The Effect of Shoe Sole Tread Groove Depth on the Gait Parameters during Walking on Dry and Slippery Surface

M Ziaei¹, SH Nabavi², HR Mokhtarinia², SF Tabatabai Ghomshe²

Abstract

Background: Prevention of slipping accidents requires provision of adequate friction through the use of suitable combinations of footwear and underfoot surfaces. Shoe sole tread groove is one of the important factors on friction coefficient during walking.

Objective: To measure the effect of different shoe sole tread groove depths and different surfaces on the required quotient of friction (Q), heel strike velocity and occurrence time of ground reaction forces (GRF) in stance phase during walking on slippery and dry surfaces.

Methods: In this semi-experimental study, 22 healthy men were studied under different conditions. The studied independent variables were shoe groove depths (included 1, 2.5 and 5 mm) and type of walking surface (dry and slippery). Biomechanical gait analysis was carried out with 396 single steps. Data were collected by motion analysis system and two force platform.

Results: The occurrence time of GRF was significantly faster on dry surface than slippery surface (p<0.01). Q was significantly lower on slippery surface and with groove depths of 1 and 2.5 mm. The highest value of Q was observed with the deepest groove depth of 5 mm. Heel strike velocity did not differ significantly in the 6 conditions tested.

Conclusion: Tread groove depth is a significant factor affecting the Q at the shoes-surface interface on dry and slippery floors. It seems that deeper groove is more appropriate for maintaining the stability during walking. The walking surface affects the occurrence time of GRF; the force components occur sooner on the dry than slippery surface.

Keywords: Accidents, occupational; Accidental falls; Shoes; Friction

Introduction

Slipping and falling accidents are among major ergonomic and safety topics in the workplace and general community. Therefore, one of the priorities is to prevent slipping- and falling-induced musculoskeletal injuries in industrial, office and public places; thus, necessary interventions in the design of a slip-resistant shoe that would prevent these events in different environments.
TAKE-HOME MESSAGE

- One of the major ergonomic and safety topics in the workplace and general community is slipping and falling accidents.
- Footwear with inadequate slip resistance is one of the key factors in increasing risk of falls in workers.
- Combination of groove depth and surface condition was ineffective. Fear of falling would mask the effect of groove depth.

are of paramount importance.

The risks associated with slipping and falling are attributed to the materials of footwear and floor, contamination condition and geometric design of the sole.1 Bentley and Haslam reported that footwear with inadequate slip resistance is one of the key factors in increasing risk of falls in mail delivery workers.2 To prevent fall or slip hazard, we should emphasize on designing “slip resistant” footwear and floor surfaces.3

Prevention of slipping accidents requires provision of adequate friction by using appropriate combinations of footwear and underfoot surfaces. It has been shown that although there are many factors that contribute to slipping accidents, footwear itself, has an important effect on the stability of the wearer.3 When stepping on a wet or lubricated floor, a shoe sole cannot touch the floor surface without squeezing the liquid out of the contact area; the liquid between the floor and sole then separates the two contact surfaces, hence reducing the friction between them.1

Measurement of friction and determination of coefficient of friction (COF) have been the major focus in tribological studies.4 Many studies conducted to measure friction on level surfaces, both in laboratory and on work sites.5-9 Li and Chen indicated that tread groove should be wide enough to allow drainage of the liquid at the footwear-floor interface.10 Li, et al, suggested that tread groove should also be deep enough to accommodate the liquids underfoot.1 Variations in tread groove depth may affect the capability of the sole to drain the liquid underfoot; they may be partially responsible for the COF value at the footwear-floor interface.1

Dimensions of shoe sole treads grooves are among the important factors in the amount of friction between the shoe and surface during walking. In previous research studies the effect of tread groove depth,1 groove width10 and groove orientation and width11 on the COF was studied. With appropriate biomechanical analysis (e.g., analysis of walking), the human factors affecting slipping and falling and their complex interaction with environmental factors can be investigated.12,13 Slips occur when the friction demand of an individual exceeds the friction available between the shoe and floor.14

The most important value for the decision about whether slipping will occur is the friction force as a quality of the contact between the shoe and the flooring. To test the slip resistance of flooring, the dynam...
ic COF ($\mu$) will be measured in the test device and compared with the requirements quotient ($Q$) in the form of the limits of $\mu$; slip blocking is sufficient if $\mu > Q$.15

In this study, we studied the effect of different groove depths on the $Q$, heel strike velocity and the time of occurrence of forces in stance phase of 22 people while walking on slippery and dry surfaces.

**Material and Methods**

Biomechanical gait analysis of 396 single steps of 22 people was performed to measure the effect of different groove depths on the $Q$, heel strike velocity and the time of occurrence of forces in stance phase while walking on slippery and dry surfaces. In this study, the value of $Q$ was considered as a criteria for prediction of the required COF for prevention of slipping. Because the heel strike is considered as the critical phase for falling accidents caused by slipping, the heel strike velocity was recorded with a high speed camera. Also, time of occurrence of forces during the stance phase was calculated to compare them among different test conditions.

**Shoes**

In our experiment, we used Oxford standard shoes with three different groove depths of 1, 2.5, and 5 mm, and a fixed groove width of 3 mm. The shoes were fit to the subject’s feet. The upper compartment of the shoes was made of leather and the sole of polyurethane (Fig 1).

**Participants**

Twenty-two healthy men were recruited from the students of University of Social Welfare and Rehabilitation Sciences. The mean±SD age of participants was 24.5±3.4 years; they had a mean±SD weight of 71.1±6.4 kg, height of 177.6±4.4 cm and body mass index (BMI) of 22.5±1.3 kg/m². Study subjects were selected randomly. The competency of participants was evaluated by a biomechanics specialist and a physiotherapist; if the participant had no exclusion criteria, they

![Figure 2: Description of ground reaction force in stance phase](image)
were tested. The exclusion criteria included having history of musculoskeletal disorders, problems in their lower limbs, use of foot orthoses, history of surgery of the lower extremity, flat foot, cross feet and antalgic gait. All subjects read and signed an informed consent approved by the Ethics Committee of University of Social Welfare and Rehabilitation Sciences.

**Experimental design**

In this study, subjects were exposed to two independent variables: shoe groove depths (three levels of 1, 2.5, and 5 mm) and walking surface (dry and slippery surfaces).

The subjects were asked to wear stretch pants and Oxford standard shoes. They were asked to walk on a walkway freely until they got comfortable with the movement rhythm and pace before data collection. We assumed that the normal rhythm for the studied people (aged 18–49 years) would be from 98 to 138 steps per minute.¹⁶

Kinematic data obtained from a six-camera motion analysis system (Vicon-460, Oxford, UK) were recorded in the Ergonomics Laboratory of University of Social Welfare and Rehabilitation Sciences. The sampling frequency was 200 Hz.

The ground reaction forces ($F_x$, $F_y$, and $F_z$) were recorded at 1000 Hz by two force platforms (Z812A, Kistler Instruments AG, Switzerland). The walkway length was three meters. Generally, six experimental conditions (two different surfaces with three groove depths) were randomly ordered; 3–5 repetitions were performed within each condition set. Sufficient rest was provided between conditions to minimize fatigue effects.

### Table 1: The abbreviations used in this study

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1dry</td>
<td>Groove depth of 1-mm on dry surface</td>
</tr>
<tr>
<td>1slip</td>
<td>Groove depth of 1-mm on slippery surface</td>
</tr>
<tr>
<td>2.5dry</td>
<td>Groove depth of 2.5-mm on dry surface</td>
</tr>
<tr>
<td>2.5slip</td>
<td>Groove depth of 2.5-mm on slippery surface</td>
</tr>
<tr>
<td>5dry</td>
<td>Groove depth of 5-mm on dry surface</td>
</tr>
<tr>
<td>5slip</td>
<td>Groove depth of 5-mm on slippery surface</td>
</tr>
</tbody>
</table>

### Table 2: Mean±SD of occurrence time of $F_z$ and $F_x$ in stance phase

<table>
<thead>
<tr>
<th>Test conditions</th>
<th>Occurrence time (% stance phase)</th>
<th>$F_z$</th>
<th>$F_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heel strike</td>
<td>Max$_1$</td>
<td>Min</td>
</tr>
<tr>
<td>1</td>
<td>8.5±3.9</td>
<td>28.2±4.4</td>
<td>46.9±4.5</td>
</tr>
<tr>
<td>2.5</td>
<td>8.0±3.7</td>
<td>28.9±4.9</td>
<td>47.8±5.6</td>
</tr>
<tr>
<td>5</td>
<td>8.3±4.0</td>
<td>29.4±4.7</td>
<td>48.6±6.2</td>
</tr>
<tr>
<td>Dry</td>
<td>6.9±3.1</td>
<td>26.9±4.3</td>
<td>46.5±5.5</td>
</tr>
<tr>
<td>Slippery</td>
<td>9.6±4.0</td>
<td>30.8±4.2</td>
<td>49.0±5.2</td>
</tr>
</tbody>
</table>
Data analysis

Time of occurrence of forces in stance phase
To determine the time of occurrence of the heel strike, we measured the first maximum (Max$_1$), minimum (Min) and the second maximum (Max$_2$) values on F$_z$ axis (vertical ground reaction force) and also the maximum (Max) and minimum (Min) values on F$_x$ axis (anterior-posterior ground reaction force) (Fig 2). Then, we measured the moment of occurrence of these forces in stance phase (%time of forces occurrence during the stance phase).

Requirements quotient ($Q$)
The values of $Q_x$ ($Q$ in anterior-posterior axis), $Q_y$ ($Q$ in medial-lateral axis) and $Q_{xy}$ ($Q$ in outcome of X and Y axis) in heel strike and toe off moments were calculated by using the following equations.

$$Q_x = \left| \frac{F_y}{F_z} \right|$$

$$Q_y = \sqrt{Q_x^2 + Q_{xy}^2}$$

Heel strike velocity
The horizontal heel strike velocity equals the parameter sliding velocity in the test device.$^{15}$ Using heel markers, the mean horizontal velocity at the moment of heel strike and four frames before that was calculated and considered as the heel strike velocity.

Data for 396 trials (22 participants $\times$ 3 groove depths $\times$ 2 types of floors $\times$ 3 trials) were obtained. One-way analysis of variance (ANOVA) was used to compare $Q$ and heel strike velocity among six different test conditions; Student’s $t$ test for paired data was used for two-two comparison of $Q$, heel strike velocity and the time of occurrence of forces in stance.
Table 1 shows the abbreviations used in this study. Table 2 shows the mean±SD of occurrence time percentage of \( F_z \) and \( F_x \) in stance phase.

Time of occurrence of forces in stance phase

Tables 3 shows the effects of groove depth, walking surface and their combination on the occurrence time percentage of \( F_z \) and \( F_x \) in stance phase. We found that occurrence time of heel strike, \( F_{z\text{max}} \), \( F_{z\text{min}} \) and \( F_{x\text{max}} \) was significantly lesser on dry surface than slippery surface \((p<0.01)\). There was no significant association between the event time of components and the tread groove depth (Table 3).

Requirements quotient \((Q)\)

Table 4 shows the mean±SD of \( Q \) in heel strike and toe off moments in anterior-posterior (X) and medial-lateral (Y) axes of gait. The values of \( Q \) in X-axis were more than Y-axis at the heel strike and toe off moments (Table 4). Table 5 shows the result of comparison of \( Q \) in heel strike and toe off moments in X, Y and XY axes under various test conditions (slippery vs dry, and slippery vs slippery). Figure 3 depicts the compression of \( Q \) in XY axis between heel strike and toe off.
Heel strike velocity

Table 6 shows the Mean±SD of heel strike velocity and ANOVA results for comparison of various test conditions. Heel strike velocity was not significantly different among the six test conditions.

Discussion

Time of occurrence of forces in stance phase

The time of occurrence of forces was lesser on the dry surface than slippery surface which is probably due to fear of falling while walking on a slippery surface which in turn leads to taking step more cautiously and resultant delay in occurrence of components.

Various groove depths did not affect the time of occurrence of vertical and antero-posterior components of GRF. Although it is expected that increasing groove depth would increase the time of occurrence of force components while walking on a slippery surface, it seems that fear of falling would mask the effect of groove depth. Therefore, combination of groove depth and surface condition was ineffective.

Requirements quotient (Q)

Heel strike

In X axis, for small groove depths (1 and 2.5 mm), Q measured on X axis was
significantly lower on slippery surface than dry surface. On slippery surface, $Q$ was highest for the deepest groove studied (5 mm). However, for the deepest groove (5 mm), $Q$ was not significantly different between dry and slippery surfaces—increasing groove depth would improve stability on both slippery and dry surfaces.

In Y axis, although $Q$ increased with increasing groove depth on slippery surface, no significant difference was observed in its value on dry surface compared to slippery surface. On slippery surface, $Q$ was highest for the deepest groove studied (5 mm).

In XY axis, although there was no significant difference in $Q$ among the slip conditions tested, it was higher in “5slip” than “1slip” and “2.5slip” while walking. $Q$ on slippery surface was significantly lower than dry surface with groove depths of 1 and 2.5 mm, but there was no significant difference using 5 mm. Therefore, higher groove depths would result in improved stability during walking.

**Toe off**

In X, Y and XY axes, $Q$ was significantly lower on slippery surface than dry surface with groove depths of 1 and 2.5 mm; however, there was no significant difference using 5-mm groove depth. In X and XY axes, $Q$ was significantly higher with groove depth of 5 mm than 1 mm on slippery surface.

In all studied axes (X, Y and XY), at the heel strike and toe off moments, there were no significant differences between $Q$ recorded during experiments with any of the dry conditions. Therefore, groove depth does not affect $Q$ during walking on dry surface.

Walking on a slippery surface evokes a gait that is distinctly different from that of normal walking. It seemingly reflects a strategy for dealing with walking on uncertain surface conditions. The strategy specifically reduces the horizontal forces while maintaining vertical forces. We found that the horizontal forces (antero-posterior and medio-lateral) were lesser on a slippery than a dry surface.

Deeper groove in shoe sole can drain liquid under shoe while walking on a slippery surface and increase the contact area between shoe and ground. This would increase the $Q$ and improve stability during walking. Otherwise, the liquid below shoe sole would result in slipping and probably falling.

As stated for safe walking, the dynamic COF should have a higher value than the $Q$. The $Q$ has a mean value of 0.22. Based on the deviation of the requirements quotient, we suggest a value of dynamic COF of 0.45 as a limit for the evaluation of the slip resistance of flooring. With a value higher than 0.45, 99.9% of walkers are able to walk without the risk of slipping and the floor can be evaluated as slip resistant. According to the results of the current study, all values of $Q$ were less than 0.45—the limit for the evaluation of the slip resistance of flooring.

**Heel strike velocity**

Although it was expected that heel strike velocity is lesser on slippery surface than dry surface because of more caution in walking, we found that not only surface condition but also combination of groove depth and surface condition had no effect on heel strike velocity. The participants in this experiment probably had more caution in mid-stance than the first moment of stance (exactly before heel strike), hence, the strike velocity at this moment on dry surface was not different from that on a slippery surface.

This study had some limitations. For example, the small sample size of this study might not have provided sufficient statistical power to detect the differences between the test conditions.

In conclusion, we found that tread groove depth is a significant factor affecting gait parameters.
ing the $Q$ at the shoe-surface interface on dry and slippery floors. The deeper tread groove would result in a significantly higher $Q$ and thus provide more stability during walking.

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Conflicts of Interest: None declared.

References


