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The effect of subject awareness and prior slip experience on tribometer-based predictions of slip probability

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Abstract

Prior knowledge of potentially slippery conditions has been shown to alter normal human gait in slip and fall experiments. We sought to quantify how the empirical relationship between slip probability and available floor friction was affected by subject awareness and prior slip experience. Sixty-eight subjects (40 females, 28 males) walked over three different low-friction surfaces inserted periodically between non-slip control trials. Three increasing levels of prior knowledge were used: deceived (unaware of the slippery surface), aware (20% chance of a slippery surface, but no prior slip experience) and experienced (aware with prior slip experience). Available friction was measured using a drag sled and a variable incidence tribometer. Of 620 low-friction trials, 124 generated slips greater than 27 mm. The proportion of slips, the slip distance and the required friction (taken from the control trial immediately before a low-friction trial) generally decreased with increasing levels of prior knowledge. These adaptations were accommodated by logistically regressing slip outcome (yes/no) against the normalized friction (available friction minus required friction) rather than against available friction alone. The regressions showed that subject awareness biased the slip probability curve toward a lower slip risk for a given normalized friction, but that the subsequent addition of slip experience generated a slip risk curve that was not significantly different from that of deceived (and presumably unprepared) subjects. These findings suggest that data to validate a tribometer's ability to predict the risk of slipping (but not falling) can be acquired from subjects with prior slip experience.

Keywords: Slip and fall; Tribometers; Gait adaptations; Slip prediction

1. Introduction

Slips and slip-related falls are responsible for many musculoskeletal injuries [1,2] and typically develop when the friction at the shoe/floor interface is less than expected [3,4]. Floor surface friction can be measured using a device called a tribometer, of which more than 50 different types exist [1]. Although tribometers are designed to measure friction, the values measured by different tribometers often vary considerably—even when identical test feet, flooring materials and contaminants are used [5–8]. As a result of this inter-tribometer variability, a tribometer's validity must be established before its measurements can be used to predict the probability of a slip on a particular surface.

Numerous studies have attempted to correlate the friction measured with a tribometer to the occurrence or severity of slips in ambulating human subjects [9–16]. Although these studies have shown that more slips and longer slips (more likely to lead to a fall) occur when floor friction is low, only one study used sufficient subjects, trials and friction conditions to establish an empirical relationship between tribometer measurements and the probability of slipping and falling [12]. Unfortunately, the

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results of this latter study are difficult to apply outside the laboratory for three reasons. First, the tribometer used in the study is a research instrument and not available commercially. Second, most of the slip trials were acquired on a sloped surface and humans alter their normal gait on sloped surfaces [17,18]. And finally, the subjects were aware of the slippery surfaces and had prior experience slipping on these surfaces, two factors that generate anticipatory gait changes and alter the probability of recovery after a slip [19–22].

The goal of this study was to quantify how the empirical relationship between the probability of slipping and tribometer-based measurements of floor friction is affected by the awareness and prior slip experience of human subjects. To improve on previous work [12], floor friction was quantified using two commonly-available tribometers and all trials were conducted on a level floor surface. Given prior evidence of a more cautious gait on potentially slippery surfaces [19–22], we hypothesized that subjects who encountered a slippery floor unexpectedly would have a greater probability of slipping than either subjects who were aware of the slippery surface or subjects who had recent slip experience. The results of this study will help provide validation data for two common tribometers and will show whether experiments designed to validate tribometers need to control their experimental conditions or correct their data for subject awareness and experience.

2. Methods

Sixty-eight healthy subjects (40 females, 28 males) between 18- and 40-year-old participated in this study. The females were 25 ± 6-year-old (mean ± S.D.), 165 ± 6 cm tall and had a mass of 61 ± 12 kg; the males were 27 ± 5-year-old, 177 ± 5 cm tall and had a mass of 77 ± 8 kg. Subjects reported no history of dizziness, vestibular dysfunction, neurological disorders, low-back pain or orthopaedic abnormalities of the lower extremities. All subjects read and signed an informed consent form approved by the university's Clinical Research Ethics Board.

2.1. Instrumentation

Ground reaction forces were measured using a force plate (Bertec 4060H, Columbus, OH) embedded near the middle of a 10 m walkway. Force plate signals were low-pass filtered (1000 Hz) before being sampled simultaneously using a 12-bit data acquisition system (Win30 DAQ, United Electronics Incorporated, Watertown, MA) at 2400 Hz for 6 s. Overhead harness loads were measured using a uni-axial load cell (Artech SS20210, Riverside, CA). Sagittal-plane motion of a heel marker on the left shoe was measured from video data acquired at 60 Hz (Sony Digital 8 DCR-TRV320).

2.2. Slip apparatus

The walkway was clad in vinyl composition tile over a concrete sub-floor. Four levels of shoe/floor friction were achieved using 40 cm × 60 cm sheets of paper placed on a 40 cm × 60 cm polished aluminum plate mounted to the top of the force plate, level with the surrounding floor. The visible surface of all paper sheets was identical and consisted of 600 grit sandpaper to eliminate sliding between the shoe and paper. Glued to the back of the sandpaper were four materials: wax paper, office printer paper, nothing (the backing of the sandpaper was used) and aluminum foil. The latter material was used as the non-slip surface for normal walking trials; the three other surfaces represented a range of low-friction surfaces for slip trials.

2.3. Test procedures

Subjects wore appropriately-sized lace-up trainers with a polyurethane rubber sole (Nike 2530c Air Pegasus). A start position was selected to ensure the left limb struck the force plate after at least five steps. Subjects were instructed to walk with a level gaze at their preferred speed and to not target the force plate. Normal light levels were used since it was not possible to discern the friction level from the outward appearance of the paper on the slip plate. A different paper sheet was used for every trial to prevent subjects from potentially identifying friction levels from blemishes or marks on the sandpaper surfaces. Subjects wore a safety harness tethered from each shoulder to an overhead trolley. Tether length was adjusted to minimize interference with normal walking.

All subjects completed 40 trials (4 blocks × 10 trials/block). Subjects accommodated to wearing the harness and walking over the high friction surface during the first block and their normal gait was measured during the second block. Despite being told there would be no slips in the first two blocks, one of the three low-friction surfaces (randomly selected) was inserted for the last trial of the second block. After this deception, subjects were told that two low-friction surfaces (the same friction level experienced in their deception trial) would be inserted randomly in the third block. All subjects were then exposed once to each of the three low-friction surfaces during the fourth block. The first 46 subjects also completed two additional blocks of 10 trials: one at a self-selected slow walking speed and the other at a self-selected fast walking speed. All three low-friction surfaces were presented once in each additional block. These trials were used to generate a broader range of walking data. The presentation order of the slow, normal and fast blocks (4th, 5th and 6th blocks) was randomized in these 46 subjects.

2.4. Tribometer measurements

Friction between the paper sheets and the aluminum force plate surface was measured using two tribometers: a