

# Slip Resistance Comparison of Footwear on Two Flooring Types Using Mechanical Testing Approach

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**Abstract**— Slips and falls are major safety concerns across various populations, including healthcare workers, kitchen staff, warehouse employees, etc. Footwear type plays a crucial role in preventing slip-related falls. A high Coefficient of Friction (COF) between footwear soles and flooring surfaces is essential to maintain balance and stability. This study evaluated the COF of 12 commonly available footwear in the market on two types of floorings — quarry tile and Majorca Fog polished rectified porcelain (MFP) — under dry and wet conditions. According to the ASTM F3445-24 threshold of 0.4, all footwear was safe on dry surfaces for both types of tiles, and on wet quarry tiles, except footwear 2, but unsafe on wet MFP tiles. Statistical analysis showed that COF values for quarry tiles were significantly lower under dry conditions compared to MFP tiles. However, under wet conditions, the COF values for the quarry tile increased significantly, exceeding that of the MFP tile. These findings were proof of concept for ongoing efforts to design safer footwear considering footwear characteristics such as outsole material, and tread patterns that may influence slipping risk.

**Keywords**— Slip-related falls, Footwear safety, Coefficient of Friction

## INTRODUCTION

Slips and falls are common among older adults and individuals in environments with high slip hazards, such as workplaces and healthcare settings [1], [2], [3]. These incidents can lead to serious injuries, reduced mobility, and a decline in quality of life [4], [5]. Footwear choice plays a vital role in preventing slip-related falls [6], [7]. In addition, recent studies showed that slipping risks depend highly on the type of flooring, such as laminate, porcelain, anti-skid, matt, and glossy [8], [9], [10]. Floor coatings also produced roughness and provided better traction compared to uncoated flooring [11]. Hence, the interaction of flooring with footwear sole is important, as specific surface texture and wet conditions increase slip risk [1]. This makes footwear testing on different

floorings essential to improve slip resistance and prevent falls.

Footwear slip resistance can be evaluated by standard tests such as mechanical methods that simulate real-world conditions [12]. Mechanical devices for measuring slip resistance typically use actuators and sensors to apply and measure various forces to calculate friction. SATRA machines, for instance, secure footwear and apply a normal force to simulate body weight. Subsequently, it induces slip on different surfaces, measuring both the horizontal and vertical forces during the motion. This data is used to calculate the COF [13]. Another cart-type device simulates varying sliding velocities to evaluate the COF accounting for both slope angle and inertial force. Subsequently, a normal load can be applied to the shoe using weights to measure traction forces [14], while horizontal pull slip meters and pendulum devices replicate controlled or dynamic conditions [15]. In addition, mechanical portable devices such as NextSTEPS enable convenient testing in real-world environments [16]. Gupta et al. also developed a 15 kg portable slip-testing device that features a three-part subassembly of horizontal motion, vertical motion, and angle adjusting mechanism. During sliding motion, the device measures the shear force and the normal force to calculate the COF [17].

Given SATRA's long-standing use in various standards [18], [19], in this paper, we use it to measure the COF values. We measure and compare the slip resistance of 12 commonly available indoor footwear in the market on two types of flooring to better understand safer environments and footwear design.

## METHODS

### Experimental protocol

We evaluated the performance of 12 types of footwear (6 pairs for women with size 7 and 6 pairs for men with size 11)



**Figure 1.** The 12 types of footwear tested in this study.

using mechanical tests according to ASTM F2913-24 [20] with the SATRA STM 603 Slip Resistance Tester (SATRA Technology Centre, Kettering, UK). The protocol involved washing the footwear outsole to ensure that dust does not affect the slip resistance measurement. An appropriate last was also placed into the footwear to fit it into the SATRA instrument. We also removed the insole to prevent the last from shifting, which could introduce unwanted acceleration. Based on the footwear size, the device was then set to apply 500 N to simulate the force exerted during walking for slip resistance testing. This test measures the COF in three specific modes: forward heel slip, forward flat slip, and backward toe slip. A contact angle of  $7^\circ \pm 0.2^\circ$  was established between the footwear and the test floor at the forefoot and heel areas. All tests were conducted in a controlled laboratory environment with a consistent air temperature of  $22.5^\circ\text{C}$ - $25^\circ\text{C}$  and humidity of 30%-45%. In addition, all footwear was tested on two tiles: standard quarry tile and Majorca Fog polished rectified porcelain (MFP) tile on two different conditions: dry and wet. Quarry tiles are the standard in very high-demand areas and the reference surface for ASTM F2913-24 test method. MFP tiles are high-quality porcelain tiles known for their durability and aesthetic appeal usually used for kitchens. We made the surface wet using distilled water and a uniform layer of water for consistency. Testing was conducted on one specimen first under dry conditions, followed by wet conditions, while another specimen was evaluated first under wet conditions and then dry. To ensure a thorough assessment, the footwear and floor were completely dried between wet and dry testing conditions.

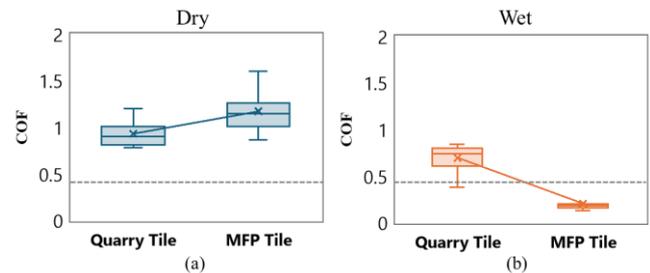
### Slip resistance analysis

The average and standard deviation of the COF for each type of footwear were calculated based on the results from the three modes. Based on ASTM F3445-24, the slip resistance of footwear must be no less than a COF of 0.40 on both dry and wet surfaces to be considered ‘safe’ [21]. In addition, to compare the COF values of 12 footwear (Figure 1)

on these tiles, we conducted a statistical test of either a paired t-test or the Wilcoxon Rank Sums test based on the results of a normality test on the data.

## RESULTS

The average and standard deviation of the COF values for each footwear across the three modes are summarized in Table 1. The statistical analysis results are presented in Figure 2, where the dotted line represents the COF value of 0.40. In general, this finding indicated that, under dry conditions, all footwear exhibited high COF values on both surfaces well above the safety threshold and significantly higher on MFP compared to quarry tiles ( $p$ -value = 0.003, Figure 2 (a)). However, under wet conditions, COF values were lower on both surfaces, but significantly lower on MFP compared to quarry tiles ( $p$ -value < 0.0001, Figure 2 (b)). Indeed, all footwear remained above the safety threshold for wet quarry tiles (except footwear 2) but fell below this threshold for wet MFP.



**Figure 2.** The COF values of 12 pairs of footwear on (a) Dry and (b) Wet tiles

The paired t-test showed a significantly lower COF on quarry tile compared to MFP on a dry condition, while the paired Wilcoxon test on a wet surface showed the opposite result. Footwear 2 showed the largest decrease in COF from dry to wet conditions on quarry tile, and it had the highest standard deviation across its three modes for both dry and wet

Table 1. The average and standard deviation of the coefficient of friction (COF) for each tested footwear type (M = Male, F = Female) across the three modes: forward heel slip, forward flat slip, and backward toe slip.

Footwear Brand (Sex: M/F)	ID	Quarry Tile		MFP Tile	
		Dry	Wet	Dry	Wet
Shows For Crews (F)	1	1.20 ± 0.03	0.59 ± 0.01	1.48 ± 0.11	0.36 ± 0.03
Shows For Crews (F)	2	1.04 ± 0.27	0.38 ± 0.24	0.99 ± 0.53	0.15 ± 0.09
Aggressor (F)	3	1.01 ± 0.13	0.74 ± 0.10	1.60 ± 0.25	0.20 ± 0.03
Sketchers Work (M)	4	1.01 ± 0.12	0.48 ± 0.05	1.21 ± 0.13	0.16 ± 0.02
Dakota (F)	5	1.00 ± 0.03	0.83 ± 0.08	1.23 ± 0.17	0.19 ± 0.05
Aggressor (M)	6	0.90 ± 0.10	0.77 ± 0.08	1.27 ± 0.20	0.18 ± 0.03
Dakota (M)	7	0.90 ± 0.04	0.81 ± 0.03	1.04 ± 0.13	0.17 ± 0.01
Dakota (M)	8	0.90 ± 0.04	0.84 ± 0.07	1.17 ± 0.09	0.13 ± 0.02
Sketchers Work (M)	9	0.82 ± 0.05	0.73 ± 0.05	1.13 ± 0.10	0.37 ± 0.03
Sketchers Work (F)	10	0.81 ± 0.19	0.74 ± 0.03	1.07 ± 0.15	0.20 ± 0.03
Sketchers Work (M)	11	0.79 ± 0.04	0.68 ± 0.05	0.87 ± 0.04	0.19 ± 0.05
Sketchers Work (F)	12	0.78 ± 0.03	0.75 ± 0.04	1.00 ± 0.03	0.18 ± 0.00

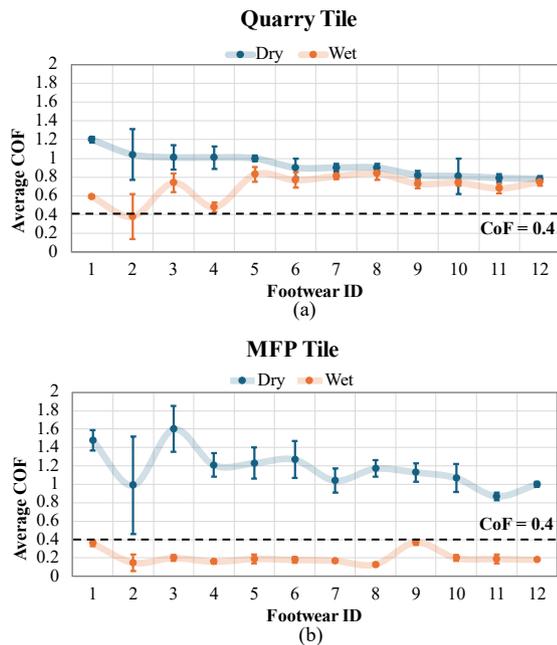


Figure 3. The average and standard deviation of COF for each footwear type across the 3 modes on a) Quarry and b) MFP tiles.

conditions (Figure 3). Additionally, on wet surfaces, this footwear’s COF fell below the safety threshold, classifying it as ‘unsafe’ for both types of tiles. This could be due to the large sections of the outsole without tread patterns, as shown in Figure 1. Additionally, the outsoles of Footwear 1 and 2 are quite similar, with the only difference being the lack of tread in the middle section of Footwear 2 and the rear section of Footwear 1. All other types of footwear, maintained COF values above the threshold for both wet and dry quarry tile with footwear 4 approaching the threshold. Footwear 8 achieved the highest mean COF of  $0.84 \pm 0.07$  on wet quarry

tiles, closely matching its COF under dry conditions ( $0.90 \pm 0.04$ ). On the MFP tile, the maximum difference between the average COF from dry to wet is for Footwear 3. All footwear tested on wet MFP tile showed COF values below 0.4 and therefore, considered as NOT ‘safe’. Footwear 1 and 9 provided the maximum COF values on wet MFP.

## DISCUSSION

In this study, we found that the type of footwear tread pattern and flooring directly impact COF values, highlighting the critical role of outsole design and surface compatibility in ensuring slip resistance. For example, certain tread patterns, such as that of Footwear 2, demonstrated inconsistent performance, with COF values varying significantly across different modes, tile types, and both wet and dry conditions. While all footwear showed COF values below the 0.4 safety threshold on wet MFP tiles, only Footwear 2 fell below this threshold on wet quarry tiles, performing worse than all other footwear. Among the 12 footwear tested, footwear 1 and 9 provided the best minimum traction (a conservative measure), with COF values nearing the 0.4 safety threshold in their worst-case scenarios, which occurred on wet MFP tiles.

These results aligned with previous literature that examined the topographical features of the heel region of outsoles using image processing [13], [22], [23], [24]. One of these studies demonstrated that horizontal treads or unthreaded regions of the outsole could significantly increase the risk of slipping. Fluid pressure exhibited a strong negative correlation with the COF ( $R^2 = 0.82$ ), while mass flow rate was strongly and positively correlated with COF ( $R^2 = 0.75$ ) [25]. Similarly, our findings showed that Footwear 2, which features an unthreaded region, performed the lowest on both tiles under both conditions. It was also indicated that a higher real contact area between the shoe and the ground can improve slip

resistance [24]. Therefore, in future studies, it is crucial to further investigate the influence of tread pattern, material composition, and tread depth on footwear performance across various flooring conditions. Additionally, the dynamic nature of footwear usage, such as the impact of wear over time and the varying conditions of floor surfaces should be considered. Understanding these factors can lead to more effective safety guidelines and standards for footwear selection, especially in environments where wet conditions are prevalent.

## CONCLUSION

Our findings were proof of concept to highlight the importance of evaluating footwear characteristics, such as outsole material and tread patterns, to design safer footwear and minimize slip-related fall risk across various environments.

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