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Evaluation of Workers' Perceived Sense of Slip and Effect of Prior Knowledge of Slipperiness During Task Performance on Slippery Surfaces

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Evaluation of Workers' Perceived Sense of Slip and Effect of Prior Knowledge of Slipperiness During Task Performance on Slippery Surfaces

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Forty healthy industrial workers (age: 41.0 ± 14.9 years) were tested for postural stability for three simulated tasks: (1) standing upright; (2) rapid trunk movement; and (3) lateral reach during lifting. These tasks were performed on four levels of slippery surfaces under different environmental lighting with new or workers' own old shoes. Prior to postural stability tests, each subject was given the opportunity to assess the surface slipperiness that he or she would encounter in the subsequent postural stability tests. A perceived sense of slip (PSOS) scale was administrated immediately after each test to determine subjects' PSOS. Subjects' postural sway and instability during task performance was determined by using a strain gauge type force platform. Results from this study indicate that subjects who were cautious in assessing surface slipperiness had less postural instability during task performance. Subjects could perceive the likely slips due to the change in task ($p=0.0001$) and surface slipperiness ($p=0.0001$). The PSOS scale is reproducible, easy to use, and provides a simple way to evaluate potential slip hazards in the workplace. Results from this study should aid understanding of the factors critical to maintaining postural stability on slippery surfaces, and will help to develop guidelines for safety training and identify slip hazards in the workplace.

Keywords: perceived sense of slip, postural stability, slip

Accidents associated with slips and falls have been recognized as a major source of injuries in the workplace. A study of underfoot first event accidents sustained by 10,000 workers found that 62% of accidents were related to foot slips.[1] These slips have been the main contributor to falls in the workplace. In 1991 the National Safety Council reported that falls were the third leading cause (17%) of occupational injury leading to disability.[2] In an accident profile analysis among New York industries, Cohen found that the majority of falls were attributable to a combination of standing/walking on wet, slippery, or uneven surfaces and poor lighting.[3]

Tribological and biomechanical aspects of slips have been studied to reduce slip accidents.[4–7] To prevent slip and fall injuries, many investigators, including Grönqvist et al. and Andres and Chaffin, have put their efforts into developing apparatus and methods to evaluate the slipperiness between footwear and the floor.[4–7] However, standardized devices and procedures that can be used to determine accurate, consistent, and reproducible results still are not available.

Occupational slips and falls often occur because of unexpected changes in floor coefficient of friction (COF) due to a spill. In an occupational and daily life environment, individuals may have to make judgments regarding the slipperiness of a surface before initiating a task if the floor appears to be contaminated. For all practical purposes, the judgment usually has to be made immediately and is done in a subjective

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TABLE I. Demographic Data (n = 40)

	Male (n = 20)		Female (n = 20)	
	Mean	SD	Mean	SD
Age (year)	41.0	14.9	39.5	14.9
Weight (kg)	84.6	12.5	75.9	18.6
Height (cm)	175.3	4.9	161.3	5.7
Left foot length (cm)	27.2	0.88	24.7	1.0
Right foot length (cm)	27.3	0.84	24.7	1.1
Left foot width (cm)	10.1	0.47	9.3	0.5
Right foot width (cm)	10.0	0.51	8.8	0.2

fashion. Subjects' ability to assess floor slipperiness has been studied by researchers.[8–10] Swensen et al. found that subjects could identify differences in the slipperiness of different types of steel coating tested.[8] There was a high correlation between the subjective ratings and the objective measurements of COF. A study conducted by Myung et al. also showed that subjects could perceive the slipperiness of floor surfaces (ceramic, steel, vinyl, plywood, and sandpaper were used).[9] In a study of the effect of shoe wear on objective and subjective assessment of slipperiness, Chiou et al. concluded that there is a need to consider subjective assessment of slipperiness as a valid way to evaluate floor slipperiness and the effect of shoe wear on slip potential.[10] A previous study found that people changed their stride as they approached and encountered slippery surfaces.[11] However, it is still unknown whether the propensity of loss of balance would be minimized if the subjects were given a chance to assess surface slipperiness they were to encounter in the workplace before performing tasks of bending down or lifting an object. There is no scientific data available regarding the effect of prior knowledge on workers' propensity of loss of balance during task performance.

The causes of slips in the workplace are complex. Factors that contribute to the mechanism of a slip include the type of task being performed; environmental factors (e.g., lighting, surface slipperiness, floor characteristics, contaminants, etc.); friction between footwear and the floor; health status of the physiological system; and perception of an impending fall and judgment of surface slipperiness. Although it is important to address the issues related to shoe/floor interface, a thorough understanding of slips requires the study of workers' perceptions of a likely slip as well. Therefore, the objectives of the current study were to (1) determine the relationship between workers' perceived sense of slip (PSOS) and objective measures of postural instability; (2) evaluate workers' PSOS when subjects were exposed to various environmental and job-task risk factors; and (3) determine the effect of prior knowledge of surface slipperiness on workers' postural balance during task performance.

METHOD

Subjects

Forty healthy worker subjects (mean 41.0 years ± 14.9 standard deviation [SD]) between the ages of 20 and 60 years participated in this study. They were recruited from local industries. These subjects represented a variety of occupations such as radio operator; sales; dock/receiving; custodian; vehicle operator; plumber; health care; student; HVAC technician; clerical/secretary; store clerk; postal worker; laborer; day care provider; and assembly line worker. Descriptive statistics are provided in Table I.

Each subject's foot length and width were determined, as these are related to the area of base of support. Foot length is the straight line distance from the most posterior point on the heel to the tip of the longest toe, measured parallel to the medial side of the foot. Foot width is the maximum horizontal breadth of the foot measured perpendicular to the medial side of the foot.

Exclusion Criteria

Subjects underwent a physical examination and medical history check-up. Subjects with a history of dizziness, tremor, alcoholism, vestibular disorders, neurological disorders, diabetic symptoms, cardiopulmonary disorders, and/or chronic back pain were excluded from this study. On each day of testing, a health questionnaire was filled out inquiring about (1) current health status, (2) current medication use, (3) consumption of caffeinated and/or alcoholic drinks in the 24-hour period prior to the tests, and (4) major injuries to the head, neck, or back. These factors could influence postural balance. The study protocol was approved by the University of Cincinnati Human Research Committee and each subject gave informed consent before participating.

Determination of Shoe-Surface Friction and Properties

In this study, subjects' postural stability was tested under different levels of surface slipperiness. The three levels of surface slipperiness were created by evenly spreading glycerin or mineral oil on two types of aluminum plates (coarse and smooth) attached to a force plate (Model OR6-5-1000, Advanced Mechanical Technology, Newton, Mass.). A series of pilot tests was conducted to determine the appropriate amount and the type of lubricant needed for creating the particular shoe-lubricant-flooring combinations with three desirable ranges of dynamic COF values: ≥ 0.30, 0.15–0.19, and 0.05–0.14. These three levels represent the slightly, medium, and very oily surfaces, respectively.[4] The slightly and medium oily surfaces were created by spreading 3.2 mL of glycerin and 4.5 mL of mineral oil on coarse aluminum plates, respectively. Nine milliliters of mineral oil were applied on smooth aluminum plates to create a very oily surface condition. The selection of the three levels of surface slipperiness was based on a previous study conducted by Grönqvist.[4] For COF values of 0.30 and greater, a slip is not likely to occur. For COF values of 0.15 to 0.19, a slip is possible, but the loss of balance is often recoverable. For COF values less than 0.14, a sudden slip will generally or frequently cause loss of balance.[4]

The dynamic COF values were measured by using a computer-controlled COF measurement device to exert a horizontal force on the shoe parallel to the force plate surface.[10] The computer-controlled COF measurement device consisted of a controller (Model NE34-005, Parker Hannifin Corp., Rohnert Park, Calif.), a stepper motor (Model S83-135, Parker Hannifin Corp.) with a gear box, and a force platform with an aluminum plate attached to it. The vertical load was controlled at 58.8 N by adding small lead balls into the shoe. A velocity of 20 cm/sec suggested by Tisserand was used to improve the accuracy and repeatability of measurements.[12]

In the current study, two pairs of new shoes and one pair of used shoes were used by each subject. One pair of new shoes was used specifically for dry conditions. The other pair of new shoes, which was of the same size, model, and manufacturer, was used for oily conditions. The purpose of using two pairs of new shoes is that once the new shoe soles have been exposed to the oil contaminant, the oil might permeate the pores of the shoe soles, and it is likely to change the slip-resistant properties of the material.

The used shoes, which reflected the natural wear patterns produced by the workers, were borrowed from the subjects and kept in the laboratory until the COF testing was over. The COF value of each shoe/floor combination was determined on a different day after subjective slipperiness evaluation tests were completed, representing the objective measurements. The method and instruments used for determining COF values were the same as those used for creating the three desirable ranges of friction for the study. Shoes were cleaned carefully between COF testing using paper towels and alcohol pads.[10]

Since subjects wore their own used shoes for the experiment, all used shoes were characterized in terms of the degrees of wear based on a previously published method.[10] The amount of shoe wear was determined by evaluating the percentage of tread available for each used shoe.[10] A shoe print was made for each shoe by using an ink roller to spread ink evenly on the sole, which was then pressed onto a piece of tracing paper. Each small area with tread available was visually determined and marked. Using Sigma Scan™ software (Jandel Scientific, Corta Madera, Calif.), the total area of the shoe and the area with tread still available were digitized. The percentage of tread available was then calculated. For this study, the average percentage of tread available of the used shoes was 78.8% (standard error = 2.1%).

Slipperiness Evaluation Test

On the first day of the experiment, the subject underwent 12 slipperiness evaluation tests under different surface conditions (slightly, medium, and very oily) with used shoes or new shoes. The COF values were 0.35, 0.18, 0.11 for slightly, medium, and very oily surfaces, respectively. These three levels of slipperiness were created according to the method stated in the previous section. This subjective slipperiness evaluation test was designed to allow subjects to be exposed to the various shoe/surface conditions they would encounter in the subsequent balance tests.

The procedures for evaluating subjective slipperiness were the same as in previously published literature.[8,10] The subject stood with his or her dominant foot placed on the aluminum plate and the other foot outside the plate. He or she was instructed to use the entire foot to move back and forth two times on an 8 × 20-inch area of an aluminum plate, which was attached to the force platform, in the diagonal direction for approximately 3 sec. Then the subject was asked to move his or her foot freely to assess slipperiness of the surface for approximately 2 sec. An additional 5 sec was used to rate the surface condition using the Subjective Slipperiness Rating Scale, which was also used by Swensen et al. to obtain subjects' evaluation of slipperiness.[8]

Immediately after each trial, subjects provided the rating by placing a vertical mark along a 3.5 inch horizontal scale representing 0 to 10 units. The ratings of 0, 5, and 10 represent very, medium, and not slippery, respectively. This rating scale has been tested for reproducibility.[10]

Evaluation of Postural Instability and Perception of Slip

After the slipperiness evaluation test, each subject went through 4 test sessions on 4 days to finish 48 postural stability tests and 12 baseline trials. At the beginning of each test session, subjects performed three tasks (standing upright, rapid trunk movement, and lateral reach during lifting) under optimal test conditions (good lighting, new shoes, dry surface) representing baseline. The 48 tests consisted of all possible test treatment combinations among 4 independent variables of task (standing upright, rapid trunk movement, or lateral reach/lifting task), lighting (good with 50 foot-candles, or poor with 0.2 foot-candles), surface slipperiness (dry, slightly, medium, or very oily), and shoe type (new or used). Subjects were told that the three types of slippery surfaces they would encounter were the same as those they experienced in the Slipperiness Evaluation Test. The order of administration of the postural stability tests was randomized for each subject.

Definition of the Incident of Slip

During the postural stability test, each subject stood on a dry or oily aluminum plate attached to the force platform in a standardized posture with heels together and toes at a 30° angle.[13,14] The outline of the shoes was drawn on the aluminum plate prior to the experiment. Subjects' feet were adjusted to match the predetermined outlines with the help of the investigator before the data collection began. The subjects were considered to be experiencing a slip whenever their feet moved outside the outer perimeter of their shoes. Subjects' feet were closely monitored by the investigator to determine whether the subject slipped. In addition, a camera was used to record the foot motion in the sagittal plane. Videotapes were replayed when there was any uncertainty regarding whether the subject slipped.

Test Protocol

The three tasks subjects performed during the experiment were of an occupational nature. The standing upright task is a common posture in industry while observing and monitoring display panels or operating equipment. The rapid trunk movement task simulates tasks that require bending the trunk down to pick up an item from the floor. For the lateral reach task, subjects were required to lift an object from a front table to a side table. The protocol of each task is described in the following.

Standing Upright Task: Subjects were required to stand quietly on the force platform with hands at their lower back on top of iliac spines for 30 sec. The top surface of the platform had the appropriate surface contamination as described before.

Rapid Trunk Movement Task: For the first 12 sec, subjects maintained upright posture on the force platform with hands at lower back. Next, the subjects were given a command to bend the trunk about 90° (with respect to vertical) in the sagittal plane. This posture was maintained for 5 sec. Finally, subjects were asked to rapidly bring the trunk back to an upright position and stay for an additional 13 sec.

Lateral Reach/Lifting Task: Subjects stood upright on the force platform facing a table (T1) with adjustable height placed at a distance (D1) (Figure 1). D1 is the straight line distance between the line jointing left and right ankle joints and the center of a 5-pound weight placed on T1. The position of the weight on T1 was properly adjusted so that D1 equals 1.2× each subject's functional reach. Another table (T2) was placed on the subject's left side at a distance (D2). D2 is the distance between the subject's right shoulder joint and the center of the weight placed on T2. D2 also equals 1.2× each subject's functional reach. D1 and D2 were adjusted so that the subject could grasp a 5-pound weight with two hands without moving the feet. The height of the tables was set at each subject's elbow height. The subject first stood upright with hands at lower back for 4 sec; then, with a voice command, the subject was instructed to reach the front table (T1) and grab the weight with both hands and bring it to the lateral table (T2). This process was repeated for a total of four lifting cycles, ending with the weight returned to its original place. At the end of the lifting task, the subject brought her or his hands

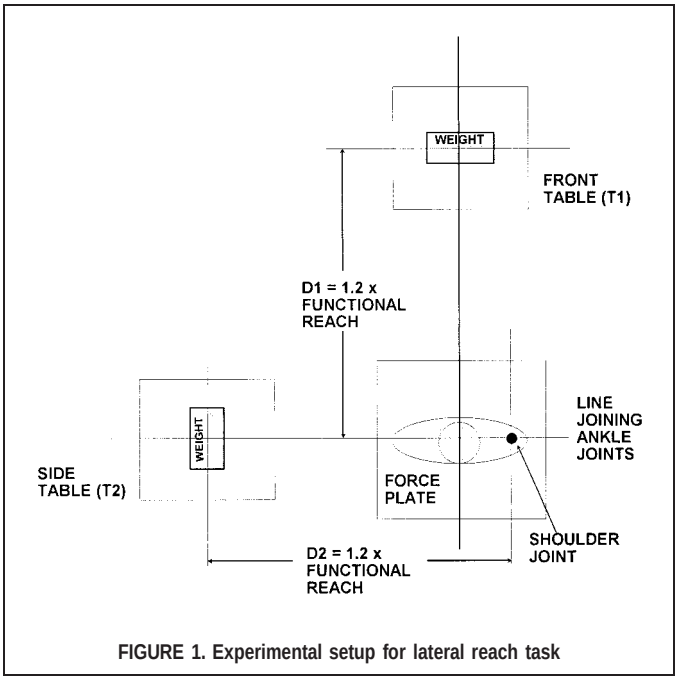

FIGURE 1. Experimental setup for lateral reach task

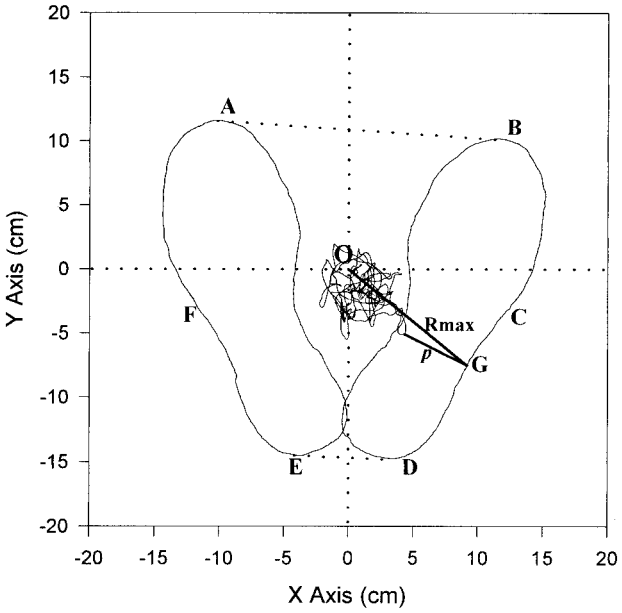

FIGURE 2. Illustration of the concept of stability boundary

to the lower back and maintained upright position for the remaining period of the test.

Between testing conditions, shoes were carefully cleaned. The subject was asked to rub the shoes on oil absorbing paper after the trial. Then, the subject sat on a chair with the feet on a foot stool and with the shoe sole facing the experimenter. The experimenter used paper towels to wipe out all the oil residue left on the shoe sole. Alcohol pads were then used to clean the treads and the channels in between the treads thoroughly.[10]

Evaluation of Workers' PSOS

In the current study, workers' PSOS was evaluated based on a previously published rating scale (Table II).[15] The scale consists of four simple questions, each representing a different aspect of information related to PSOS. This was designed to avoid a "double-barreled" question that asks for a single response to a combination of questions.[16] The PSOS is determined by adding the scores of four answers. The sum of four answers integrates various kinds information based on the principals of psychometrics.

The scale was administered immediately after each postural stability test to determine workers' PSOS during task performance.

TABLE II. Perceived Sense of Slip (PSOS) Rating Scale

1. How much did you feel yourself slip (i.e., loss of foot traction)?				
a litte		some		a lot
0	0.5	1	1.5	2
2. Did you have any difficulty in maintaining balance (how much did you or your muscles compensate for your movement)?				
a little		some		a lot
0	0.5	1	1.5	2
3. Did you feel at any time that you would slip?				
a little		some		a lot
0	0.5	1	1.5	2
4. What would you say was the overall difficulty of this task?				
a little		some		a lot
0	0.5	1	1.5	2

A high score implies a high subjective perception of slip and loss of balance. The reproducibility of this scale was tested using baseline data.

Description of Postural Sway and Propensity of Postural Instability Parameters

A strain gauge type force platform was used to evaluate workers' postural sway and the propensity of postural instability.[14] The data collected from the force platform were analyzed using a custom-developed software package to calculate the body's center of pressure (CP) movement during task performance. Two parameters, sway length (SL) and sway area (SA), were used for characterizing the postural sway. The sway length measures the distance traveled by the body's CP, and the sway area is the area of the region contained within the outer envelope of the CP movement in the x-y plane.

The propensity of postural instability was evaluated using three indices, Index of Proximity to Stability Boundary (IPSB), Weighted Residence Time Index (WRTI), and Stability Area Ratio (SAR). These three nondimensional indices, which are similar to those described by Bagchee and Bhattacharya,[13,14] were used to determine quantitatively the propensity of momentary loss of postural stability associated with a sway pattern formed by the CP with respect to the postural stability boundary (basal support area, outlined by ABCDEF in Figure 2). IPSB measures how close the body's CP travels to a person's stability boundary. It is defined as the minimum distance (p) between the CP and the stability boundary divided by the radial distance (Rmax) of the point on the stability boundary that is closest to the CP movement (Figure 2). WRTI is an indirect measure of the propensity of postural instability, which estimates the time that the CP is in the vicinity of the stability boundary. It is the weighted measure of time that the subject's CP lies in various proximity zones (200, 180, 160, 140, 120, 100, 80, 60, 40, and 20%) constructed by drawing concentric lines to the stability boundary at the predetermined distances from the stability boundary. SAR compares the spread

of the stabilogram to the stability boundary and is defined as the sway area divided by the area of the stability boundary.

Sway length is defined as the distance traveled by the CP, and the sway area is defined as the area enclosed by the CP without considering the importance of an individual's stability boundary. SAR considers the spread of the stabilogram with respect to the stability boundary, but it is calculated based on the sway area. On the other hand, IPSB and WRTI provide a quantitative estimation of the postural instability based on the proximity to the stability boundary and the time spent in the external proximity zones, respectively.

RESULTS

Reproducibility Testing of the PSOS Scale

The reproducibility of the PSOS scale was tested using baseline data (data from optimal test conditions of good lighting, dry surfaces, and new shoes). A repeated measure analysis of variance (ANOVA) was performed to determine the within-subject effects of visit and task on PSOS score. The results showed that there was no significant change ($p = 0.11$) in PSOS score due to different visits, but the independent variable of task produced a statistically significant difference in the score ($p = 0.0001$). These results indicate that no learning trend developed with repeated testing on different days, and that only different tasks were associated with the PSOS scores. Based on the baseline data, the mean PSOS scores for standing upright, rapid trunk movement, and lateral reach/lifting tasks were 0.13, 0.18, and 0.42, respectively. The coefficients of variations of the PSOS score among the four different visits ranged from 4.3 to 10%.

Effect of Test Conditions on PSOS Score, Postural Sway, and Postural Instability

Before any statistical testing was performed, the PSOS, postural sway, and postural instability parameters were transformed to their natural logarithms to achieve approximate normality of the statistical distributions. The results of repeated measure ANOVA showed that the main effects of task and surface, as well as the Task × Surface, interaction were highly significant on the PSOS score (all p values = 0.0001). A posteriori comparisons revealed that the mean PSOS score of the lateral reach/lifting task was significantly different from that of the standing upright or rapid trunk movement tasks (both p values ≤ 0.0001). However, the mean PSOS score for the rapid trunk movement task was not significantly different from that of the standing upright task ($p > 0.05$). The mean PSOS score for all four levels of surface slipperiness were significantly different from each other (all p values = 0.0001). The mean PSOS score for the lateral reach task (2.01) was the greatest of the three tasks (0.21 and 0.26 for standing upright and rapid trunk movement, respectively). This was also true when comparing the lateral reach/lifting task to other tasks for each level of surface slipperiness. Among all four surfaces, the greatest mean PSOS score occurred for the very oily surface (1.24), followed by the medium oily (1.13), slightly oily (0.64), and dry surfaces (0.30). Figure 3 illustrates the mean PSOS scores for the three tasks under various surface conditions. The mean PSOS scores for the standing upright and rapid trunk movement tasks were about the same across all four surfaces, ranging from 0.19 to 0.28. The mean PSOS scores for the lateral reach/lifting task were much higher than those found for rapid trunk movement and standing upright tasks, ranging from 0.49 (dry) to 3.20 (very oily). The only flooring effect was observed for lateral reach tasks. There was a 553.1% increase in mean PSOS score noted to occur between the dry surface and the very oily surface for the lateral reach/lifting task.

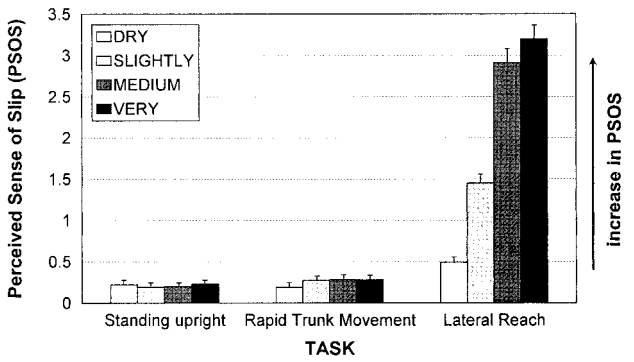

FIGURE 3. Mean and standard errors of PSOS for various task and surface conditions

The five parameters of sway and instability (sway length, sway area, IPSB, SAR, and WRTI) were analyzed by both univariate and multivariate repeated measure ANOVA. Results from univariate analysis indicate that the effects of task and surface were significant on all five parameters (all p values <0.03). The effect of lighting was significant on SL ($p=0.0001$), SA ($p=0.0001$), and SAR ($p=0.0001$) and the effect of shoe was only significant on SA ($p=0.04$) and SAR ($p=0.04$). For each of the three tasks, a multivariate repeated ANOVA was performed to analyze all five parameters simultaneously. A combined p value for each of the independent variables was obtaining by calculating the geometric means of the p values found for the three individual tasks:

$$\bar{p} = \exp\left\{\frac{1}{n}\sum_{i=1}^{3} \ln p_i\right\}$$

The p value associated with the task effect was obtained from the univariate analyses performed for the five variables. The importance of the independent variables was then ranked by comparing the p values. The effect of task was found to be the most important effect on postural sway and instability ($p = 0.0002$), followed by lighting ($p = 0.0005$), and surface ($p = 0.027$). The effect of shoe was marginally significant ($p = 0.093$). The greatest postural sway (highest mean sway length and sway area) and instability (lowest IPSB and highest SAR and WRTI) was found to occur for the lateral reach/lifting task (Table III). The mean of the lateral reach/lifting task's postural sway and instability were significantly different from those of the rapid trunk movement and standing upright tasks (both p values = 0.0001). The mean sway length and area found for poor lighting were higher than those observed for good lighting (Table III). The mean IPSB and SAR indicated greater postural instability for poor lighting compared with good lighting, but this trend was not seen for WRTI. The mean sway length of very oily surfaces was the greatest (78.21) among the four surfaces, followed by medium oily (77.93), slightly oily (76.27), and dry surfaces (75.84) (Table III). Both variables of IPSB and WRTI indicated that the postural instability of very oily surfaces was the greatest among the four surfaces, followed by medium oily, slightly oily, and dry surfaces (Table III).

TABLE III. Geometric Means and Standard Deviations of Postural Sway and Instability for Task, Lighting, and Surface Factors

	Sway Length	Sway Area	IPSB	SAR	WRTI
Task (p = 0.0002)					
Standing upright[A]	38.04	2.45	0.770	0.004	0.009
	(1.27)	(1.92)	(1.06)	(1.93)	(1.05)
Rapid trunk movement[A]	69.45	11.56	0.643	0.017	0.013
	(1.23)	(1.53)	(1.08)	(1.52)	(1.05)
Lateral reach/lifting[A]	173.14	54.70	0.262	0.082	0.225
	(1.20)	(1.52)	(1.33)	(1.50)	(1.53)
Lighting (p = 0.0005)					
Good[A]	70.98	10.04	0.554	0.015	0.087
	(1.98)	(4.31)	(1.26)	(4.34)	(1.33)
Poor[A]	83.67	13.36	0.543	0.020	0.069
	(1.86)	(3.48)	(1.24)	(3.48)	(1.26)
Surface Slipperiness (p = 0.027)					
Dry[A]	75.84	11.48	0.589	0.017	0.029
	(1.90)	(3.71)	(1.14)	(3.70)	(1.06)
Slightly oily[A]	76.27	11.34	0.579	0.017	0.043
	(1.89)	(3.74)	(1.17)	(3.76)	(1.14)
Medium oily[A]	77.93	11.79	0.514	0.018	0.105
	(1.95)	(4.10)	(1.20)	(4.15)	(1.35)
Very oily[A]	78.21	11.72	0.500	0.018	0.139
	(1.98)	(4.15)	(1.34)	(4.15)	(1.48)

[A]Standard deviations shown in parentheses

Effect of Prior Knowledge of Slipperiness on Postural Instability

The subjects' ability to correctly assess the surface slipperiness was evaluated by comparing their subjective ratings of surface slipperiness with the COF values of the shoe/floor surface. Figure 4 presents the scatter plot of the subjective rating versus the COF values. The COF values of new shoes were 0.35, 0.18, and 0.11 for slightly, medium, and very oily surfaces, respectively. The three clusters in Figure 4 at COF values of 0.11, 0.18, and 0.35 represent the COF values for new shoes.

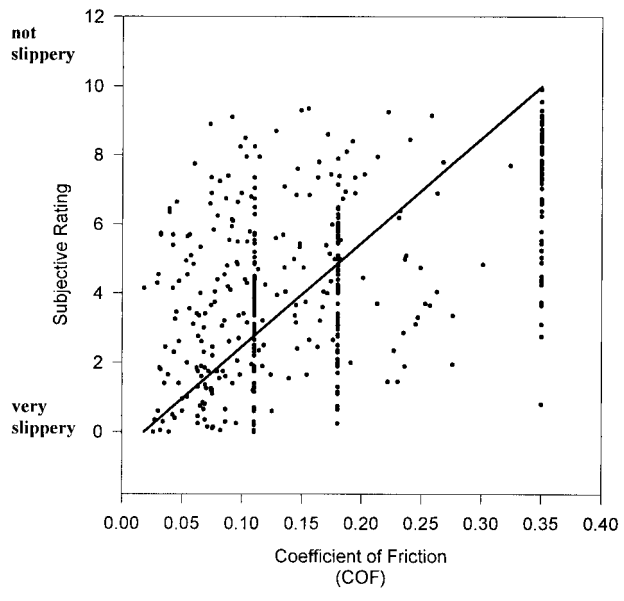

FIGURE 4. Illustration of the regression relationship between subject rating and dynamic COF (subjective rating = 2.21 + 13.33 × COF)

Subjects used the 10-unit rating scale to judge the slipperiness of various shoe/floor surfaces with COF values ranging from 0 to 0.35. Ideally, subjects would rate the most slippery surface (COF = 0.02) with the subjective slipperiness rating scale value of 0 and the least slippery surface (COF = 0.35) with the scale value of 10. A regression line (subjective rating = 2.21 + 13.33 × COF) was fitted to the empirical data points (Figure 4). This linear relationship between the subjective ratings and the dynamic COF values was statistically significant ($p < 0.0001$, $R^2 = 0.28$). Residuals (differences between each observation and the predicted value for each observation based on the regression line) were calculated to represent the discrepancies between the rating given by the subject and that value predicted by the regression relationship.

To investigate whether the subjects who were more "accurate" in assessing surface slipperiness (i.e., evidenced small residuals) would have less postural sway and instability during task performance, a correlation analysis was performed. Table IV contains the correlation coefficients between the residuals and the number of slips, postural sway variables, and indices of postural instability. A significant negative correlation between the residuals and IPSB and a significant positive association between the residuals and WRTI was found. The larger the residuals, the smaller the IPSB values or larger the WRTI, implying greater postural instability.

Slip Occurrence During Task Performance on Slippery Surfaces

In the current study the subject was considered to be experiencing a slip when his or her foot moved outside the stability boundary defined by the outer perimeter of his or her feet. Among all test trials performed by the 40 subjects, there were 464 slips (24.2%). Four hundred and thirty-four out of 464 slips (93.5%) occurred during lateral reach tasks.

To understand better whether the subjects were able to perceive a likely slip while performing lateral reach tasks, the number of slips and percentage of slip occurrence in various ranges of PSOS score were compared. Figure 5 graphically illustrates the relationship of slips and the PSOS score. The percentage of slip

TABLE IV. Pearson Correlation Coefficients Between Residuals and Postural Sway and Instability Variables

	Sway Length	Sway Area	IPSB	SAR	WRTI	Number of Slips
Residue	0.19 (p = 0.14)	0.16 (p = 0.18)	−0.35[A] (p = 0.03)	0.18 (p = 0.15)	0.39[A] (p = 0.02)	0.001 (p = 0.50)

Note: One-tailed tests were performed.
[A]Any findings with $p < 0.05$ were considered statistically significant.

occurrence increased as PSOS increased. The percentage of slip occurrence reached 100% in the PSOS score range of 4.0 to 4.5 and stayed at 100% beyond this range.

Relationship of PSOS with the Postural Instability Variables

Repeated measure analysis of covariance was performed to investigate the relationship between PSOS score and each postural instability variable. It was found that there were significant associations between PSOS and the postural instability variables of IPSB ($p = 0.001$) and WRTI ($p = 0.0006$). Marginally significant associations were found between PSOS and sway area ($p = 0.09$) and between PSOS and SAR ($p = 0.09$). The regression coefficient for PSOS on IPSB was −0.045, indicating that the higher the PSOS, the lower the IPSB. Lower IPSB implies greater postural instability, and higher PSOS indicates greater perception of slip. The regression coefficient for PSOS on WRTI was 0.066, which also indicated that there was a significant increase in postural instability (higher WRTI) with increasing PSOS score. The strongest correlation ($r = 0.46$) was found between PSOS and WRTI.

DISCUSSION

Effect of Prior Knowledge of Surface Slipperiness on Postural Instability

Prior to postural balance testing, each subject had an opportunity to assess the three levels of surface slipperiness that he or she would encounter in the subsequent postural balance tests, using a slipperiness rating scale. Regression analyses indicated that there was a significant linear relationship (subject rating = 2.21 +13.3 COF) between subjective rating of slipperiness and the dynamic COF values of the surface ($p = 0.0001$). Subjects rated the surfaces less oily as the dynamic COF of the particular shoe/surface combination increased. For a given value of COF, there is a predicted subjective rating, given by the regression line. It can be hypothesized that subjects were considered to be overconfident if the subjective rating given was larger than the predicted value (i.e., leading to a positive residual was calculated). In other words, subjects were overconfident since they rated the surface less slippery whereas the COF value suggested a relatively greater slipperiness based. On the other hand, ratings below the regression line (leading to a negative residual) imply that subjects were very cautious. The subjective ratings were lower relative to the COF value, suggesting relatively less slipperiness. Therefore, it can be theorized that if a subject is very cautious in assessing the surface slipperiness, he or she will have a better idea of the slipperiness of the working environment. Such knowledge will be incorporated with other information coming from vision, vestibular, and proprioception to form a body segment movement strategy that may provide a better postural stability during task performance on slippery surfaces.

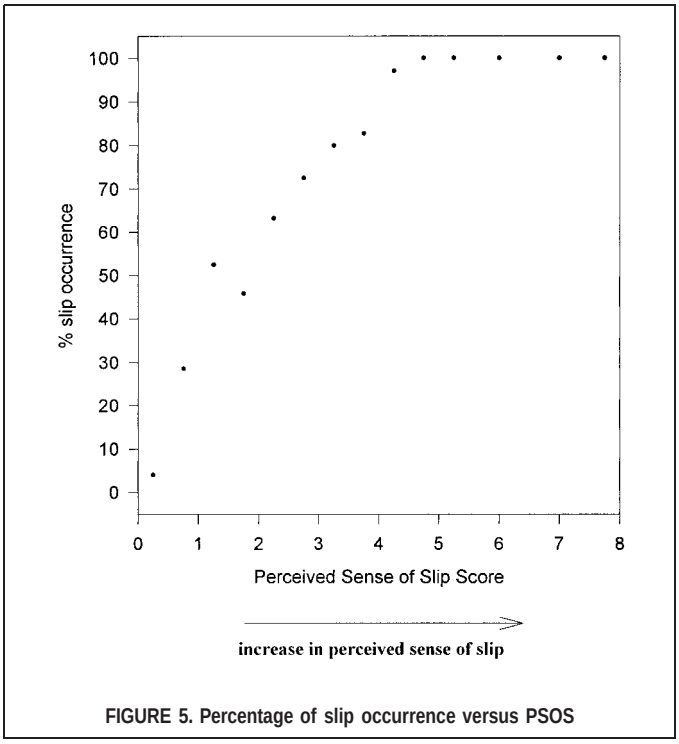

FIGURE 5. Percentage of slip occurrence versus PSOS

The results from correlation analyses showed that there were significant negative correlations between the residuals and IPSB. The lesser the residuals, the higher the IPSB, indicating a lesser proximity to the stability boundary and hence decreased postural instability. Significant positive correlation was observed between the residuals and the WRTI index (Table IV). By definition, WRTI is a quantitative estimation of the postural instability based on the time spent in the external proximity zones. The lesser the residuals, the smaller the values of WRTI, indicating less postural instability. Thus, subjects who were cautious (lesser, possibly negative residuals) in assessing the surface slipperiness had better performance on slippery surfaces as indicated by the postural instability indices of IPSB and WRTI. Such findings have practical applications in safety training.

The insignificant relationships between the residuals and the variables of sway length, sway area, SAR, and the number of slips can be attributed to the nature of these variables. Sway length is sensitive in measuring motor function, which is highly correlated with muscle contraction and speed of motion. Sway area is an integrated response of sway, which is good in detecting neurotoxicity. SAR is established based on sway area with respect to each subject's area of base of support. Poor ability in judging the surface slipperiness may not necessarily cause slips, but lack of correct judgment can increase postural instability.

Slip Occurrence During Task Performance on Slippery Surfaces

The percentage of slip occurrence increased with increasing PSOS score. The percentage of slip occurrence reached 100% when the PSOS score was above 4.5 (Figure 5). A PSOS value of 4.5 appears to represent a "ceiling effect" for this scale. Beyond this

point, slips always occurred during task performance observed in the current study. Subjects' ability to maintain postural balance is controlled by the central nervous system input to motor pathways and the continual afferent input from vision, the vestibular system, and proprioceptors. These three afferent inputs are used to form a body movement strategy to maintain balance on slippery surfaces. When a subject's movement coordination cannot function properly in response to the afferent input, a slip must occur. However, there is a possibility that the "ceiling effect" in Figure 5 was partly due to the fact that only a small discrete number of values is allowed for the score of each question in the rating scale. The PSOS score for the cases in which a slip did not occur in the 0 to 4 range had a mean value of 0.21. A small mean PSOS score (0.21) implies that subjects used small values to describe their perception of situations in which a slip did not occur and the PSOS scale therefore is sensitive in discriminating between situations in which a slip did and did not occur.

Effect of Test Conditions on PSOS Score, Postural Sway, and Postural Instability

The main factor of task was found to be highly significant on PSOS ($p = 0.0001$). The mean PSOS of either the rapid trunk movement (0.26) or lateral reach/lifting tasks (2.01) was greater than that of the stationary task (0.21). This trend was consistent with the results obtained from objective measurement of postural sway and instability (Table III), implying that subjects were able to perceive the different levels of propensity of slip among the three tasks.

The surface effect was significant on PSOS ($p = 0.0001$) as well as postural sway and instability parameters ($p = 0.027$). Subjects were able to sense the propensity of slip as the surface oiliness increased from dry to slightly to medium to very oily levels (all p values = 0.0001). Subjects consistently perceived the least propensity of slip on dry surfaces (mean subjective rating = 0.30) and greatest propensity of slip on very oily surfaces (mean subjective rating = 1.24). Such findings are consistent with the results found in studies by Myung et al., Swensen et al., and Chiou et al. in which subjects were able to identify a difference in slipperiness for the surfaces studied.[8–10]

A significant interaction between task and surface was found for PSOS. This interaction clearly indicated that with the change in surface condition from dry to very oily surfaces, PSOS increased more drastically (553.1%) for the lateral reach/lifting task compared with the other two tasks (Figure 3). The effect of lighting was highly significant on postural sway and instability ($p = 0.005$), but not on PSOS. This implies that subjects were unable to perceive the change in postural sway and instability due to the reduced afferent inputs of vision modified by the poor lighting. Thus, a worker's safety might be jeopardized because his or her perception may result in the underestimation of postural sway and instability while in poor lighting conditions.

Relationship of PSOS with the Postural Instability Variables

There were significant associations between PSOS and the postural instability variables of IPSB and WRTI (p values of 0.001 and 0.0006 for IPSB and WRTI, respectively). Postural instability was increased with increasing PSOS. Using the PSOS scale, subjects could predict the postural instability as measured by the objective variables of IPSB and WRTI. During the task performance, IPSB was determined from one CP point, which was the nearest to the stability boundary. Subjects were able to detect the CP nearest to the stability boundary and reflected that in their PSOS score. Subjects gave higher scores to those test conditions that caused the body's CP to spend more time in the outer zones of the stability boundary.

The fact that the PSOS score did not predict the objective variables of sway length, sway area, and SAR (all p values > 0.05) could be attributed to the lack of power with a sample size of 40. Another explanation is that the PSOS scale may not be sensitive enough to reflect the change in sway length, sway area, and SAR due to various intrinsic and extrinsic risk factors. That is, subjects may not be able to describe accurately the degree of postural sway using this scale.

Theoretically, the overall PSOS reflects various sensory inputs, including the many signals elicited from the vestibular system, from working muscles and joints, and from the visual system in response to environmental and job risk factors. All these signals and perceptions, as well as workers' experiences, are incorporated into the reporting of PSOS. Any discrepancy between this configuration for judging PSOS and the actual environment may result in a slip incident.

CONCLUSION

Slips did occur during task performance in the standing position on slippery surfaces as simulated in the current study, even though such tasks are less dynamic than those performed during walking. The slip occurrence rate was high (70.5%) for the reach task due to the shift of center of gravity near or out of the base of support.

Subjects always slipped when the PSOS rated by the subjects was beyond the "ceiling" value of 4.5. Subjects were able to perceive the instability, and this perception was reflected in their rating. This finding has practical implication in identifying tasks and workplace areas with potential for slips. A field survey can be conducted to investigate workers' PSOS in regard to possible extrinsic and intrinsic risk factors using the PSOS scale. Prevention strategies can then be developed once the workers' PSOS scores are close to the ceiling value.

Workers who were cautious in assessing surface slipperiness had less postural instability during task performance, as indicated by IPSB and WRTI. However, the current study did not address the issue of whether there is a learning trend in assessing surface slipperiness with repeated assessment. If the ability to assess surface slipperiness can be improved by training, then a training program can be developed to help minimize slip incidence. In addition, workers can also be instructed to avoid working on potentially hazardous surfaces without first carefully assessing the working surface.

In summary, results from this study indicate that subjects were able to perceive the likely slips due to the change in job-task and surface slipperiness. The PSOS scale is reproducible, easy to use, and provides a simple way to evaluate the potential slip hazard in the workplace.

REFERENCES

1. **Manning, D.P., I. Ayers, C. Jones, M Bruce, and K. Cohen:** The incidence of underfoot accidents during 1985 in a working population of 10,000 Merseyside people. *J. Occup. Accid. 10*:121–130 (1988).
2. **National Safety Council:** *Accident Facts.* Chicago: National Safety Council, 1991.

3. **Cohen, H.H., and D.M. Compton:** Fall accident patterns. Characterization of most frequent work surface-related injuries. *Prof. Safety 27(6)*:16–22 (1982).
4. **Grönqvist, R., J. Roine, E. Järvinen, et al.:** An apparatus and a method for determining the slip resistance of shoes and floors by simulation of human foot motions. *Ergonomics 32*:979–995 (1989).
5. **Andres, R.O., and D.B. Chaffin:** Ergonomic analysis of slip-resistance measurement devices. *Ergonomics 28*:1065–1078 (1985).
6. **Jung, K., and H. Schenk:** An international comparison of test methods for determining the slip resistance of shoes. *J. Occup. Accid. 13*: 271–190 (1990).
7. **Chaffin, D.B., J.C. Woldstad, and A. Trujillo:** Floor/shoe slip resistance measurement. *Am. Ind. Hyg. Assoc. J. 53*:283–289 (1992).
8. **Swensen, E.E., J.L. Purswell, R.E. Schlegel, and R.L. Stanevich:** Coefficient of friction and subjective assessment of slippery work surfaces. *Human Factors 34*:66–77 (1992).
9. **Myung, R., J.L. Smith, and T.B. Leamon:** Subjective assessment of floor slipperiness. *Int. J. Ind. Ergonom. 11*:313–319 (1993).
10. **Chiou, S., A. Bhattacharya, and P.A. Succop:** Effect of workers' shoe wear on objective and subjective assessment of slipperiness. *Am. Ind. Hyg. Assoc. J. 57*:825–831 (1996).
11. **Andres, R.O., D. O'Connor, and T. Eng:** A practical synthesis of biomechanical results to prevent slips and falls in the workplace. In *Advances in Industrial Ergonomics and Safety IV,* S. Kumar (ed.). London: Taylor & Francis, 1992. pp. 1001–1006.
12. **Tisserand, M.:** Progress in the prevention of falls caused by slipping. *Ergonomics 28*:1027–1042 (1985).
13. **Bagchee, A., A. Bhattacharya, P.A. Succop, P.A., and R. Emerich:** Postural stability assessment during task performance. *Occup. Ergonom. 1*:41–53 (1998).
14. **Bhattacharya, A., R. Shukla, K.N. Dietrich, et al:** Functional implications of postural disequilibrium due to lead exposure. *Neurotoxicology 14*:179–190 (1993).
15. **Chiou, S., A. Bhattacharya, C. Lai, and P.A. Succop:** Effects of environmental and task risk factors on workers' perceived sense of postural sway and instability. *Occup. Ergonom. 1*:81–93 (1998).
16. **Lemasters, G.K., and M.R. Atterbury:** The design and evaluation of a musculoskeletal and work history questionnaire. In *Occupational Ergonomics—Theory and Application,* A. Bhattacharya and J. McGlothlin (Eds.). New York: Marcel Dekker. pp. 431–441.