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An observational ergonomic tool for assessing the worn condition of slip-resistant shoes

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Abstract

Worn shoes are known to contribute to slip-and-fall risk, a common cause of workplace injuries. However, guidelines for replacing shoes are not well developed. Recent experiments and lubrication theory suggest that the size of the worn region is an important contributor to the shoe tread's ability to drain fluid and therefore the under-shoe friction. This study evaluated a simple test for comparing the size of the worn region relative to a common object (AAA and AA battery) as a means of determining shoe replacement. This study consisted of three components involving slip-resistant shoes: Experiment #1: a longitudinal, mechanical, accelerated wear experiment; Experiment #2: a longitudinal experiment where the same shoes were tested after each month of worker use; and Experiment #3: a cross-sectional experiment that exposed participants to a slippery condition, while donning their own worn shoes. The COF (Experiments #1 and #2); under-shoe fluid pressure (all experiments); and slip severity (Experiment #3) were compared across outcomes (fail/pass) of the battery tests. Shoes that failed the battery tests led to larger fluid pressures, lower coefficient of friction, and more severe slips. This method offers promise for assessing loss in friction and an increase in slip risk for slip-resistant shoes.

Keywords

Slip; trip; fall accidents; footwear; observational tools; personal protective equipment; equipment inspection

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

1. Introduction

Slip-and-falls account for a significant proportion of workplace injuries but can be ameliorated by footwear with high friction. The rate of nonfatal occupational injuries due to falls has been consistently in the range of 25% to 27% between the years of 2011 and 2018 (U.S. Department of Labor- Bureau of Labor Statistics, 2020a, b). Slips are the initiating event for around 50% of these injuries (Courtney et al., 2001). Slip-resistant footwear has emerged as an effective intervention in preventing slips although the efficacy of this footwear is reduced as the shoe ages (Bell et al., 2019; Verma et al., 2011; Verma et al., 2014). Recent research has demonstrated that programs that take an active role in selecting high performance footwear can reduce slip events (Bell et al., 2019). However, best practices for this type of program are still emerging.

The design of the shoe tread is known to influence an individual's slip risk. Coefficient of friction (COF) can vary dramatically across footwear designs (Beschorner et al., 2019a; Grönqvist, 1995; Grönqvist et al., 1993; Iraqi et al., 2018; Iraqi et al., 2020; Jones et al., 2017; Yamaguchi et al., 2015; Yamaguchi et al., 2017). Outsole parameters including contact area (Iraqi et al., 2020; Jones et al., 2018), tread channel features (depth and width) (Beschorner and Singh, 2012; Blanchette and Powers, 2015; Li and Chen, 2004, 2005), and material hardness (Cowap et al., 2015; Iraqi et al., 2020; Jones et al., 2018; Moore et al., 2012; Strobel et al., 2012) have been shown to influence COF. Furthermore, naturally worn (Grönqvist, 1995; Hemler et al., 2018) and artificially worn shoes (Beschorner and Singh, 2012; Gao et al., 2003; Hemler and Beschorner, 2017) have demonstrated a reduced shoe-floor COF on oily surfaces relative to their new counterparts. Lower COF values are associated with higher slip risk (Beschorner et al., 2019a; Hanson et al., 1999; Iraqi et al., 2018). Thus, identifying footwear tread features that enhance friction and thus lower slip risk is critical to preventing slip events.

Hydrodynamic theory can be used to explain the relationship between worn shoes and lower COF. In hydrodynamic lubrication, the fluid between the two surfaces becomes pressurized, which causes the surfaces to separate and the COF to decrease (Hamrock et al., 2004). Substantial under-shoe fluid pressures have been observed for worn and partially worn shoes in the presence of high viscosity contaminants (Beschorner et al., 2014; Beschorner and Singh, 2012; Hemler et al., 2019a; Singh and Beschorner, 2014). The Reynolds equation describes the relationship between fluid pressure and the separation between the surfaces (Beschorner et al., 2009; Chang et al., 2001b; Hamrock et al., 2004). These pressures can develop due to converging surfaces in motion (the wedge effect) (Beschorner et al., 2009; Beschorner et al., 2014; Chang et al., 2001b; Moore et al., 2012; Proctor and Coleman, 1988) or the squeeze-film effect (Beschorner et al., 2014; Chang et al., 2001b; Grönqvist et al., 2003; Strandberg, 1985), which are both believed to apply to shoes. Both the wedge and squeeze-film effects predict that fluid pressurization is sensitive to the size of the interacting surfaces (Hamrock et al., 2004; Hemler and Beschorner, 2017; Proctor and Coleman, 1988; Strandberg and Lanshammar, 1981). This concept has been recently applied to shoes by quantifying the size of the fully worn region. Specifically, shoes with a larger worn region were found to have higher fluid pressures and lower COF (Hemler et al., 2020a; Hemler et al., 2019a). Thus, both hydrodynamic theory and experimental studies suggest that larger worn regions have a negative influence on a shoe's friction performance.

Few methods are available to determine when a worn shoe should be replaced. Two potential metrics have been suggested for tracking shoe wear: shoe age and shoe condition. Slip-resistant footwear companies often recommend replacing shoes older than six months and replacing shoes is associated with reduced slip risk (Verma et al., 2014). One limitation of this approach is that individuals wear through shoe tread at different rates depending on their gait style and usage (Hemler et al., 2019b; Pliner et al., 2019). A second approach is to determine replacement thresholds based on the condition of the tread. For example, one footwear company provides a tool for assessing tread depth, which has an indicator for when to replace the shoes (Shoes for Crews, 2019). This method mirrors tread gauges, which are commonly used to assess tire tread (Gunaratne et al., 2000; Tracy et al., 2004). A potential limitation to this approach is that tread wears unevenly across the shoe surface (Grönqvist, 1995; Hemler et al., 2019a; Hemler et al., 2018) and the tread depth measurement is dependent on the location. Presumably, the tool could be applied to the location of least depth. Yet localized wear can occur rapidly and reductions in shoe friction performance occur substantially after a region of the shoe becomes fully worn (Hemler et al., 2019a). Therefore, using the minimum tread depth may be overly conservative and tread gauges may not translate very well to shoes. Given recent evidence that the size of the heel worn region is predictive of friction performance (Beschorner et al., 2019b; Hemler et al., 2019a), tools that assess the size of the worn region may have potential in determining if a shoe should be replaced.

Inexpensive and easy-to-use ergonomic tools tend to be frequently used among ergonomists or safety practitioners. The choice of ergonomic tool mainly depends on the nature of an injury risk, practicality (e.g., time, cost, availability), and an ergonomist's preference (e.g., expertise, experience) (Dempsey et al., 2005). A survey of ergonomics practitioners revealed high usage rates (60–87%) of observational assessment methods such as the NIOSH Lifting Equation (87%). However, a much lower usage rate (15–29%) was found for instrumentation-based methods such as the trunk electrogoniometer (e.g. Lumbar Motion Monitor) (18%) (Lowe et al., 2018). The higher usage of observational-tools over instrumentation-based methods is likely because observational tools cost less and require less expertise to use (Dempsey et al., 2005). Given the under-usage of slipmeters or tribometers (14.8%) among safety practitioners (Lowe et al., 2018), development of easy-to-use and inexpensive tools may increase adoption of shoe traction assessments. Furthermore, shoe tribometers (i.e., whole-shoe testers) are likely less utilized than floor tribometers since shoe tribometers (Chang et al., 2001a) are not typically portable and are relatively expensive (Iraqi et al., 2020). The lack of inexpensive and easy-to-use tools to assess the friction of shoes is a barrier for safety practitioners to assess footwear friction. Thus, the development of a new ergonomic method that meets the attributes of an ideal ergonomic tool (i.e., predictive, robust, quick to administer, inexpensive, non-invasive and easy-to-use) (Marras and Karwowski, 2006) could have an impact on reducing the magnitude of occupational slip and fall injuries.

The purpose of this study is to determine the ability of a simple observational test (i.e., appropriate ergonomic tool) that uses a readily available object (alkaline batteries) to assess wear-related loss of friction performance in slip-resistant shoes based on the size of the worn region. Under-shoe fluid pressures will also be analyzed to assess the role of fluid pressurization in shoe performance.

2. Methods

2.1. Selection of an Instrument for Assessing the Worn Region

The instruments chosen to assess the worn region of a shoe for this study were AAA and AA batteries. The criteria were a readily-available object that: 1) is a standardized and stable size over several years; and 2) corresponds with worn region sizes that lead to an increase in fluid pressure and reduction in COF. AAA and AA batteries became popular decades ago and their sizes (diameter of 10.5 mm for AAA and diameter of 14.5 mm for AA) are standardized (National Electrical Manufacturers Association/American National Standards Institute, 2015). Previous research has demonstrated that larger worn regions, especially as multiple treads become completely worn, are associated with increased under-shoe fluid pressures and reduction in COF (Hemler et al., 2019a). Given that slip-resistant shoes tend to have treads that are 2–10 mm in size (Iraqi et al., 2020; Moghaddam et al., 2019), selecting an object that is 10–15 mm across is appropriate for capturing wear that is larger than typical tread.

The battery tests were applied to shoes by determining whether the worn region was larger than the base of the battery (negative side of the battery terminal). When the worn region was larger than the base of the battery, the tread was labeled as “failing” the test whereas when the worn region was smaller than the base of the battery, the tread was labeled as “passing” the test. (AAA battery: “AAA test” and AA battery: “AA test”) (Figure 1). This test was applied to the tread from shoes used in all three previous experiments.

2.2 Methodologies of Previous Studies

This current study applied the battery tests to data from three previous studies (Hemler et al., 2019a; Hemler et al., 2020b; Sundaram et al., 2020). These prior studies included similar outcome measures to the present study but did not assess the battery tests. As such, the experimental methodologies from these studies are only briefly described here. Experiment #1 implemented a mechanical accelerated wear protocol that abraded the outsole of the shoe under controlled conditions (Hemler and Beschorner, 2017; Hemler et al., 2019a). Experiment #2 was a longitudinal study where the slip resistance of naturally worn shoes were assessed at monthly intervals throughout their life (Hemler et al., 2020b). Experiment #3 was a cross-sectional study that exposed human participants to a slippery contaminant, while wearing their own shoes (Sundaram et al., 2020). Under-shoe fluid pressures were measured for all three experiments. COF was measured for Experiments #1 and #2. The slip response was measured for Experiment #3.

2.2.1 Experiment #1 (Hemler et al., 2019a): Accelerated wear protocol—Five shoes labeled as slip-resistant by their manufacturers were worn through mechanical abrasion. All shoes had a grid-style tread pattern, which is generally representative of slip-resistant shoes (Iraqi et al., 2020). An iterative process of 1) simulating wear and 2) measuring the shoe's COF and under-shoe fluid pressures was performed. Shoes were worn using sliding abrasive paper (180μm diameter particles) moving at 9.65 m/s with a normal force of 40 N at each of three angles (2°, 7°, and 17°, in the sagittal plane of the shoe) between the shoe and the belt. A mold of each shoe's heel tread was created to record the state of the tread at baseline and after each cycle of wear using a silicone rubber compound (Smooth-On Inc.; Macungie, PA; Oomoo® 25). Friction and fluid pressure measurements were collected at each iteration, while each shoe was slid across a contaminated surface using a robotic slip testing device. Shoes were slid across a vinyl composite tile (Armstrong, 51804; Ra = 2.19±0.29 μm, Rz = 16.13±2.74 μm, Rq = 3.13±0.42 μm, cutoff length = 0.8 mm, sampling length = 8.0 mm) contaminated with a diluted glycerol solution (90% glycerol, 10% water by volume; 219 cP) at a speed of 0.3 m/s, angle of 17°, at a normal force of 250 N. Four fluid pressure sensors embedded in the floor tile were separated by 25 mm and each had an inlet diameter of 3.2 mm. The adjustable platform was moved 5 mm lateral in the direction relative to the shoe between each of five trials. This enabled 20 fluid pressure scans (4 scans per trial * 5 trials) each separated by 5 mm.

2.2.2 Experiment #2 (Hemler et al., 2020b): Natural wear of shoe tread— Twenty-three participants were recruited to wear slip-resistant shoes in their workplace. Three brands (SR Max ®, SafeTStep ®, Shoes for Crews ®) were used in the study. Participants were provided with shoes or boots depending on the footwear requirements of their workplace. Each participant was provided with two different pairs of shoes that they wore on alternating months. These shoes contained grid-style tread, which is representative of slip-resistant shoes (Iraqi et al., 2020). The shoes or boots were returned to the research team on a monthly basis for testing. Twelve participants were excluded due to lack of follow-up (n=6), withdrawal from the study (n=4), and discomfort wearing the shoes (1 of the pairs of shoes were excluded from 2 participants). The included participants worked in the following industry sectors: trade, transportation & utilities; accommodation and food services; and manufacturing. The slip resistance and fluid pressure from the outsoles were tested using the same methods outlined in Experiment #1 at baseline and after each month of wear.

2.2.3 Experiment #3 (Sundaram et al., 2020): Human slip response—Of the 57 participants that were part of a larger study (Sundaram et al., 2020), 32 (13 females, 19 males; mean age: 36±12 years) were included for this analysis. Inclusion criteria were that they: 1) wore shoes labeled as slip resistant by the manufacturer, and 2) stepped on the fluid-pressure plate with contaminate during laboratory slip testing. Of these shoes, 24 (75%) utilized a grid-style tread pattern and 8 (25%) utilized a lug-style tread pattern. Participants completed approximately 15 to 30 walking trials prior to contaminate exposure. The last trial of every assessment was the unexpected exposure to a liquid contaminant. During the unexpected exposure to a slippery contaminant, 100mL of a 90%:10% glycerol: water solution was spread over the fluid sensor array. The outcome measures included the peak fluid pressure and the peak slipping speed that occurred during the human exposure to the liquid contaminant.

2.3 Data analysis methods for battery tests

For data from Experiments #1 and 2, the available COF was calculated for each shoe and at each wear time point (Hemler et al., 2019a; Iraqi et al., 2018; Jones et al., 2018). The peak fluid pressure across the 20 scans was used to quantify the fluid drainage capabilities of the shoe outsole (higher fluid pressure indicated poorer drainage capability). The median available COF and peak fluid pressure for the cycles preceding and following the shoe's first occurrence of failing the AAA test were included. Similarly, the median COF and fluid pressure values for the AA test were included. Mixed-model repeated-measures ANOVAs (one for the AAA test and one for the AA test) were then performed with the COF and fluid pressure as the dependent variables and the following independent variables: test outcome (pass, fail), mode of wear (simulated/Experiment #1, natural/Experiment #2), and their interaction. If an interaction was observed, separate paired t-tests were performed for Experiment #1 and #2. A significance level of 0.05 was used for all analyses.

For data from Experiment #3, non-parametric methods (Wilcoxon Rank Sums test) were applied to test fluid pressure and peak slipping speed between shoes that passed versus failed the AAA and AA tests. Non-parametric methods were applied since it was determined that the assumptions of normal residuals and homoscedasticity were not satisfied and could not be corrected using transformations. In addition, relative risk, sensitivity, specificity, and accuracy of the test to identify slips was calculated. Slips were categorized based on a cutoff peak slipping speed of 0.3 m/s consistent with the previous study (Sundaram et al., 2020). A significance level of 0.05 was used.

3. Results

3.1. Influence of wear on shoe friction performance (Experiments #1 and #2)

Shoes that failed the AAA test had lower COF values ($F_{1,14} = 19.9$, $p<0.001$) and higher fluid pressures ($F_{1,14} = 20.9$, $p<0.001$) than those that passed (Table 1, Figure 2). On average, the COF for shoes that failed (mean: 0.158) was 29% lower than shoes that passed (mean: 0.224). Shoes that failed (mean: 81 kPa) had higher fluid pressures than shoes that passed (mean: 37 kPa). Neither the mode of wear nor its interaction with battery test outcome influenced either COF values or fluid pressures for the AAA test (Table 1).

Similar to the AAA test, shoes that failed the AA test had lower COF values ($F_{1,8} = 74.9$, $p<0.001$) and higher fluid pressures ($F_{1,8} = 17.9$, $p = 0.003$) than those that passed (Table 1, Figure 2). Shoes that failed the AA test (mean: 0.147) had COF values that were 30% lower than shoes that passed (mean 0.211). The mode of wear and its interaction with test outcome did not influence either COF. The mode of wear did not influence fluid pressure. However, an interaction effect was observed between the mode of wear and the test outcome on fluid pressure ($F_{1,8} = 13.0$, $p = 0.007$). Specifically, a larger difference in pressures between passing and failing shoes was observed for mechanically worn shoes (pass: 40 kPa; fail: 140kPa; $t_4 = 5.9$; $p = 0.004$). This effect was smaller and not significant for naturally worn shoes (pass: 70 kPa; fail: 80 kPa; $t_4 = 0.4$; $p = 0.695$).

3.2. Influence of wear on human slipping (Experiment #3)

Fluid pressures ranged from 2 to 696 kPa while peak slipping speeds ranged from 0.07 m/s to 2.63 m/s across the exposures to slippery contaminants in data from Experiment #3. A third of the shoes failed the AA test and 42% of the shoes failed the AAA test. Shoes failing the AA test were associated with a 9-fold increase in fluid pressures ($X^2_{(1)}{}^{AA} = 12.2$, $p^{AA} < 0.001$) and a 67% increase in peak slipping speed ($X^2_{(1)}{}^{AA} = 7.6$; $p^{AA} = 0.006$) (Figure 3). Similar trends were observed for shoes failing the AAA tests (330% increase in fluid pressures and 80% increase in peak slipping speed). These trends reached significance for peak pressure ($X^2_{(1)}{}^{AAA} = 6.2$; $p^{AAA} = 0.013$) but not for peak slipping speed ($X^2_{(1)}{}^{AAA} = 2.8$, $p^{AAA} = 0.095$). The relative risk (95% confidence interval) was 1.87 (0.82–4.26) for shoes failing the AAA test and 2.67 (1.20 – 5.94) for shoes failing the AA test. The sensitivity/specificity (accuracy) was 57%/68% (64%) for the AAA test and 57%/82% (72%) for the AA test. Thus, the AA test better differentiated human slipping than the AAA test (Figure 3).

4. Discussion

This study demonstrates that the wear-induced reduction in fluid drainage capacity and friction in slip-resistant shoes can be assessed by comparing the size of the worn region to an object such as a AAA and AA battery. Consistent trends were observed in data from the three different experiments, including: a controlled accelerated wear procedure; a longitudinal study tracking shoe performance throughout its naturally-worn life; and a cross-sectional study examining human exposures to slippery contaminants, while wearing naturally-worn shoes. Specifically, a reduction of approximately 30% in COF was observed for shoes failing these tests relative to their passing counterparts. Higher fluid pressures were consistently observed in cases where shoes failed the test, however the magnitude of this difference varied across experiments. For the human slip study, increased slipping and slip severity were observed for participants wearing shoes that failed the test compared with participants wearing shoes that passed the test. Although, the battery tests were not fully deterministic of shoe friction performance, they were highly predictive in *loss of friction* performance within the longitudinal experiments. In fact, every shoe that was tracked during wear (shown in Figure 2A) had less friction for the fail condition relative to the pass condition. Furthermore, the tests (particularly the AA test) were moderately sensitive and highly specific predictors of human slipping. The consistency of the results across these three experiments yields robust evidence that applying these tests are an effective way of identifying worn shoes that have degraded performance. However, potential users should be trained to properly apply these tests and understand their scope of applicability. Both tests (AAA and AA) were demonstrated to predict a degradation in friction performance. The AAA test will lead to more frequent replacement of footwear than the AA test. Therefore, the AAA test is an option for more risk-averse practitioners, while the AA test may be more appropriate to those who are more risk-tolerant.

The proposed battery tests are designed to be a simple and inexpensive solution in assessing the worn condition of slip-resistant shoes. The batteries are a consistent and available product that can lead to wide adoption to assess tread wear and prevent slip-initiated falls.

These features are consistent with attributes of an ideal ergonomic tool (i.e., predictive, robust, quick to administer, inexpensive, non-invasive and easy-to-use) (Marras and Karwowski, 2006). While this test is easy to perform, future research should examine the human factors aspects of this test including inter-rater reliability, usability, and usefulness of the test.

This test assesses the actual worn condition of shoes as opposed to other cutoffs like the age of the shoe. Commonly, shoes are replaced according to a time schedule (e.g., every 6 months) (Verma et al., 2014). However, shoe age guidelines do not account for variation in wear due to differences in individual usage or biomechanics. This study found that a substantial portion of shoes with less than 6 months of use failed one of the battery tests (27–36% from Experiment #2) and a substantial portion of shoes older than 6 months passed the test (56–70%). Thus, discrepancies exist between time-based replacement thresholds and worn-condition thresholds. Presumably, replacing shoes on a set time-based schedule may expose high wear individuals (high use or gait pattern that is associated with faster wear (Hemler et al., 2019b)) to increased slip and fall risk and may lead to unnecessary cost for low wear individuals (lower use or gait pattern associated with slower wear). Thus, the utilization of this test may enable reallocation of resources to the individuals at greatest slipping risk.

The results of this study are consistent with previous research that demonstrated degraded performance for worn shoes. Our previous research has found that an increase in fluid pressures and a reduction in COF is associated with shoe wear (Beschorner et al., 2014; Beschorner and Singh, 2012; Hemler and Beschorner, 2017; Hemler et al., 2018; Singh and Beschorner, 2014). In addition, we also showed a relationship between the size of the worn area and friction (Beschorner et al., 2019b; Hemler and Beschorner, 2017), which is consistent with assessments targeting the size of the worn region. Thus, the results of these experiments are generally consistent with previously-identified trends of the influence of shoe wear on slip risk.

This study focused on wear in the heel region of the shoe as opposed to the midfoot or forefoot regions. The heel is appropriate for tracking wear since previous research has identified that wear commonly occurs in this region (Hemler et al., 2020b). Furthermore, slips occurring during the heel contact phase of gait are relevant to fall risk since they are 1) capable of generating a backward fall away from the point of contact; 2) occur during the initiation of swing phase for the contralateral limb; and 3) have high frictional requirements (Redfern et al., 2001). While wear in other regions of the shoe may lead to loss of friction, wear in the heel region is more likely to lead to slips resulting in a fall. Thus, observing wear in the heel region is justified for achieving the goal of reduced slip and fall events.

Certain limitations of this study should be acknowledged regarding the scope of applicability. First, the study focused on shoes that were labeled as “slip-resistant” by the manufacturers and it is unclear if the same test is valid across all shoe types. Second, although this test was effective at predicting loss of friction, it was not fully deterministic of friction performance as indicated by the variability in COF across shoes (Figure 2). Other parameters are known to be relevant to friction performance including tread surface area, material hardness, heel shape, and tread bending stiffness (Iraqi et al., 2020; Jones et al., 2018; Yamaguchi et al., 2017). Third, while the threshold was tested across data from multiple experiments using a variety of slip-resistant shoes, further efforts are needed to generalize the results to different contaminants and flooring. Tribology theory suggests that the worn regions assessed in this study would lead to greater hydrodynamic pressures and lower COF values when utilized with lower roughness flooring and higher viscosity contaminants (Hamrock et al., 2004). Thus, some correction factor may be warranted when applying these results to smooth floor surfaces with high viscosity contaminants. Lastly, validating these tests using actual workplace slip and fall data would increase confidence in the test.

This study demonstrates that worn shoes, as assessed using a simple test of comparing the worn region to the size of batteries, are associated with a loss in friction. This result was demonstrated consistently across three experiments and is consistent with previous research and theory. The test is expected to offer workers a simple, quick and inexpensive way to assess their shoe wear condition and enable employers to appropriately allocate resources based on the actual worn condition of the shoes. Broader use of shoe wear monitoring through the proposed tests has an opportunity to reduce the burden of slip and fall events in the workplace.

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Highlights

- The size of tread worn regions were compared with AAA and AA batteries
- Shoes “passed” the test if the worn region was smaller than the battery base.
- Shoes across three wear experiments were assessed using this test.
- Failed shoes led to lower friction, worse drainage, and more severe slips.

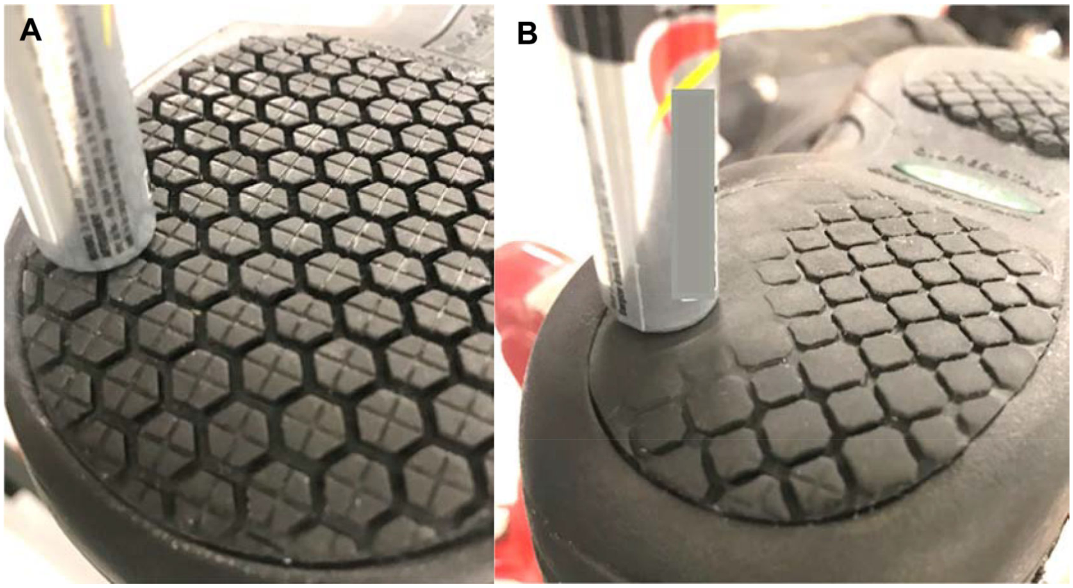

Figure 1:

A) The shoe tread passes the battery test because the size of the worn region is smaller than the battery. B) The shoe tread fails the battery test because the worn region fully surrounds the base of the battery. Only the heel region (posterior half of the shoe) is considered in this test.

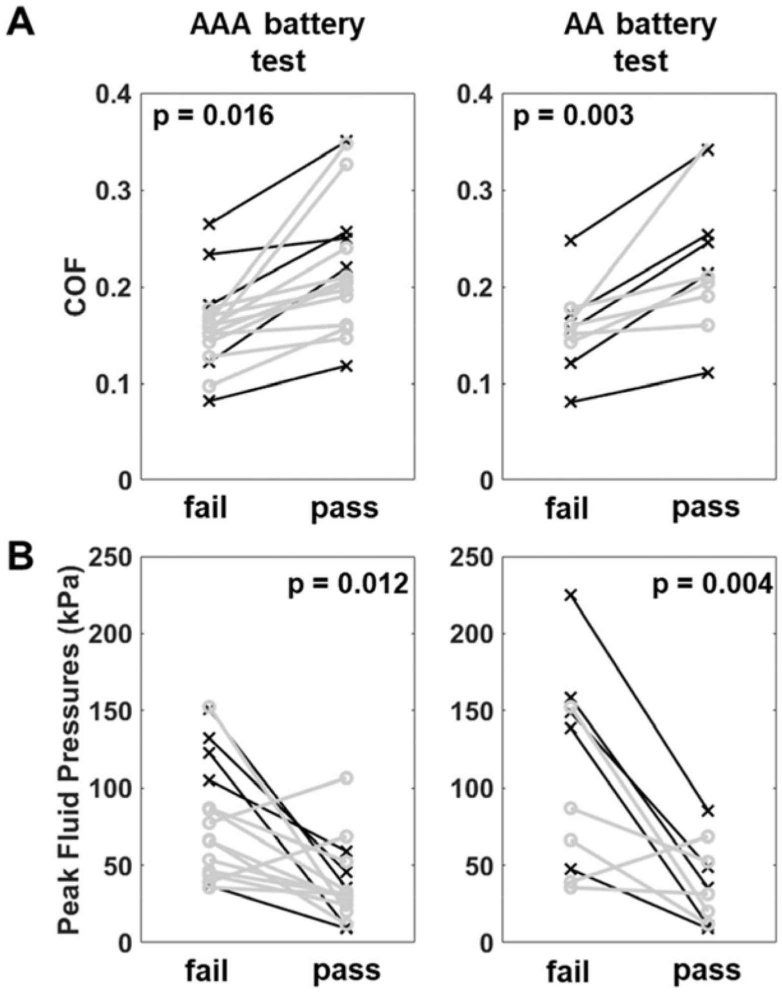

Figure 2:

Change in COF (A) and peak fluid pressure values (B) between passing and failing the AAA battery test (left) and the AA battery test (right). The black lines with the “X” markers represent data from the accelerated wear protocol (Experiment 1) and the gray lines with the “O” markers represent data from the human wear experiment (Experiment #2). Each line represents a single shoe before and after failing the test.

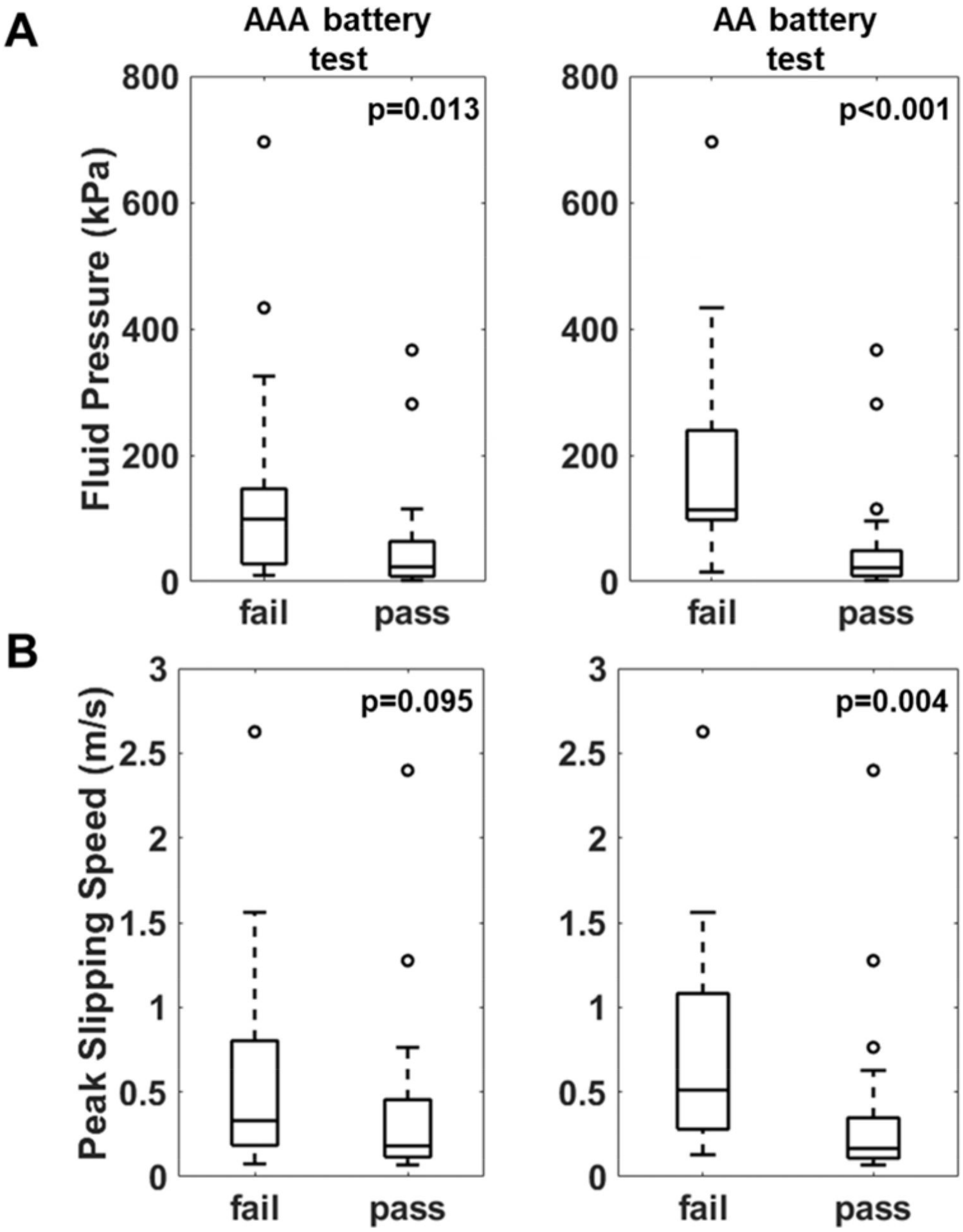

Figure 3:

Box plots of peak fluid pressure (A) and peak slipping speed (B) for fail/pass outcomes of the AAA battery test (left) and the AA battery test (right).

Table 1:

Statistical results for the influence of the test outcome, the mode of wear, and their interaction on COF and under-shoe fluid pressure using data from Experiments #1 and #2.

	AAA Test				AA Test			
Dependent variable	**COF**		**Fluid pressure**		**COF**		**Fluid pressure**	
Independent variable	**F(1,14)**	**p**	**F(1,14)**	**p**	**F(1,8)**	**p**	**F(1,8)**	**p**
Test outcome	19.9	<0.001	20.9	<0.001	74.9	<0.001	17.9	0.003
Mode of wear	0.4	0.411	1.8	0.204	0.8	0.402	0.2	0.675
Mode of wear * Test outcome	0	0.874	4.4	0.054	3.1	0.114	13.0	0.007