# Perception of Floor Slipperiness Before and After a Walk

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**Abstract.** Nowadays, Slips and falls have become the leading causes of deaths and injuries at both workplaces and public sectors. Perception of floor slipperiness has been considered as one of the important item affecting the gait pattern of a walker and thus affects the risk of slip and fall. For investigating the factors affecting the perception of floor slipperiness and the relationship between the perception rating of floor slipperiness before and after a walk, a gait experiment was conducted. Two walkways, each of 5.4 m long, were installed. The floors on these walkways were polished granite and ceramic tile. There were two floor surface conditions: dry and water-detergent solution contaminated conditions. Two types of shoes were tested: rubber-soled and EVA-soled. In addition, the illumination conditions included light and dark. In the experiment, the subject stood in front of the walkway and reported his perception rating of floor slipperiness though a five-point scales from 1 extremely slippery to 5 not slippery at all. He, then walked through the walkway and gave his perception rating of floor slipperiness again. In addition, he also gave a perceive sense of slipperiness. The results indicated that the perception rating of floor slipperiness both before and after walk and the perceive sense of slip were all affected significantly by floor ($p < 0.0001$) and floor surface conditions ($p < 0.0001$). Details of the results were discussed. The information in this study is helpful in understanding human behaviors when walking on slippery and non-slippery floors.

**Keywords:** Floor slipperiness · Perception rating of floor slipperiness · PSOS

## 1 Introduction

Slips and falls often occur. They are leading causes of deaths and injuries at workplaces [1]. Slip and fall accidents have accounted for 14.6% of the total cost of the occupational incidents in the USA, the cost was more than USD 7.7 billion in 2007 [2]. In 2009, the cost of slip and fall accidents was USD 6.2 billion, which was lower than that in 2007. But slips and falls have been ranked second among the top 10 causes and direct cost of the most disabling workplace injuries in the USA [3]. In Taiwan, falls are common occupational hazard for service workers, which were next only to traffic accidents [4].


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More than two thousands same level falls has been reported in 2013, which has accounted for 17.89% of all job-related injuries [5].

Reducing the occurrence of slipping has become one of the major issues in the scientific community. When the friction coefficient between the shoe and the ground is lower than the friction required to balancing the body, a fall could occur. Friction on the floor has been widely used as an index of the risk of slips and falls. Li et al. [6] compared the performances of the Brungraber Mark II (BM II) and Mark III (BM III) slipmeters in assessing the friction of the floor. Although there were certain differences in the values measured by two instruments on the coefficient of friction (COF) and normal force, the BM III was found to be equivalent to the BM II on the measurement of friction. Chang et al. [7] investigated the friction mechanisms between shoe and four different floor interfaces which included dry, liquid, icy and solid contaminated surfaces. They pointed out that static friction measurement can be only used for dry surface and clean surface, and dynamic and transition friction methods are required to properly estimate the potential risks of the contaminated surface. Liu et al. [8] studied the effects of shoe sole, floor, floor contamination and inclined angle of the floor surface on the COF. They reported that all the four factors have significantly effect on friction coefficient.

Floor slipperiness is one of the most important parameters in evaluating the risk of slips and falls. Before stepping on the floor, people judge the floor slipperiness through the observation of the floor. Then they adjust the forces applied on the floor so as not to exceed those limits. Tisserand [9] suggested that there is a mental model of friction limits when a person is walking. Some scholars studied the floor slipperiness by measuring subjective response of human subjects. Swensen et al. [10] investigated the subjective ratings and rankings of the slipperiness about the steel beams. They reported that the subjective ratings had a high correlation ($r \geq 0.75$) with the measured COF.

Chang et al. [11] used friction measurements as the objective measurement and the employees' ratings of floor slipperiness as the subjective measurement to investigate the floor slipperiness in 7 kitchen areas of 10 western-style fast-food restaurants in Taiwan. They found that the Pearson's correlation coefficients between the averaged COF and subjective ratings was 0.49 and Spearman's was 0.45 ($p < 0.001$). Bang et al. [12] used two subjective rating methods to evaluate floor slipperiness on seven floor surfaces contaminated with detergent solution. They found a higher correlation ($r = 0.99$) between the two tests results except for the ground steel. These studies showed that the perception of slipperiness not only could be used to assess the floor slipperiness but also be the subsidiary measurement of the friction on the floor.

Cohen et al. [13] requested their subjects to slid their barefoot on the test titles and compared the slipperiness of these tiles with a standard tile whose value COF value was 0.5. They found disagreements between the COF values and the subjects' ratings of the tiles. In a subsequent research, Cohen et al. [14] conducted an experiment to test the subjects' perceptions in conditions closer to real life. This experiment contained 10 outdoor walking surfaces and each had two conditions (dry and wet), and the subjects were asked to look at each floor and ranked its perception of slipperiness (observed), then walked on each surface under each condition and ranked the slipperiness of the floor again (experienced). They found that no matter on dry surface or wet surface, the difference between the "observed" and "experienced" ratings was not statistically significant. They reported that subject evaluated the slipperiness of one surface condition when they observing it, then tended to evaluate it after a walk. This implied that prior observation may affect the following perception of the floor slipperiness after a walk.

Both floor slipperiness and floor roughness affect the happen of slips and falls. Li et al. [15] compared the perception of floor roughness and the perception of floor slipperiness, which was evaluated based on tactual sensations from different body segments for males and females. They found that both the perception of floor roughness and floor slipperiness were predicted better by using the floor roughness parameter $R_a$ than that using the COF of the floor. Yu et al. [16] compared the perception of floor slipperiness with and without shoes for males and females. They found that the subjects made more adjustments on the rating of the perception of floor slipperiness when they were wearing shoes than when they had bare foot. The adjustment of the perception of floor slipperiness was affected by gender, floor, surface conditions, and footwear conditions.

Floor slipperiness, floor roughness, and shod conditions are all believed to have effects on the happen of slipping and falling during a gait. Perception of floor slipperiness and floor roughness are important measures in understanding the risk of slipping and falling [15]. This study aimed to compare the perception of floor slipperiness before and after a walk on the floor.

# 2 Methods

A gait experiment was carried out in the ergonomics laboratory at Hunan Institute of Technology. The mean (SD) temperature and humidity were 21.12 °C (±3.29) and 78.2% (±7.05), respectively.

## 2.1 Human Subjects

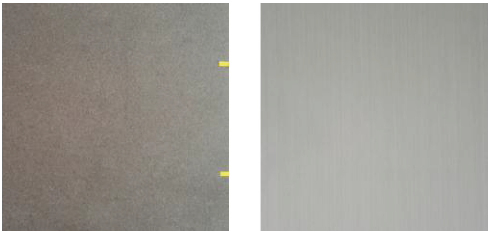
Six adult males participated in the experiment. Their age, height, body weight, and length of lower extremity were 20.17 yrs (±0.37), 169.00 cm (±5.03), 63.83 kg (±6.73), and 89.92 cm (±3.34), respectively. All the subjects was asked to read the instructions carefully and sign the experimental protocol before the experiment (Table 1).

**Table 1.** Fundamental data for human subjects

| Item | Mean | Std | Min | Max |
|---|---|---|---|---|
| Age (yrs) | 20.17 | 0.37 | 20.0 | 21.0 |
| Height (cm) | 169.00 | 5.03 | 160.0 | 177.0 |
| Body weight (kg) | 63.83 | 6.73 | 55.0 | 75.0 |
| Length of lower extremity (cm) | 89.92 | 3.34 | 83.5 | 93.0 |

## 2.2 Experimental Conditions

The experimental conditions included floor, floor surface, shoes, and level of illumination. There were two walkways, each of 5.4 m long, were installed. The floors on these walkways were polished ceramic tile and granite (see Fig. 1). Ceramic tile ($R_a = 14.95$) had higher surface roughness than granite ($R_a = 0.05$). A suspension rail was installed overhear to support a safety harness along the walkway to provide safety precaution for the gait.



(a) ceramic tile (b) granite

**Fig. 1.** Tested floors

The floor surface condition included dry and water-detergent solution contaminated surface. For dry condition, the test floors' surfaces were clean and dry. For water-detergent solution, the target area (the final 1.2 m floor, see Fig. 2) of the test trail was covered by a detergent solution which was mixed with water and detergent according to the proportion of 1:30, and other floors of the test trail were clean and dry as the dry condition.

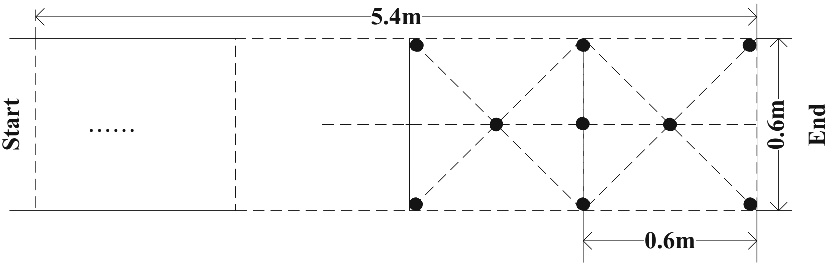



**Fig. 2.** Illumination measurements spots on the walkway

The illumination conditions included light and dark. The illumination was measured at 9 locations (see Fig. 2) on the test floor using a TES1336A light meter. For light condition, the illumination was 366.07 (±70.47) lx. For dark condition, the illumination was 0.05 (±0.02) lx.

The shoes condition included rubber-soled shoes and Ethylene-vinyl acetate (EVA)-soled shoes (see Fig. 3). The left shoe sole was EVA and the right shoe sole was rubber.

**Fig. 3.** Shoes

## 2.3 Experiment Procedure

When the subjects first entered the laboratory, his fundamental data were collected by the research personnel. In the light condition, the subject was requested to stand at the starting point of the walkway and wore the safety harness (see Fig. 4). For dark condition, the subject was waiting in a preparation room next door to the laboratory, and wore an eye mask before entering the lab. Then the research personnel led the subjects to the starting point of the walkway and removed their eye mask. When the subjects adapted to the dark condition which approximately takes five minutes, the research personnel continued the same procedure as in the light condition. The subject looked at the target area of floor and gave a subjective rating of floor slipperiness before the gait trial start. This rating was termed $RFS_{before}$ (perception rating of floor slipperiness before a walk). Then he was asked to put on the suitable laboratory shoes and walked at a speed following the sound of a metronome toward the end of the walkway and stopped. The metronome pace of the metronome was 100 per minute and it was closest to the normal gait frequency which was determined after repeated tests. The subject gave a subjective rating of floor slipperiness after the gait trial. This rating was termed $RFS_{after}$ (perception rating of floor slipperiness before a walk). In addition, a perceived sense of slip (PSOS) rating was also collected.

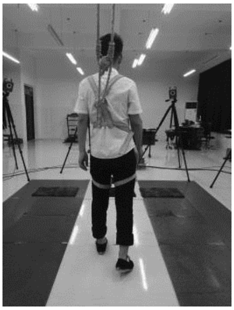


**Fig. 4.** Trial experiment

### 2.4 Dependent Variables

In the experiment, the following dependent variables were collected: $RFS_{before}$, $RFS_{after}$, and PSOS. A five-point scale was adopted for both the $RFS_{before}$ and $RFS_{after}$: from 1 extremely slippery to 5 not slippery at all. The PSOS [17] was composed of the following four questions:

(1) How much did you feel yourself slip?
(2) Did you have any difficulty in maintaining balance?
(3) Did you feel at any time that you would slip?
(4) What would you say was the overall difficulty of this task?

Each of the questions required a five-point responses from 0 (not at all) to 2 (a lot) with an increment of 0.5. The final score of PSOS was addition of the scores from these four questions.

### 2.5 Experiment Design and Data Analysis

A factorial randomly block design experiment was performed. The illumination condition was the block. The total trial was 96 (6 subjects × 2 shoes × 2 floors × 2 surfaces × 2 illumination conditions). Analysis of variance (ANOVA) was performed. Duncan's multiple range tests were performed for factors with more than two levels if the main factor reached the significance level of 0.05. The statistical analyses were performed using the SAS®14.0 software.

## 3 Results

### 3.1 Descriptive Statistics

Figure 5 shows the $RFS_{before}$ under floor, surface conditions, and illumination conditions. Figure 6 shows the $RFS_{after}$ under floor and surface conditions. Figure 7 shows the PSOS under shoes, floor and surface conditions.

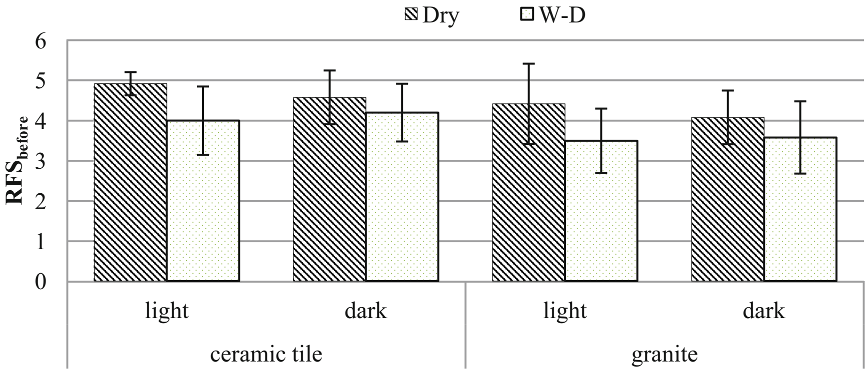



**Fig. 5.** $RFS_{before}$ under floor, surface, and illumination conditions, Note: $RFS_{before}$ = perception of floor slipperiness before a walk; W-D = water-detergent solution

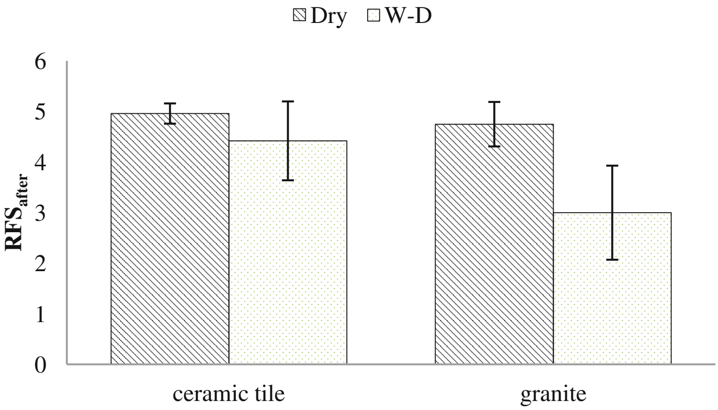



**Fig. 6.** $RFS_{after}$ under floor and surface conditions, Note: $RFS_{after}$ = perception of floor slipperiness after a walk; W-D = water-detergent solution

### 3.2 Analyses of Variance

The ANOVA results of the $RFS_{before}$ indicate that the effects of floor ($p = 0.0016$) and surface conditions ($p < 0.0001$) were significant. The results of Duncan's multiple range test showed that $RFS_{before}$ (4.23) of EVA-soled footwear was not significantly different from that (4.08) of Rubber-soled footwear. $RFS_{before}$ (4.21) of light condition was not significantly different with that (4.10) of dark condition. The effects of shoes and illumination conditions were not significant. The Duncan's multiple range test results for the floor, surface conditions are shown in Tables 2 and 3.

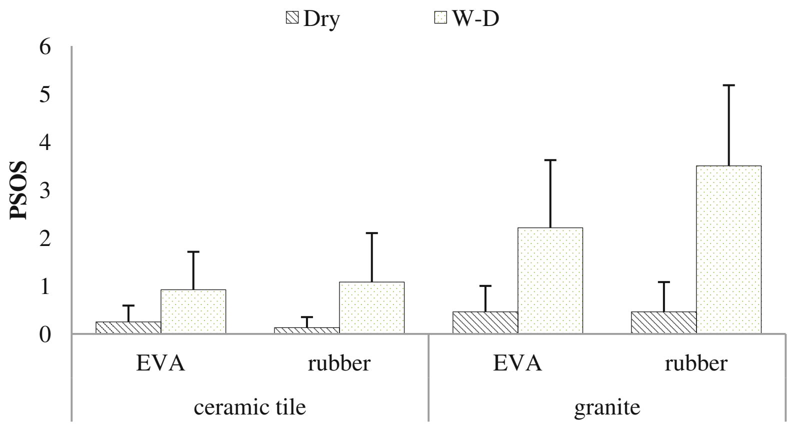



**Fig. 7.** PSOS under shoes, floor and surface conditions, Note: W-D = water-detergent solution

**Table 2.** Results of Duncan's multiple range test for $RFS_{before}$ of floor conditions

| Floor | Mean $RFS_{before}$ | Duncan's grouping* |
|---|---|---|
| Ceramic tile | 4.42 | A |
| Granite | 3.90 | B |

*different letters indicating they are statistically significant at $\alpha = 0.05$.

**Table 3.** Results of Duncan's multiple range test for $RFS_{before}$ of surface conditions

| Surface conditions | Mean $RFS_{before}$ | Duncan's grouping* |
|---|---|---|
| Dry | 4.50 | A |
| Water-Detergent | 3.81 | B |

*different letters indicating they are statistically significant at $\alpha = 0.05$.

The ANOVA results of the $RFS_{after}$ indicated that the following effects were significant: floor ($p < 0.0001$), surface conditions ($p < 0.001$), shoes × surface conditions ($p < 0.05$), floor × surface conditions ($p < 0.0001$). The effects of shoes were not significant. Neither were the effects of illumination significant. The Duncan's multiple range test results for the floor and surface are shown in Tables 4 and 5.

**Table 4.** Results of Duncan's multiple range test for $RFS_{after}$ of floor conditions

| Floor | Mean $RFS_{after}$ | Duncan's grouping* |
|---|---|---|
| Ceramic tile | 4.67 | A |
| Granite | 3.88 | B |

*different letters indicating they are statistically significant at $\alpha = 0.05$.

**Table 5.** Results of Duncan's multiple range test for $RFS_{after}$ of surface conditions

| Surface conditions | Mean $RFS_{after}$ | Duncan's grouping* |
|---|---|---|
| Dry | 4.85 | A |
| Water-Detergent | 3.71 | B |

*different letters indicating they are statistically significant at $\alpha = 0.05$.

The ANOVA results of the PSOS indicate that the following effects were significant: floor ($p < 0.0001$), surface conditions ($p < 0.0001$), floor × surface conditions ($p < 0.001$). The effects of illumination conditions and shoe were not significant. The Duncan's multiple range test results for the floor, and surface conditions are shown in Tables 6 and 7.

**Table 6.** Results of Duncan's multiple range test for PSOS of floor conditions

| Floor | Mean PSOS | Duncan's grouping* |
|---|---|---|
| Granite | 1.66 | A |
| Ceramic tile | 0.60 | B |

*different letters indicating they are statistically significant at $\alpha = 0.05$.

**Table 7.** Results of Duncan's multiple range test for PSOS of surface conditions

| Surface conditions | Mean PSOS | Duncan's grouping* |
|---|---|---|
| Water-Detergent | 1.93 | A |
| Dry | 0.33 | B |

*different letters indicating they are statistically significant at $\alpha = 0.05$.

### 3.3 Analyses of Correlation

The results of correlation analyses between the variables were calculated and are shown in Table 8.

**Table 8.** Correlation analysis between the variables

| | $RFS_{before}$ | $RFS_{after}$ | PSOS |
|---|---|---|---|
| $RFS_{before}$ | | 0.594 | −0.651 |
| $RFS_{after}$ | | | −0.924 |

## 4 Discussion

Before the experiment, illumination was considered an important factor affecting the perceived floor slipperiness. One of the illumination conditions represents the ordinary daylight condition and the illuminations of the target area of the test floors were more than 300 lx. The dark condition was at night and with all the curtains in the laboratory pulled up to prevent the outside light in, the illuminations of the target area of the test floors were less than 0.10 lx. The $RFS_{before}$ was the rating of floor slipperiness based on visual judgment. Therefore, the floor and floor conditions we had observed would have an impact on the $RFS_{before}$. The experimental results confirm this version. Table 2 shows the $RFS_{before}$ of ceramic tile (4.42) was significantly different from that of the granite (3.90). Table 3 shows $RFS_{before}$ of dry condition (4.50) was significantly different from that of the water-detergent (3.81). For illumination conditions, it was anticipated that the subjects would reluctant to give a NOT SLIPPERY rating when they could not see clearly the walkway. Li et al. [18] confirmed this hypothesis. However, the ANOVA results in the current research indicated that the effects of illumination was not significant ($p > 0.05$) on the $RFS_{before}$.

For the $RFS_{after}$, the subjects gave their ratings of floor slipperiness based on their perception during the gait. Therefore, the subjects used the traction of their foot on the floor to make judgment instead of the vision. Our ANOVA results showed that the effect of illumination on $RFS_{after}$ was not significant ($p = 0.6390$), and the $RFS_{after}$ was significantly affected by the interaction between the shoes and surface conditions ($p < 0.05$), floor and surface conditions ($p < 0.0001$). However, prior observation could influence later experience in the perception of floor slipperiness [14]. Table 8 shows there was a significant positive correlation between the $RFS_{after}$ and $RFS_{before}$ ($r = 0.594$, $p < 0.0001$).

Chiou et al. [17] proposed the PSOS to indicate the risk of slip and fall when walking. The final score of PSOS was the addition of the scores from the four questions. As each of the response of the question was in the range of 0 to 2, the final score of PSOS was between 0 and 8. Chiou et al. [17] indicated that a fall will occur if the PSOS exceeds 4.5. In our experiment, the PSOS ranged from 0 to 5.5. However, 95% of the PSOS values were lower than 4.5 and most of them were 1.0 or lower. This infers that the overall risk of slip and fall in our experiment was low. For the floors, the PSOS of granite (1.66) was significantly ($p < 0.05$) higher than those of ceramic tile (0.60). This infers that the granite floor provided higher risk of slip and fall than the ceramic tile floors. For the surface conditions, the PSOS of the water-detergent condition (1.93) was significantly ($p < 0.05$) higher than that of the dry (0.33) surface conditions. The subjects certainly perceived higher risk of slip and fall when they were walking on detergent contaminated surfaces than the dry surfaces. For shoes conditions, the PSOS difference between the rubber (1.29) and EVA (0.96) was not significant ($p > 0.05$). This implies that rubber and EVA have a small difference on the risk of slip and fall. However, Fig. 5 shows that the mean PSOS of rubber soled were higher than that of EVA soled no matter which conditions. The inconsistency between Fig. 5 and the ANOVA results may be due to the small sample size of the study.

## 5 Conclusion

A gait experiment was carried out to test the subjective ratings of human subjects concerning their perception on floor slipperiness. It was found that the $RFS_{before}$, $RFS_{after}$ and PSOS were all affected significantly by floor and floor surface conditions. In addition, the $RFS_{after}$ and PSOS were significantly affected by the interaction between floor and floor surface condition. For $RFS_{after}$, there was also interaction between shoe sole material and floor surface conditions. There are significant correlations between $RFS_{before}$, $RFS_{after}$ and PSOS.

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