime, may change the correlation results slightly due to some changes in the ACOF measurements (Beschorner et al., 2007). ACOF values might change more dramatically in cases where hydrodynamic pressures are substantial (i.e., high viscosity, high sliding speed, low force) since this would fundamentally change the mechanisms contributing to ACOF. Thus, these results may be poorly applicable to traction testing at high sliding speeds and low normal forces. However, small changes in testing conditions are not expected to change the friction mechanisms and, therefore, the conclusions from this work.

In conclusion, this study provides important information on the generalizability of shoe traction performance across different flooring and contaminant conditions. This information can lead to a better understanding of the similarities of shoe traction performance across contaminants and across vinyl and quarry floorings. Lastly, the results of this study can help reduce redundant slip testing, by decreasing the number of test conditions needed to assess a shoe's performance on vinyl and quarry tiles.

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Occupational Applications

This study investigate the correlations between available coefficients-of-friction (ACOF) of 17 work shoes across different flooring and contaminant conditions. Five floorings (two vinyl tiles and three quarry tiles) were tested with water, sodium laurel sulphate (SLS), and canola oil. Shoe ACOF performance on a single quarry surface with any of the three contaminants was generally applicable to all other quarry-contaminant conditions. Shoe ACOF performance for a vinyl tile was generally applicable to another vinyl flooring for the same contaminant. These findings are anticipated to reduce the need for redundant shoe ACOF testing and clarify the generalizability of traction testing results.

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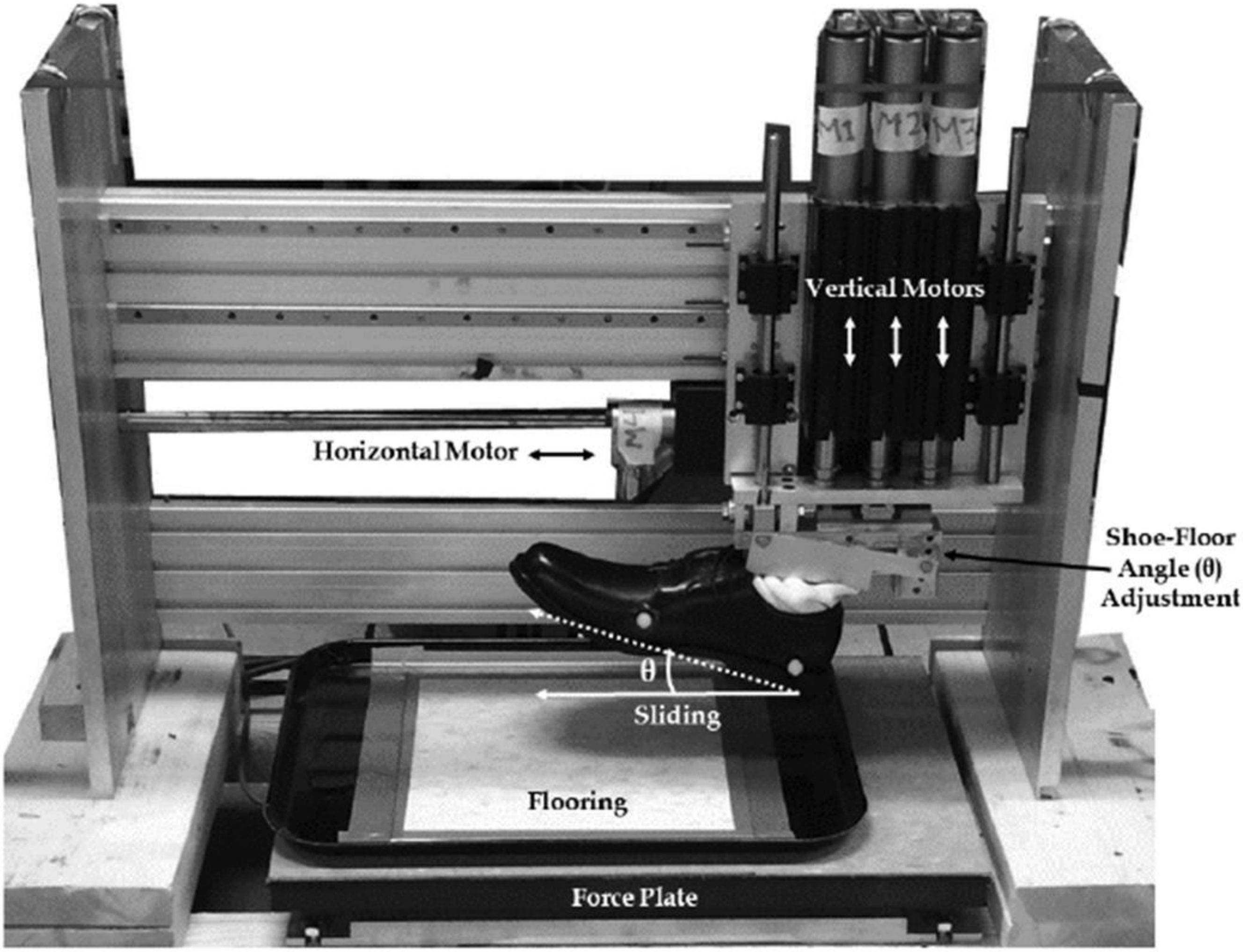

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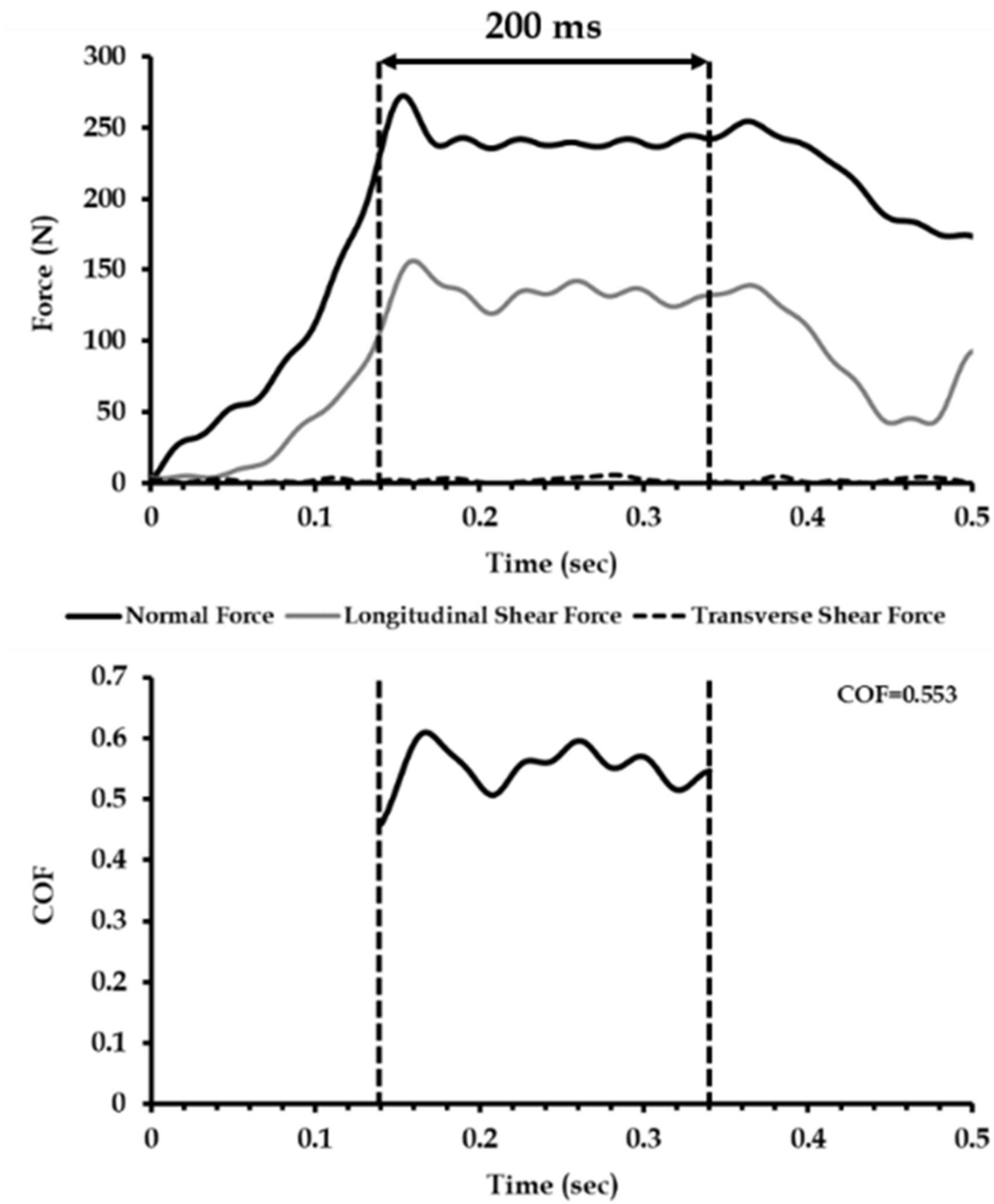

Figure 1:

A) Portable slip tester used in the current testing (Aschan et al., 2005; Jones et al., 2018), B) Representative forces for a slip-testing trial. The COF is determined as the mean COF from the time that the force first exceeds 250N until 200 ms later.

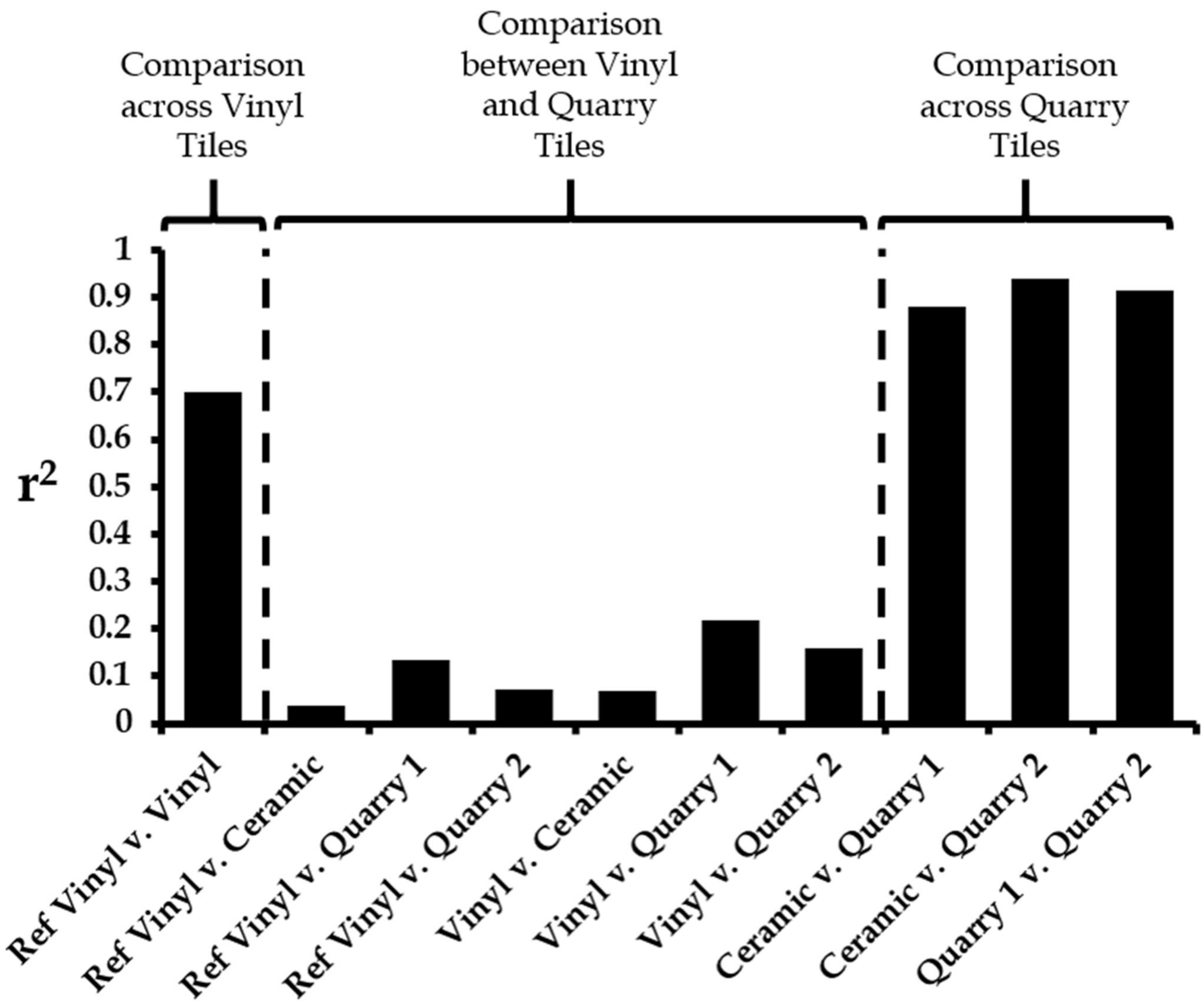

Figure 2:
ACOF correlations for different floorings with water contaminant exposure.

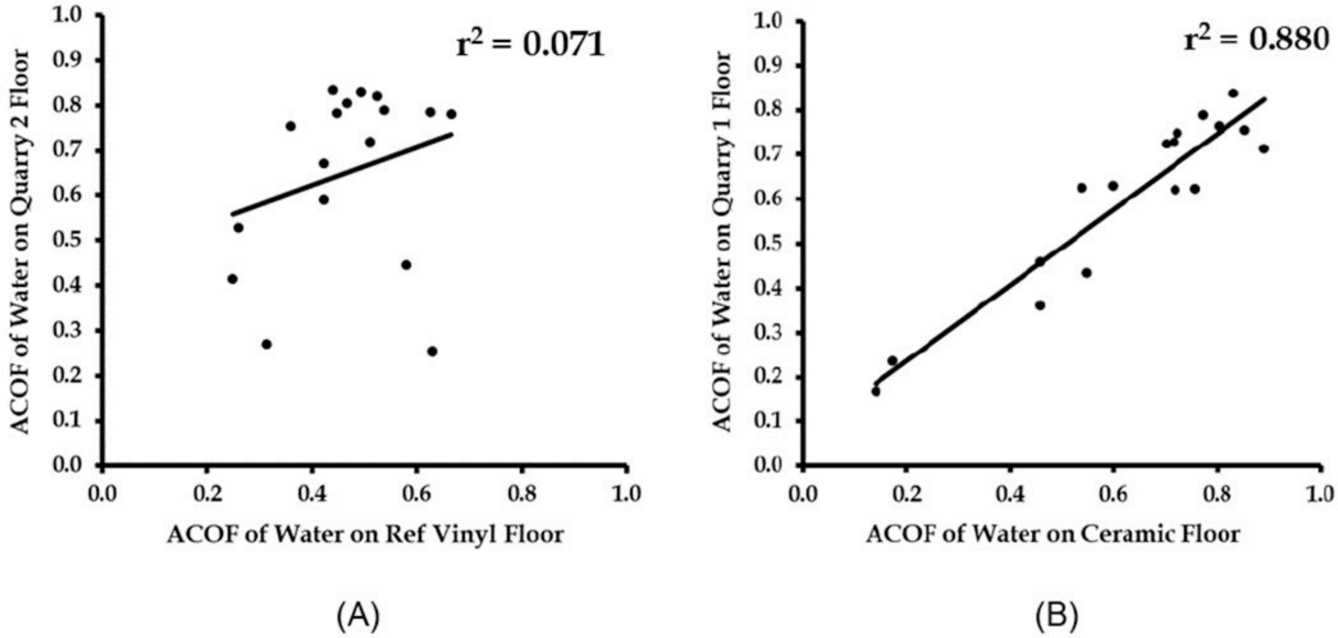

Figure 3:

Correlations of ACOF between floorings for all 17 shoes with water contamination: A) Ref vinyl and quarry 2, and B) Ceramic and quarry 1.

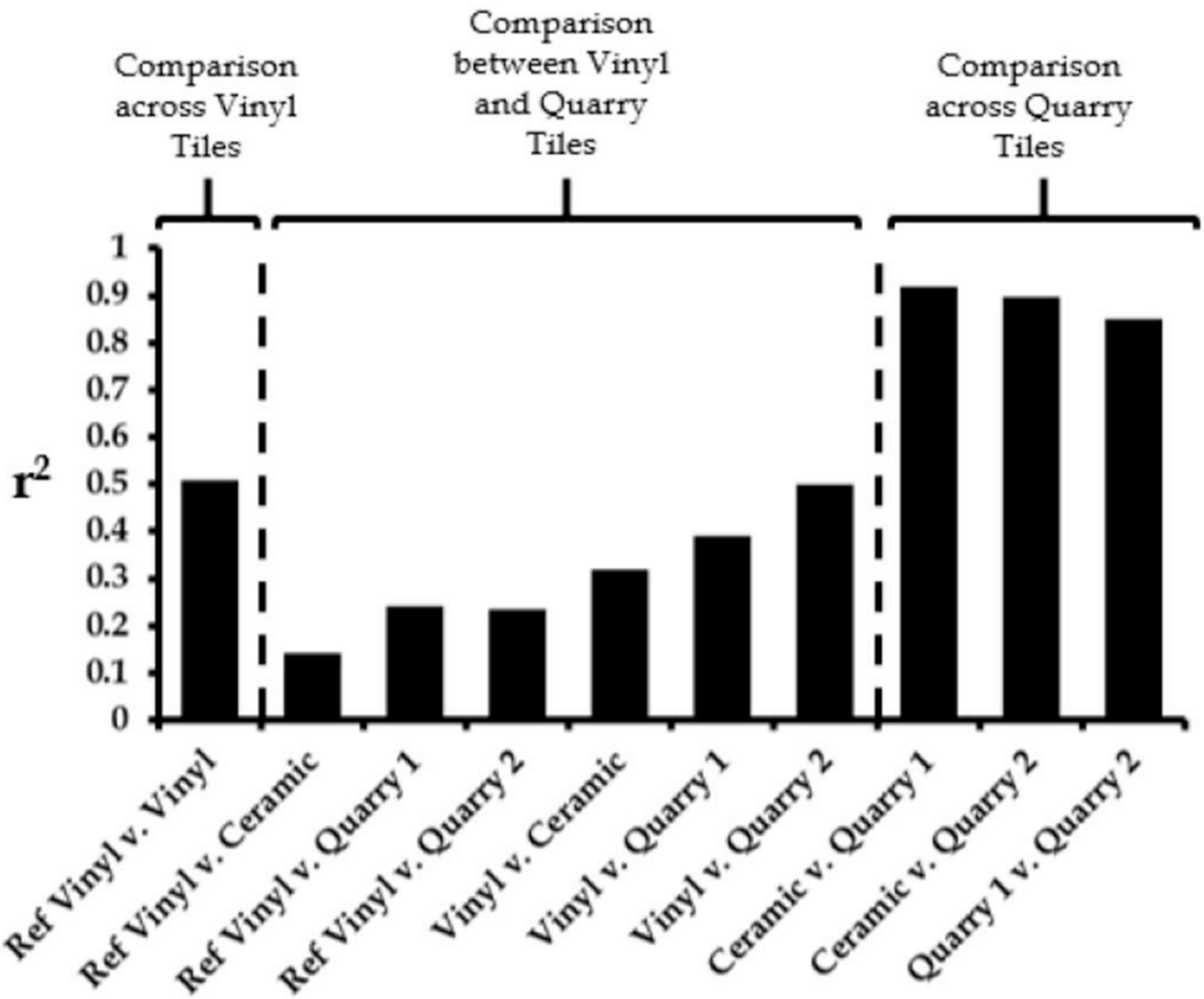

Figure 4:
ACOF correlations for different floorings with SLS contaminant exposure.

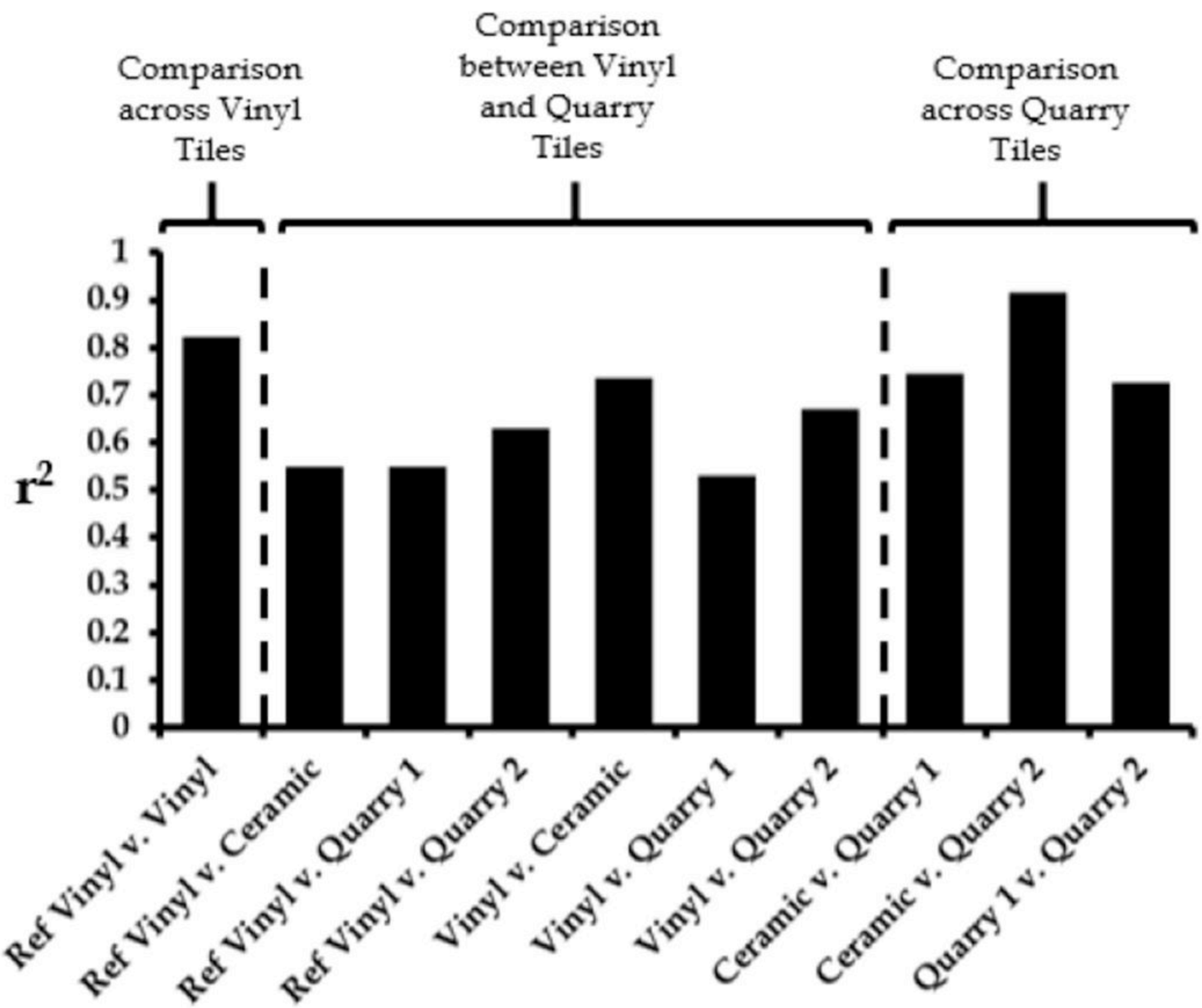

Figure 5:
ACOF correlations for different floorings with Canola Oil contaminant exposure

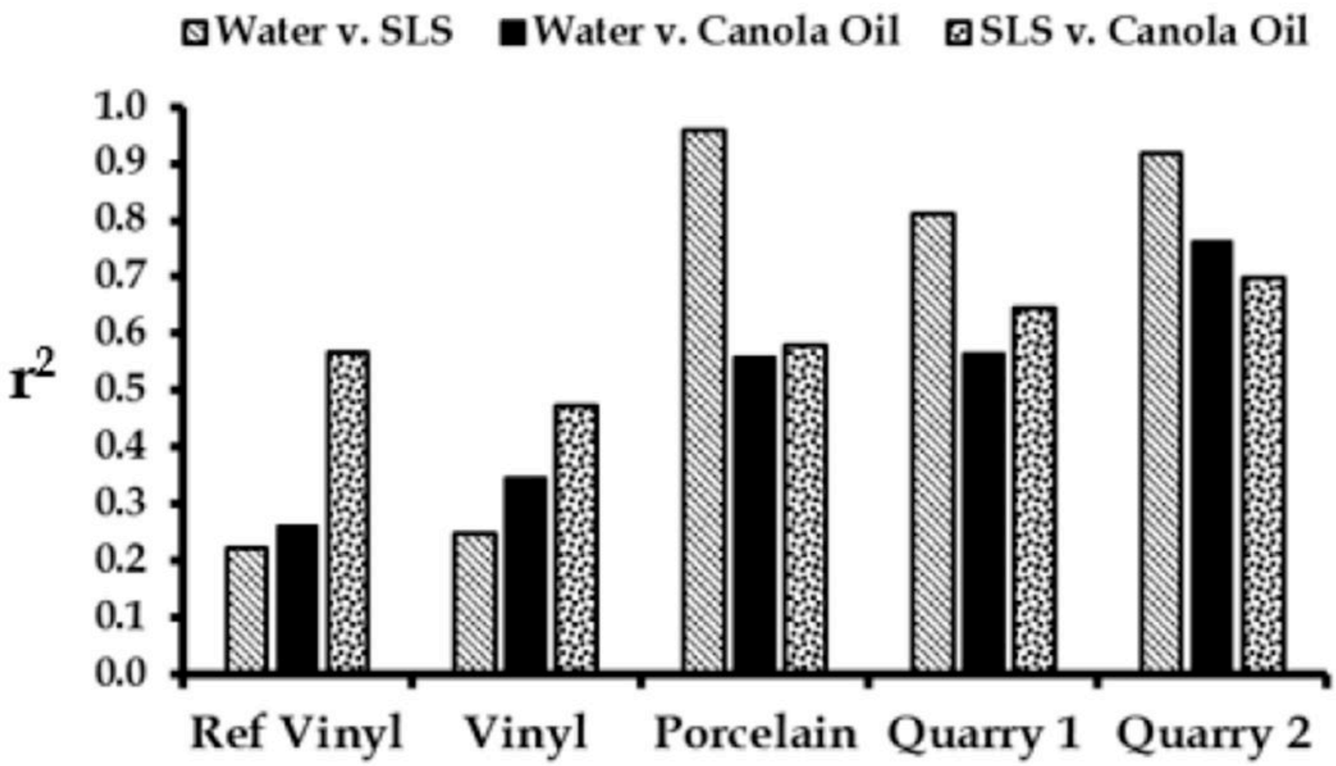

Figure 6:
ACOF correlations for floorings with different contaminant exposures.

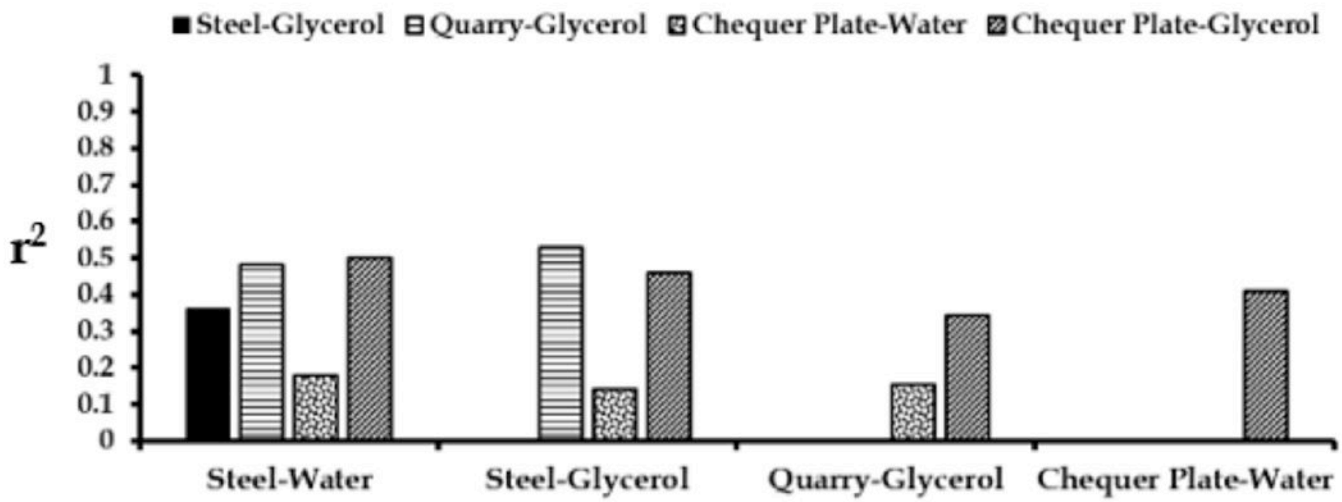

Figure 7:
ACOF correlations across flooring-contaminant combinations.

Table 1:

Specifications of shoes tested including shoe code, SR (Slip Resistant) and NSR (Non Slip Resistant) designation, shoe style, shoe brand and model.

Shoe Code	SR/NSR Type	Shoe Style	Shoe Brand (*Model*)
A1	SR	Dress	SR Max (*SRM3500*)
A2	SR	Comfort	SR Max (*SRM6200*)
A3	SR	Clog	SR Max (*SRM7500*)
B1	SR	Dress	Shoes for Crews (*Cambridge 6006*)
B2	SR	Comfort	Shoes for Crews (*Freestyle 6010*)
C1	SR	Dress	Keuka (*Equity 5000*)
C2	SR	Comfort	Keuka (*Galley 55014*)
D1	SR	Dress	SafeTstep (*Able 151864*)
D2	SR	Comfort	SafeTstep (*Apollo 140060*)
E1	SR	Dress	Tredsafe (*MNTS0541002*)
E2	SR	Comfort	Tredsafe (*M151044BU*)
E3	SR	Clog	Tredsafe (*M151045AD*)
F1	NSR	Dress	ECCO (7582583)
G2	NSR	Comfort	Converse (IT865)
H4	NSR	Athletic	Nike (705149010)
J2	NSR	Comfort	TOMS (001001B07)
K3	NSR	Clog	Crocs (203261)

Table 2:

Specifications of flooring materials and contaminants tested

Flooring Material Specifications		
Floor Type	**Make (*Model*)**	**Surface Roughness, R_a (μm)**
Ref Vinyl	ASTM (*ADJF250801*)	1.44 ± 0.22
Vinyl	Armstrong (*51804*)	1.76 ± 0.28
Ceramic	ASTM (*ADJF250803*)	3.82 ± 0.19
Quarry 1	Daltile (*0T01881P*)	4.74 ± 0.72
Quarry 2	Summitville (*01 010 SM 1*)	6.51 ± 1.83
Contaminant Specifications		
Contaminant Type	**Viscosities (cP)**	
Water	0.98 ± 0.01	
SLS	1.21 ± 0.02	
Canola oil	65.4 ± 0.20	

Table 3:

ACOF Correlation Coefficients (r^2), t-values, and p-values (p<0.05, shaded gray) for the same flooring (Bold), same contaminant and different floorings (bold and italics), different contaminants and different floorings (plain text)

		REF VINYL			VINYL			CERAMIC			QUARRY 1			QUARRY 2			
		Water	SLS	Canola	Water	SLS	Canola	Water	SLS	Canola	Water	SLS	Canola	Water	SLS	Canola	
REF VINYL	Water		**2.07, 0.55**	**2.29, 0.03**	***5.90, <0.001***	1.60, 0.13	2.92, 0.01	***0.75, 0.46***	0.70, 0.49	2.24, 0.04	***1.53, 0.15***	1.30, 0.21	1.57, 0.14	***1.07, 0.30***	1.14, 0.27	2.16, 0.04	
	SLS	**0.22**		**4.43, <0.001**	2.82, 0.01	***3.92, <0.001***	4.22, <0.001	1.86, 0.08	***1.57, 0.13***	3.17, 0.006	2.85, 0.01	***2.17, 0.04***	2.25, 0.04	2.63, 0.02	***2.14, 0.052***	3.52, 0.003	
	Canola	**0.26**	**0.57**		2.37, 0.03	2.93, 0.01	***8.29, <0.001***	2.15, 0.04	2.07, 0.051	***4.27, <0.001***	3.20, 0.005	3.03, 0.008	***4.28, <0.001***	2.74, 0.01	2.70, 0.01	***5.04, <0.001***	
VINYL	Water	***0.70***	0.35	0.27		**2.21, 0.04**	**2.80, 0.01**	***1.05, 0.30***	0.80, 0.43	2.28, 0.03	***2.04, 0.06***	1.27, 0.22	2.21, 0.04	***1.67, 0.11***	1.34, 0.20	2.24, 0.04	
	SLS	0.15	***0.50***	0.36	**0.24**		**3.65, 0.002**	3.26, <0.001	***2.66, 0.02***	4.19, <0.001	3.86, 0.0015	***3.10, 0.007***	3.92, 0.0013	4.58, <0.001	***3.86, 0.0015***	3.55, 0.003	
	Canola	0.36	0.54	***0.82***	**0.34**	**0.46**		2.02, 0.06	1.96, 0.07	***6.44, <0.001***	2.78, 0.01	3.05, 0.008	***4.12, <0.001***	2.75, 0.01	2.74, 0.01	***5.54, <0.001***	
CERAMIC	Water	***0.04***	0.19	0.24	***0.07***	0.41	0.21		**18.57, <0.001**	**4.36, <0.001**	***10.47, <0.001***	10.32, <0.001	4.07, <0.001	***15.24, <0.001***	12.91, <0.001	5.41, <0.001	
	SLS	0.03	***0.14***	0.22	0.04	***0.32***	0.20	**0.96**		**4.53, <0.001**	7.99, <0.001	***12.96, <0.001***	3.86, 0.0015	10.58, <0.001	***11.39, <0.001***	5.59, <0.001	t-value, p-value
	Canola	0.25	0.40	***0.55***	0.26	0.54	***0.73***	**0.56**	**0.58**		4.66, <0.001	7.37, <0.001	***6.62, <0.001***	5.95, <0.001	5.64, <0.001	***12.79, <0.001***	
QUARRY 1	Water	***0.13***	0.35	0.41	***0.22***	0.50	0.34	***0.88***	0.81	0.59		**8.02, <0.001**	**4.40, <0.001**	***12.66, <0.001***	8.70, <0.001	6.07, <0.001	
	SLS	0.10	***0.24***	0.38	0.10	***0.39***	0.38	0.88	***0.92***	0.78	**0.81**		**5.22, <0.001**	10.38, <0.001	***9.23, <0.001***	9.71, <0.001	
	Canola	0.14	0.25	***0.55***	0.25	0.51	***0.53***	0.53	0.50	***0.74***	**0.56**	**0.64**		5.51, <0.001	5.15, <0.001	***6.29, <0.001***	
QUARRY 2	Water	***0.07***	0.32	0.33	***0.16***	0.58	0.34	***0.94***	0.88	0.70	***0.91***	0.88	0.67		**13.04, <0.001**	**6.96, <0.001**	
	SLS	0.08	***0.23***	0.33	0.11	***0.50***	0.33	0.92	***0.90***	0.68	0.83	***0.85***	0.64	**0.92**		**5.90, <0.001**	
	Canola	0.24	0.45	***0.63***	0.25	0.46	***0.67***	0.66	0.68	***0.92***	0.71	0.86	***0.73***	**0.76**	**0.70**		
		r^2															