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Why walkers slip: Shine is not a reliable cue for slippery ground

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In a series of four studies, we investigated the visual cues that walkers use to predict slippery ground surfaces and tested whether visual information is reliable for specifying low-friction conditions. In Study 1, 91% of participants surveyed responded that they would use shine to identify upcoming slippery ground. Studies 2–4 confirmed participants' reliance on shine to predict slip. Participants viewed ground surfaces varying in gloss, paint color, and viewing distance under indoor and outdoor lighting conditions. Shine and slip ratings and functional walking judgments were related to surface gloss level and to surface coefficient of friction (COF). However, judgments were strongly affected by surface color, viewing distance, and lighting conditions—extraneous factors that do not change the surface COF. Results suggest that, although walkers rely on shine to predict slippery ground, shine is not a reliable visual cue for friction. Poor visual information for friction may underlie the high prevalence of friction-related slips and falls.

Visual information plays a crucial role in the prospective control of locomotion. It provides observers with the requisite perceptual information to plan their movements adaptively. For example, walkers must lift their feet to avoid tripping over the curb and veer to avoid slipping on a slick patch of ice. A variety of visual depth cues—texture gradients, linear perspective, occlusion, motion parallax, binocular disparity, convergence, and so on—prompt walkers to lift their legs to clear the curb. But what visual information alerts walkers to beware of low-friction conditions? Are there visual "friction" cues that allow for prospective control as walkers approach a slippery ground surface? In four studies, we examined the cues that walkers use to predict slippery ground surfaces and asked whether visual information is reliable for specifying friction conditions.

Prospective Control of Walking Under Low-Friction Conditions

Friction presents an interesting problem for understanding the prospective control of locomotion for several reasons. First, friction is everywhere: It is an emergent, resistive force that is created when two surfaces come into contact. In locomotion, friction is necessary for balance and forward propulsion. Friction keeps one foot planted firmly to the ground while the other foot swings forward, and friction stops the swinging foot from sliding when it recontacts the floor.

Second, friction is of practical importance for safety during everyday walking. Generally, walkers fare poorly under low-friction conditions. Falls are the leading cause of unintentional, nonfatal injuries in the home and workplace in the United States across all age groups (National Center for Injury Prevention and Control, 2002). Almost half of all falls result from friction-related slips (Courtney, Sorock, Manning, Collins, & Holbein-Jenny, 2001), a fifth of all emergency-room visits in the United States are precipitated by slip-and-fall injuries (National Safety Council, 1998), and almost two thirds of workplace injuries are due to slipping, tripping, or stumbling (Courtney et al., 2001).

Third, friction poses a special dilemma for prospective control because walkers must obtain visual information for low friction prior to landing on the target surface (Adolph & Berger, 2006; Adolph, Eppler, Marin, Weise, & Clearfield, 2000; Patla, 1991, 1997). Given sufficient warning, walkers have multiple coping strategies for avoiding low-friction surfaces or for increasing friction at the foot–floor interface. If alerted one to two steps ahead of time (approximately 500–1,120 msec), walkers can avoid stepping onto a slippery patch of ground by shortening the step prior to the surface, lengthening the step over the surface, or widening the step around the surface (Patla, 1991; Patla, Robinson, Samways, & Armstrong, 1989). They can veer slightly (0º–30º) to the side opposite their last footfall and stop short in front of the target sur-

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face (Patla, 1997; Patla, Prentice, Robinson, & Neufeld, 1991). If alerted three to four steps in advance, walkers can steer sharply (0º–60º) around the low-friction area (Patla, 1989). They can adjust their gait patterns to walk over the surface by slowing down, taking shorter steps, keeping the body stiffly upright, landing flat-footed, and reducing the speed at which the foot moves when the heel contacts the floor and when the toes push off the floor (Cham & Redfern, 2002; Marigold & Patla, 2002; Myung & Smith, 1997; Patla, 1991, 1997; Swensen, Purswell, Schlegel, & Stanevich, 1992). However, without sufficient advance warning, walkers cannot execute their antislip strategies. After the feet begin to slip, the opportunity for prospective control is lost. Walkers must resort to reactive adjustments (e.g., waving the arms and scrambling with the legs to keep the body over the moving base of support), which are themselves a source of injury (Manning, Ayers, Jones, Bruce, & Cohen, 1988).

Friction poses a similar problem for prospective control of manual actions on objects. Given prior knowledge about the surface coefficient of friction (COF), observers can adjust their fingertip forces appropriately so as to grasp a rod without it slipping through their fingers (Fikes, Klatzky, & Lederman, 1994; Johansson & Cole, 1992; Johansson & Westling, 1984, 1987). Without prior knowledge about potential slip, observers must resort to adjusting their fingertip forces after they grasp the rod. However, fingertip movements are sufficiently small and quick that errors in prospective control have minimal consequences in terms of slip. In contrast, locomotor movements are large and slow. If walkers' feet land on a low-friction surface without prospective gait modifications, reactive measures become their only mode for maintaining balance.

Finally, friction is a unique problem because researchers know surprisingly little about the availability of visual cues that specify low-friction ground. In contrast to the large literature on the biomechanics of slipping, to date, only a handful of studies have investigated walkers' visual judgments of friction conditions. The sparse collection of findings suggests that walkers are prone to errors about the likelihood of slipping, even when judging familiar surfaces and contaminants (Cohen & Cohen, 1994a, 1994b; Lockhart, Woldstad, Smith, & Ramsey, 2002). For example, after watching experimenters slosh water over several familiar ground coverings, participants' visual judgments about the effects of the contaminant were not always consistent with their tactile judgments (Cohen & Cohen, 1994a). They rated some surfaces as more slippery when wet than when dry on the basis of visual information, but they rated these surfaces as equally slippery when they walked over the surfaces. They rated other surfaces as equally slippery when wet and when dry on the basis of visual information, but they rated these surfaces as more slippery when wet after they walked over the surfaces.

In summary, low-friction conditions are frequent occurrences in everyday locomotion. The high incidence of slip-induced falls in the home and the workplace may result from a failure of prospective control. The available data suggest that walkers may overestimate or underestimate the probability of slipping even with familiar surfaces set in familiar contexts. Therefore, we investigated why walkers are prone to slip-related falls by asking participants about the visual cues they use to identify upcoming slippery ground (Study 1), by testing whether visual information for shine and slip is reliable under indoor (Study 2) and outdoor (Study 3) lighting conditions, and by examining what cues participants rely on to gauge whether surfaces are safe for walking (Study 4).

STUDY 1
Visual Cues to Predict Slippery Ground

To our knowledge, there are no previous studies that provide direct evidence for the type of visual information that contributes to viewers' perception of friction conditions. Therefore, the first step in our investigation was to ask the participants to tell us the cues that they would use to predict a slippery floor. We obtained written responses with an open-ended, unstructured, and untimed survey. Responses were unrestricted in order to allow the participants to provide multiple categories of cues and multiple examples of cues within each category. By examining the range of categories provided and the number of examples within each category, we hoped to capture a detailed picture of the visual information walkers use to predict slip.

Method

Participants and Procedure. One hundred fifty New York University undergraduates filled out a short, anonymous survey. The participants did not reveal their gender, age, or other demographic information. They were told only that the survey was part of a study about walking, and they provided written responses to a single question: "By only looking at it, how would you tell if the floor was slippery?"

Coding survey responses. Since the questionnaire was open-ended, the participants were allowed to provide multiple responses (e.g., "if it looks shiny or wet; if it looks like something has spilled on it"). Each response was broken down into major descriptive phrases ("shiny," "wet," "something spilled"). On the basis of a content analysis of the responses, we classified each descriptive phrase into one of five categories (see Table 1, columns 1 and 2, for examples). Words or phrases about *shine* referred to light reflecting off the floor ("gloss," "shiny," "glare"). Words or phrases about *contaminants* referred to wet and dry pollutants, lubricants, residues, and polishes that coat the floor ("wet," "something spilled," "wax," "ice"). The *texture* category referred to the microstructure of the floor in terms of its relief and wear ("smooth," "rough"). *Warning signs* included explicit verbal references to slippery floor conditions ("Wet Floor," "Slippery When Wet," "Caution"). Finally, a *miscellaneous* category included a hodgepodge of references to banana peels, ball bearings, sloping floors, and observation of other people slipping.

Responses could contain more descriptive phrases than categories. For example, "It would appear to be shiny, greasy or wet" received credit for two categories of cues (shine and contaminants) and three descriptives (shiny, greasy, wet).

Results and Discussion

Most participants responded with a variety of descriptives (Figure 1A) falling into multiple categories (Figure 1B). However, shine was the most frequently mentioned visual cue for predicting slipperiness, far

Table 1
Category Examples and Frequency in Study 1

Category	Examples	% Participants	% Descriptives	No. of Descriptives per Participant	
				M	*SD*
Shine	Gloss, reflection, shimmer, luster	91.3	47.4	1.15	0.55
Contaminants	Wet, puddle, grease, wax, residue	58.7	34.4	0.83	0.90
Texture	Rough, smooth	14.0	6.6	0.16	0.42
Warning signs	"Caution," "Slippery When Wet"	8.7	3.9	0.09	0.31
Miscellaneous	Other people slipping, banana peels	13.3	7.7	0.19	0.51

Note—One hundred fifty participants provided a total of 363 descriptives. The mean number of descriptives per participant was 2.42 ($SD = 1.26$).

outweighing the frequency of other cues. As shown in Table 1, column 3, nearly all participants provided at least one descriptive phrase pertaining to shine (91.3%). Most participants gave a shine descriptive as their first response (68.7%), and shine was the most popular response even for the participants who provided only one descriptive phrase (83.3%). Of the 363 descriptives generated by the participants, a majority (47.4%) pertained to shine (Table 1, column 4). On average, the participants mentioned shine at least once (Table 1, column 5).

The next most frequent category—contaminants—was mentioned by only about half of the participants (58.7%), and less than 15% of the participants mentioned each of the remaining three categories (Table 1, column 3). Only a third of the 363 descriptives were related to contaminants (34.4%). Added together, less than a fifth of the descriptives pertained to texture, warning signs, and miscellaneous cues (Table 1, column 4). The participants averaged less than 1 descriptive from categories other than shine (Table 1, column 5). A one-way repeated measures ANOVA confirmed that the participants responded with more shine descriptives than words/phrases from other categories [$F(4,596) = 102.44$, $p < .01$]. Post hoc comparisons revealed that shine descriptives occurred more frequently than the other four types of descriptives ($ps < .01$) and that contaminants occurred more frequently than texture, warning signs, and miscellaneous ($ps < .01$).

STUDY 2
Shine and Slip Judgments Under Indoor Lighting Conditions

Study 1 showed that naive participants consider shine to be an important visual cue for predicting low-friction ground. On the one hand, a predictive shine–slip relationship makes good intuitive sense. Smooth surfaces tend to be shiny (Pfund, 1930). Rough, textured surfaces scatter light and thus appear dull. Smooth surfaces reflect light more directly, thus producing more shine (perfect mirrors have the highest ratio of directly reflected light to diffusely reflected light). Smooth surfaces also tend to be slippery because they lack a rough microtexture that helps shoes and feet to grip surfaces securely. Moreover, many contaminants that cause walkers to slip (ice, oil, water, soap, etc.) increase the shininess of floors by increasing the amount of reflected light. Indeed, the participants in Study 1 most frequently mentioned contaminants that increase shine, and they often causally linked the two kinds of descriptives (e.g., "if it appeared high gloss as in being wet or waxed"). Finally, shine may be especially useful

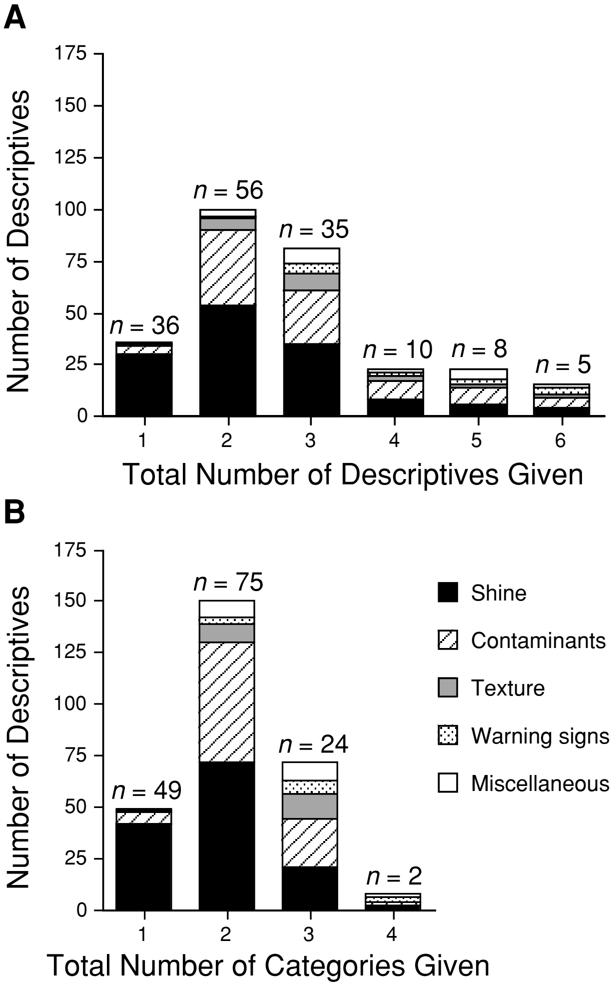

Figure 1. Number of descriptives in each cue category generated by the participants in Study 1. The data are depicted separately for (A) the participants providing 1–6 total descriptives and (B) the participants providing 1–4 cue categories. The number of participants providing each total number of descriptives is represented by *n*.

for predicting slip during locomotion because reflected images move with observers' motion, causing salient, attention-grabbing cues for surface characteristics. Thus, through years of experience traversing various surfaces, walkers may have learned to associate shine with slip.

On the other hand, there are several reasons to question the commonsense intuition about the link between shine and slip. Shine may not be a reliable visual cue for predicting low-friction conditions. In fact, shine is notoriously difficult to study even under the most controlled laboratory conditions. Although researchers measure shine in terms of the intensity of directly reflected light, observers' perception of shine is likely to include several factors that are independent of the intensity of specular reflectance (Braun & Braun, 1995; Hunter, 1952; O'Donnell & Billmeyer, 1986). For example, observers may rate surfaces as shinier when there is more contrast between the highlights and the background ("contrast gloss"), when reflected images are more distinct without a milky halo ("absence of bloom"), and when reflections lack a bluish haze caused by scattered light ("reflection haze"), despite a uniformity in physical measurements of specular reflectance. Color is especially influential for shine perception. Darker surfaces may appear shinier than lighter colored surfaces because of increased contrast gloss, regardless of smoothness and slipperiness (Sève, 1993).

Moreover, environmental conditions and viewing angle can affect perceived shine, regardless of surface characteristics. In contrast to lightness and color constancy, controlled laboratory studies provide no evidence for shine constancy under varying illumination conditions. Specular reflectance and perception of shine vary with the strength of the overhead light, point light versus diffuse light sources, the number of light sources, and the position of the light source (Nishida & Shinya, 1998; Pfund, 1930). Given that lighting conditions influence shine, observers' angle of observation also affects shine perception. Shine tends to increase as the distance between the observer and the target surface decreases and as the angle of observation increases (Pfund, 1930). Matte surfaces may require viewing angles of at least 75º (standing over the surface and looking down at it), whereas high-gloss surfaces can appear shiny with a viewing angle of only 5º (standing at a distance from the surface and looking at it obliquely). Viewing distance poses a unique constraint for prospective control of locomotion because walkers require several steps to stop, veer, and modify their walking patterns (Patla, 1997; Patla et al., 1991; Patla et al., 1989).

An additional reason to doubt the reliability of shine as a visual cue for slip is that shine can vary while slip remains constant, and vice versa. Although some contaminants increase shine, many others do not. In contrast to ice, oil, and soap, contaminants such as dust, dirt, sand, and talc increase slip but are dry and grainy and give floors a dull appearance. Moreover, contaminants can interact differentially with various surfaces to create slippery or high-traction surfaces. Homeowners treat their hardwood floors with wax (a common contaminant) to create a visually pleasing sheen but unintentionally increase slipperiness. Conversely, the linoleum-tiled floors of office buildings and schools are waxed regularly for walkers' safety. Linoleum is less slippery when it is clean and shiny and more slippery when it is dusty and dull.

In Study 2, we tested the reliability of shine as a visual cue to predict slip in the context of walking. One group of participants made visual judgments of shine and another group made visual judgments of slip, so that we could assess whether the two types of ratings were related. To determine the effect of color on shine and slip ratings, we asked the participants to rate surfaces painted with three gloss levels of white, black, and blue paint. The white paint was selected to crudely approximate the color of ice/snow, the black to resemble oil/water on pavement, and the blue to represent a novel surface color. To determine the nature of shine and friction perception under normal, real-world lighting conditions, we tested the participants using the diffuse, overhead, fluorescent lights found in most office buildings. Finally, to investigate the influence of distance and viewing angle on shine and slip perception, we had the participants make judgments from three distances: approximately 4, 2, and 0 steps in front of the target surface. On the basis of laboratory studies of shine perception (Pfund, 1930), we expected that visual information for shine and slipperiness would be the most available at 0 steps from the target surface. However, we expected that the participants' options for implementing various anti-slip strategies would be the best at 4 steps from the target surface.

Method

Participants. Thirty-two New York University undergraduate students (12 men, 20 women; *M* age = 21.12 years, *SD* = 2.81) participated for course credit or money ($10). The participants were Caucasian (*n* = 17), Asian (*n* = 8), Hispanic (*n* = 4), and African/African-American (*n* = 3). Sixteen wore corrective lenses during testing. During a structured interview administered at the start of the session, 5 participants reported serious slip-induced falls (e.g., a fall while ice-skating that required stitches). The participants' heights ranged from 1.55 to 1.92 m (*M* = 1.69 m).

Apparatus and Stimuli. We constructed nine custom-made surfaces. To ensure consistent texture across the surfaces and to keep them lightweight for easy switching between trials, we painted foam core boards (61.00 cm wide × 81.30 cm long × 0.48 cm thick) with nine color–gloss combinations: black, blue, and white colors of Behr Premium Plus paint (lampblack, southern blue, and ultra pure white) each mixed with low-, medium-, and high-gloss levels (interior flat paint, interior satin enamel, and interior/exterior high-gloss enamel). We constructed three identical copies of each surface (27 surfaces in total) and housed them in a portable wooden shelving unit that stored each surface separately. This arrangement protected the surfaces from contaminants and damage and minimized the time required to switch surfaces between trials.

For each test surface, we derived an estimate of the static COF: the ratio of frictional forces between two surfaces. The COF decreases as slipperiness increases. Generally, a COF of .50 (and greater) is considered safe for walking (e.g., Leclercq, 1999). We measured the COF by placing a nylon-covered lead block (4,330 g) on each surface. A lead block is widely accepted for measuring static COF because weight does not affect static COF mathematically (see formula below). By slowly increasing the slant of the slope from 0º, we determined the shallowest angle that caused the block to slide continuously down the slope. We calculated the COF on the basis of the formula $\text{COF} = F_f/N$. N, the normal force, is the force of the ground surface acting on the object and takes the object's weight (gravity $*$ mass) into account. Because we placed the lead block on a slope, only a part of the block's weight was factored into N. Thus, N = weight $*$ cosine of the angle of slant. F_f, force of friction, is the amount of frictional force acting to oppose the motion of the object. On a slant, friction is partitioned so that it is equal to the weight of the object $*$ sine of the angle of slant. Thus, the object's weight cancels out of each part of the equation, and COF = (sine of the angle of slant)/(cosine of the angle of slant) = (tangent of the angle of slant).

As shown in Table 2, the COF of the test surfaces were similar across colors and decreased as gloss level increased. The COF for the least slippery, low-gloss surfaces was .78 averaged across colors. The COF for the most slippery, high-gloss surfaces was .38. The COF for the medium-gloss surfaces averaged .50, right on the cusp between safe and risky slip levels.

The participants viewed the surfaces while standing on a large walkway (4.88 m long × 0.97 m wide × 0.58 m high) covered with a canvas runner. The far end of the canvas runner served as a target area where the test surfaces were placed with the long axis perpendicular to the participants' line of sight. Three lines were drawn horizontally across the runner to delineate three viewing distances: approximately 4 steps in front of the target surface (2.88 m), approximately 2 steps in front of the target area (1.44 m), and directly adjacent (0 steps) to the target area (0.00 m). We based the distance of the lines on an average step length of 0.72 m for men and women 18–49 years of age (Whittle, 1996). A numbered pair of footprints drawn directly in front of each line showed the participants where to place their feet when they stopped to make visual judgments of shine or slip. A dashed line drawn vertically down the center of the runner encouraged the participants to maintain a straight path as they approached the target area.

Lighting conditions were typical of a moderately bright laboratory, schoolroom, or office building. The canvas runner was centered beneath five overhead light fixtures (0.61 × 0.61 m Mercury Lighting Products' Recessed Fluorescent Fixtures with an H8224 diffuser) recessed 11 cm into the ceiling. The light fixtures were spaced 0.98 m apart, for a total length of 6.97 m, and the diffuser was located 2.45 m above the surface of the walkway. Each light fixture contained two Sylvania Octron T8 Curvalume U-shaped lightbulbs (31 W, medium bipin). The runner was positioned in the same location for each session to ensure identical lighting conditions for all participants.

Procedure. As they became available for study, the participants were assigned to one of two judgment conditions (shine or slip) and one of three random presentation orders within the condition. All six experimental groups were balanced for gender, gloss level, surface color, and viewing distance. Half of the participants received the shine condition ("How shiny does this look?"), and half received the slip condition ("How slippery does this look?"). The participants rated each surface on a 7-point scale. The anchor points were *not at all shiny* or *not at all slippery* for a rating of 1 and *extremely shiny* or *extremely slippery* for a rating of 7. Each participant gave 54 verbal ratings in total (1 rating per trial): 3 surface colors × 3 levels of gloss × 3 distances × 2 repeated judgments. Due to the large number of test trials, the participants did not receive any practice trials.

Table 2
Coefficients of Friction for Judgment Surfaces

Gloss Level	Color White	 Black	 Blue	M	SD
Low	.75	.81	.77	.78	.03
Medium	.49	.49	.53	.50	.02
High	.35	.38	.42	.38	.04

At the start of each session, the participants were told to stop walking with their feet on the appropriate footprint markers and to take as much time as they needed to decide on each rating. The participants began each trial with their backs to the target area while the experimenter retrieved the correct surface and placed it on the target area. At the experimenter's instruction, the participants turned around and walked to the specified viewing line. Once they reached the line, the participants reported their rating to the experimenter, then turned and walked back to the starting area. Sessions were videotaped with two camera views mixed into a single video frame (front and side views). The participants wore wireless microphones so that their judgments were amplified and recorded on videotape.

Results and Discussion

Initial analyses showed no effects of trial number on the participants' ratings ($ps > .10$), demonstrating that a lack of practice trials did not lead the participants to calibrate their judgments along the ratings scale during testing. We collapsed the data across trial number for further analyses. For each judgment condition (shine or slip), we subjected the participants' ratings to a 3 (gloss levels) × 3 (colors) × 3 (viewing distances) repeated measures ANOVA. Interactions were further analyzed with one-way repeated measures ANOVAs, and main effects were followed up with paired *t* tests. Because each set of post hoc tests required three comparisons, we used a Bonferroni-adjusted alpha level of $p = .017$ to correct for experimentwise error rates (overall $p = .05$).

Shine judgments. In general, the participants rated the high-gloss surfaces as most shiny ($M = 4.14$, $SD = 0.83$), the low-gloss surfaces as least shiny ($M = 1.47$, $SD = 0.63$), and the medium-gloss surfaces in the middle ($M = 2.25$, $SD = 0.63$). All gloss levels were statistically different from each other ($ps < .01$). Moreover, visual ratings of shine were moderately correlated with the surface COF for each color [$r(N = 864) = -.53, p < .01$].

However, as shown in Figure 2A, effects of gloss were moderated by color and viewing distance, suggesting that perception of shine is not constant over changes in environmental conditions and that shine is not a reliable visual cue for low-friction ground surfaces. Across gloss levels and viewing distances, the participants rated the white surfaces ($M = 1.77$, $SD = 0.77$) as significantly less shiny than the darker black surfaces ($M = 3.11$, $SD = 0.64$; $p < .01$) and the blue surfaces ($M = 2.98$, $SD = 0.63$; $p < .01$). Across gloss levels and colors, the participants rated surfaces as more shiny at the closest (0-step) viewing distance ($M = 2.94$, $SD = 0.65$), relative to the 2-step distance ($M = 2.45$, $SD = 0.66$; $p < .01$) and the 4-step distance ($M = 2.46$, $SD = 0.52$; $p < .01$). Most striking, the participants rated high-gloss white as shiny only when they viewed it while standing with their toes at the edge of the target surfaces.

The overall ANOVA revealed that all main effects and interactions were significant ($ps < .01$). To determine the cause of the gloss × color × viewing distance interaction [$F(8,120) = 9.20, p < .01$], we analyzed the data for each gloss level separately. For the low-gloss surfaces, viewing distance [$F(2,30) = 6.70, p < .01$] and the color × viewing distance interaction [$F(4,60) = 5.06, p < .01$] were

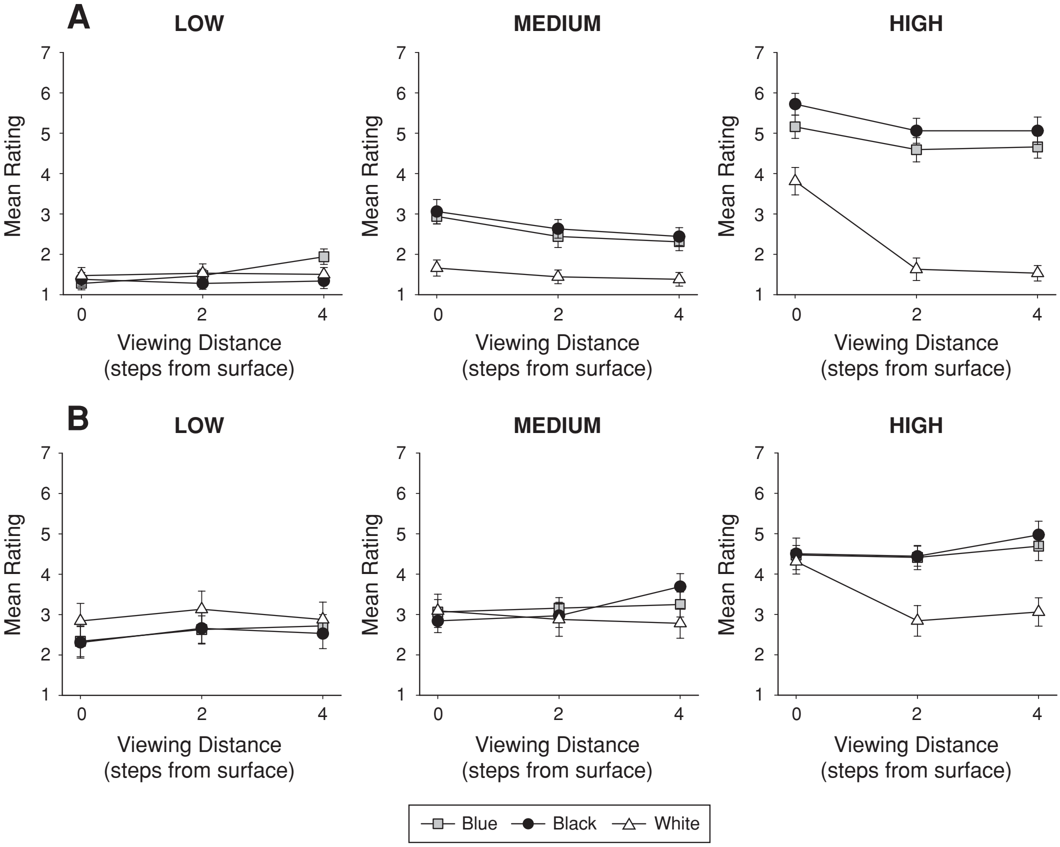

Figure 2. Indoor judgments of (A) shine and (B) slip for low-, medium-, and high-gloss levels in Study 2. Error bars represent standard errors.

significant. The interaction was caused by higher ratings for the blue surfaces ($M = 1.94$, $SD = 0.77$) at the farthest (4-step) viewing distance, relative to the black surfaces ($M = 1.34$, $SD = 0.75$; $p < .01$) and white surfaces ($M = 1.50$, $SD = 0.68$; $p < .01$). Ratings were uniformly low at the closer 2- and 0-step viewing distances ($ps > .10$).

For the medium-gloss surfaces, there were significant main effects for color [$F(2,30) = 21.76$, $p < .01$] and viewing distance [$F(2,30) = 9.10$, $p < .01$]. The participants rated the white surfaces as less shiny ($M = 1.49$, $SD = 0.69$) than the blue surfaces ($M = 2.56$, $SD = 0.79$; $p < .01$) and the black surfaces ($M = 2.71$, $SD = 0.85$; $p < .01$). They rated the surfaces as most shiny at the 0-step viewing distance ($M = 2.55$, $SD = 0.71$), relative to the 4-step viewing distance ($M = 2.04$, $SD = 0.61$; $p < .01$) and the 2-step viewing distance ($M = 2.17$, $SD = 0.75$; $p = .018$).

For the high-gloss surfaces, we found main effects for color [$F(2,30) = 71.64$, $p < .01$] and viewing distance [$F(2,30) = 32.16$, $p < .01$] and an interaction between color and viewing distance [$F(4,60) = 13.94$, $p < .01$]. The interaction resulted from different patterns of change for each surface color across the different viewing distances. The participants' ratings of the blue surfaces remained constant across changes in viewing distance ($ps > .10$), but their ratings of the black-and-white surfaces increased as viewing distance decreased. Scores for the black surfaces increased slightly across the viewing distances, so that ratings made from 0 steps ($M = 5.72$, $SD = 1.09$) were significantly higher than ratings made from 2 steps ($M = 5.06$, $SD = 1.25$; $p < .01$) and marginally higher than ratings made from 4 steps ($M = 5.06$, $SD = 1.35$; $p = .019$). Scores for the white surfaces were consistently low at 4 steps ($M = 1.53$, $SD = 0.74$) and 2 steps ($M = 1.63$, $SD = 1.12$; $p > .10$) but increased dramatically at 0 steps ($M = 3.81$, $SD = 1.36$), where ratings were more than twice as high as those made from the two farther distances ($ps < .01$).

Slip judgments. General trends in slip judgments were similar to those in shine judgments (compare Figures 2A and 2B). Like their counterparts in the shine condition, the participants in the slip condition rated the high-gloss surfaces as most slippery ($M = 4.19$, $SD = 0.86$), followed by medium-gloss surfaces ($M = 3.08$, $SD = 1.09$) and low-gloss surfaces ($M = 2.67$, $SD = 1.42$). Again, all gloss levels were statistically different from each other ($ps < .01$).

The overall ANOVA on slip ratings yielded a significant main effect only for gloss [$F(2,30) = 20.04$, $p < .01$]. The two- and three-way interactions involving gloss were significant ($ps < .05$) and the color × viewing distance interaction was significant ($p < .01$). As with shine ratings, we analyzed each gloss level separately to examine the gloss × color × viewing distance interaction [$F(8,120) = 3.60$, $p < .01$]. For low-gloss surfaces, there was only a trend for color [$F(2,30) = 3.03$, $p = .06$] caused by marginally higher ratings for the white surfaces ($M = 2.95$, $SD = 1.69$) than for the black surfaces ($M = 2.50$, $SD = 1.47$; $p = .05$).

For medium-gloss surfaces, a color × viewing distance interaction emerged [$F(4,60) = 4.28$, $p < .01$]. The interaction was caused by an increase in ratings for the black surfaces at the farthest viewing distance of 4 steps: Ratings for the black surfaces ($M = 3.69$, $SD = 1.26$) were significantly higher than ratings for the white surfaces ($M = 2.78$, $SD = 1.49$; $p < .01$). There were no differences between colors at other viewing distances ($ps > .10$).

For high-gloss surfaces, there was a significant main effect for color [$F(2,30) = 9.80$, $p < .01$] and an interaction between color and viewing distance [$F(4,60) = 8.96$, $p < .01$]. In general, ratings for the white surfaces ($M = 3.41$, $SD = 1.20$) were significantly lower than ratings for the blue surfaces ($M = 4.52$, $SD = 0.99$; $p < .01$) and the black surfaces ($M = 4.64$, $SD = 1.15$; $p < .01$). Ratings for the blue and black surfaces were not statistically different and did not change across viewing distances ($ps > .01$). However, as in the shine condition, ratings for the white surfaces increased at the closest viewing distance of 0 steps. Ratings for the white surfaces were significantly higher from 0 steps ($M = 4.31$, $SD = 1.22$) than from 2 steps ($M = 2.84$, $SD = 1.52$; $p < .01$) and 4 steps ($M = 3.06$, $SD = 1.41$; $p < .01$). At the closest viewing distance, slip ratings for the white, blue, and black surfaces were not different ($ps > .10$).

Like shine ratings, slip judgments were moderately correlated with surface COF of each color [$r(N = 864) = -.32$, $p < .01$]. Moreover, as shown in Figure 3A, average shine and slip ratings for each gloss/color/viewing distance combination were highly correlated [$r(N = 27) = .93$, $p < .01$], suggesting that shine and slip judgments were based on the same visual information.

However, we found two important differences between shine and slip ratings. First, the participants' slip judgments were less affected by the white surfaces. That is, the participants showed a smaller disparity between colors for slip judgments at the medium- and high-gloss levels, relative to the disparity between colors for shine judgments at the same gloss levels (compare the middle and right panels of Figures 2A and 2B). Post hoc tests confirmed that slip ratings for the black surfaces ($M = 3.43$, $SD = 0.95$) and the blue surfaces ($M = 3.41$, $SD = 0.86$) were similar to those for the white surfaces ($M = 3.09$, $SD = 1.45$; $ps > .10$). A second difference—possibly a consequence of the first—was the overall compression in the range of ratings for slip judgments (*M*s ranged from 2.31 to 4.97 across colors, viewing distances, and gloss levels), relative to that in the range of ratings for shine judgments (*M*s ranged from 1.28 to 5.72). One possible explanation for these differences is that the participants implicitly took color-related differences into account when reporting slip judgments, as if correcting for less shine on the white surfaces.

STUDY 3
Shine and Slip Judgments Under Outdoor Lighting Conditions

In Study 2, the participants rated high-gloss surfaces as shinier and more slippery than low-gloss surfaces in general accordance with variations in surface COF. However,

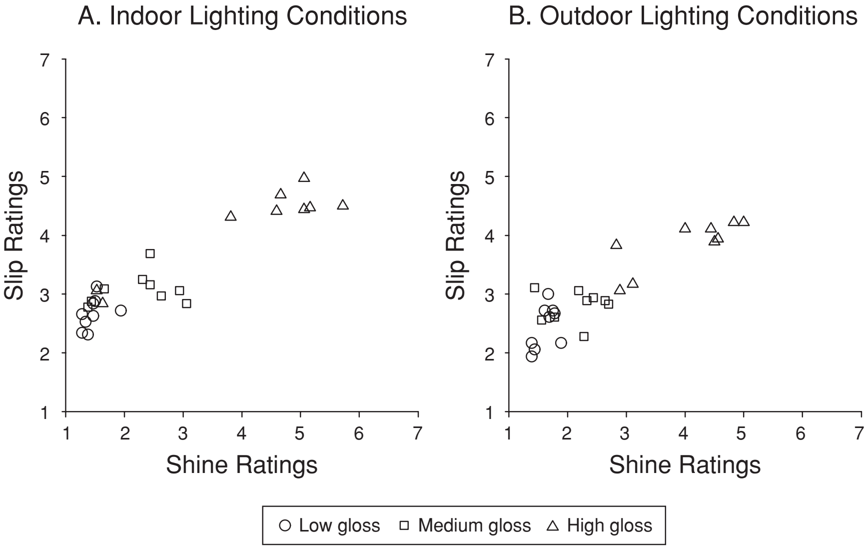

Figure 3. Correlation between shine and slip ratings for each of the 27 gloss/color/viewing distance combinations under (A) indoor and (B) outdoor lighting conditions.

shine and slip ratings were affected by surface color and viewing distance—extraneous factors that do not change the surface COF—suggesting that shine is not a reliable visual cue for slip across variations in environmental context.

In Study 2, lighting conditions in the laboratory were strictly controlled to ensure that all participants viewed the test surfaces under identical illumination conditions. However, walkers must frequently make decisions about slip outdoors, where lighting conditions vary from moment to moment (e.g., as a cloud passes over the sun) and over the course of the day (e.g., as the sun rises and sets). Lighting is of particular importance for shine perception because shine results from light reflected from the viewing surface. Although lighting conditions do not change the surface COF, lighting may influence observers' perception of slip, especially if slip judgments are based on shine. Therefore, in Study 3, we tested the generality of our findings across natural lighting conditions: We tested an additional group of participants outdoors to determine how shine and slip judgments change with surface color and viewing distance under natural sunlight.

Method

Participants. Eighteen New York University undergraduate and graduate students (9 men, 9 women; *M* age $= 23.77$ years, *SD* $=$ 5.85) participated on a voluntary basis. The participants were Caucasian ($n = 12$), Asian ($n = 4$), and other/unidentified ($n = 2$). Eleven participants wore glasses or contact lenses during testing. Two participants had experienced serious slip-related falls. The participants were between 1.57 and 1.83 m in height ($M = 1.69$ m).

Apparatus, Stimuli, and Procedure. Testing took place over 2 days in early autumn in Washington Square Park in New York City. Materials and procedures were identical to those in Study 2 with a few modifications for outdoor testing: The canvas runner marked with the different viewing distances was placed directly on the ground rather than on a raised walkway. We recorded a single view of the participants rather than multiple views. We recorded the participants' verbal ratings by loudly repeating them into the camera rather than fitting the participants with a wireless microphone.

Most important, the participants viewed each surface under variable sunlight conditions rather than under fixed, diffuse, fluorescent lights. The first session of each day began at 9 a.m., and the last session ended at 6 p.m. Thus, the amount of sunlight, the position of the sun, and the distance between the sun and the surface varied significantly from participant to participant. Shadows cast by nearby trees and a fleeting overcast sky resulted in moment-to-moment variations in light. We made no efforts to control the location and the amount of light.

Results and Discussion

As in Study 2, preliminary analyses showed no effects of trial number on the participants' ratings ($ps > .08$), and data were averaged over trials for further analyses. We used separate repeated measures ANOVAs for shine and slip conditions to test the effects of 3 (gloss levels) × 3 (colors) × 3 (viewing distances) on the participants' ratings. Post hoc comparisons were performed with Bonferroni-adjusted alpha levels of $p = .017$.

Shine judgments. Overall, high-gloss surfaces were rated as the shiniest ($M = 4.02$, $SD = 0.89$), followed by the medium-gloss surfaces ($M = 2.14$, $SD = 0.87$), then by the low-gloss surfaces ($M = 1.62$, $SD = 0.68$). Ratings of the three gloss levels differed from each other ($ps <$ .01), but not from indoor ratings of the same gloss levels in Study 2 ($ps > .10$). As in Study 2, visual ratings of shine were moderately correlated with surface COF for each color [$r(N = 486) = -.52$, $p < .01$].

As with the indoor ratings from Study 2, color moderated the effects of gloss level under outdoor lighting conditions (compare Figure 4A with Figure 2A). The white surfaces ($M = 2.07$, $SD = 0.74$) were rated as less shiny than the black surfaces ($M = 2.88$, $SD = 0.67$; $p < .01$) and the blue surfaces ($M = 2.83$, $SD = 0.75$; $p < .01$). In contrast to the indoor ratings generated in Study 2, outdoor shine perception was not affected by viewing distance ($ps > .10$), even for the white surfaces. Possibly, the sunlight was too diffuse, was reflected from too oblique of an angle, or was too far from the target to generate the specular reflectance that appeared to increase the participants' ratings at the closer distance in the indoor study.

The overall ANOVA confirmed main effects for gloss and color ($ps < .01$). To investigate the interaction between gloss and color [$F(4,28) = 12.96$, $p < .01$], we conducted a series of post hoc comparisons at each gloss level. At the low-gloss level, ratings for the blue surfaces ($M = 1.76$, $SD = 0.76$) and the black surfaces ($M = 1.41$, $SD = 0.61$) were marginally different ($p = .02$), but ratings for the white surfaces were similar to those for the blue and black surfaces ($ps > .10$). At the medium-gloss level, the white surfaces ($M = 1.59$, $SD = 0.78$) were rated as less shiny than the blue surfaces ($M = 2.39$, $SD =$ 0.98; $p < .01$) and the black surfaces ($M = 2.44$, $SD =$ 1.03; $p < .01$), but ratings for the blue and black surfaces were similar ($p > .10$). At the high-gloss level, all three color ratings differed (all $ps < .01$), with the white surfaces rated least shiny ($M = 2.94$, $SD = 0.99$), the black surfaces rated most shiny ($M = 4.78$, $SD = 0.92$), and the blue surfaces rated between ($M = 4.33$, $SD = 1.06$).

Slip judgments. As in the previous conditions, outdoor slip ratings varied with gloss level (compare Figure 4B and Figure 2B). The participants rated the high-gloss surfaces as the most slippery ($M = 3.84$, $SD = 0.97$), followed by the medium-gloss surfaces ($M = 2.80$, $SD =$ 0.58) and the low-gloss surfaces ($M = 2.45$, $SD = 0.52$). Ratings for the high-gloss surfaces were higher than ratings for the medium- and low-gloss surfaces ($ps < .01$), and scores for the two lower gloss levels were similar ($p =$ .04). At each gloss level, indoor and outdoor slip ratings were similar ($ps > .10$). However, outdoor slip ratings were not affected by surface color or viewing distance. Judgments for the black surfaces ($M = 2.94$, $SD = 0.61$), the blue surfaces ($M = 3.17$, $SD = 0.62$), and the white surfaces ($M = 2.97$, $SD = 0.72$) were similar ($ps > .10$), as were ratings made from viewing distances of 0 steps ($M = 3.15$, $SD = 0.56$), 2 steps ($M = 2.93$, $SD = 0.55$), and 4 steps ($M = 3.00$, $SD = 0.77$), with $ps > .10$.

The overall ANOVA confirmed a main effect only for gloss [$F(2,16) = 17.48$, $p < .01$] and an interaction only between color and gloss [$F(4,32) = 3.50$, $p < .02$]. As illustrated in Figure 4B, the interaction resulted from higher slip ratings for the white surfaces ($M = 2.80$, $SD = 0.68$)

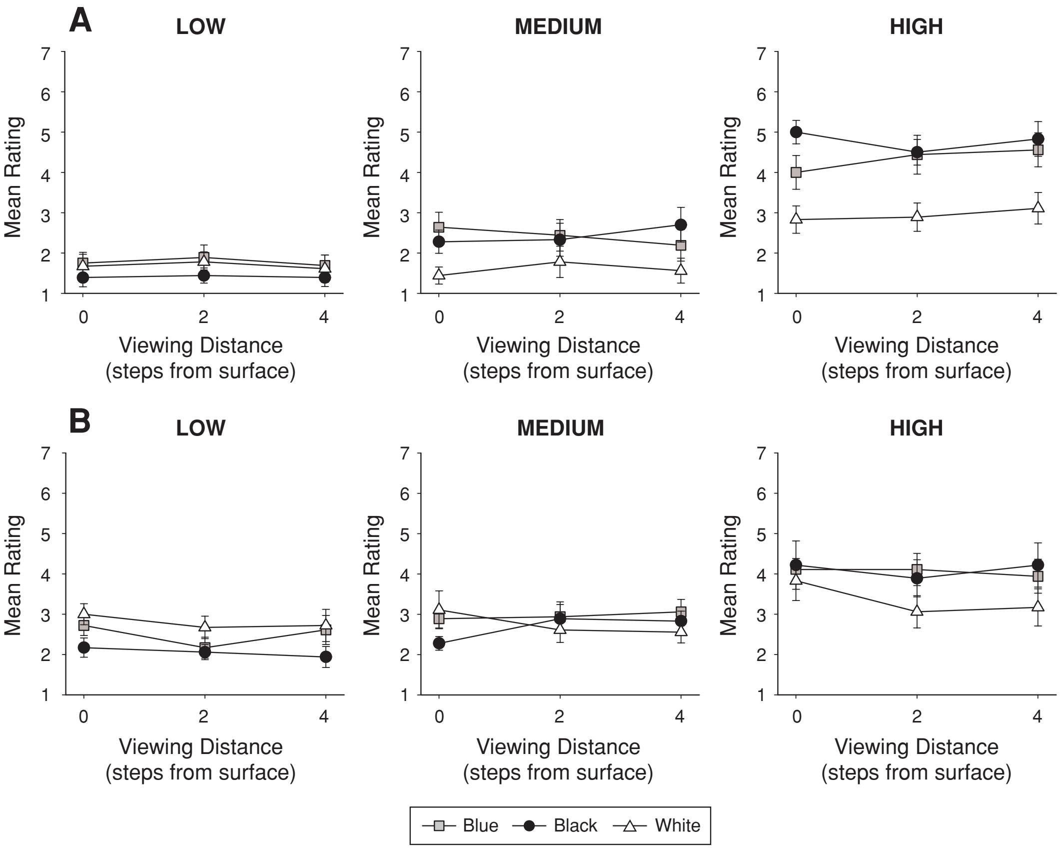

Figure 4. Outdoor judgments of (A) shine and (B) slip for low-, medium-, and high-gloss levels in Study 3. Error bars represent standard errors.

than for the black surfaces ($M = 2.06$, $SD = 0.44$; $p = .01$) at the low-gloss level and lower ratings for the white surfaces ($M = 3.35$, $SD = 0.94$) than for the blue surfaces ($M = 4.06$, $SD = 0.98$; $p = .017$) at the high-gloss level.

As in the indoor lighting condition, outdoor slip ratings were moderately correlated with surface COF for each color [$r(N = 486) = -.36$, $p < .01$]. Moreover, as illustrated in the scatterplot in Figure 3B, average shine and slip ratings for each gloss/color/viewing distance were highly correlated [$r(N = 27) = .89$, $p < .01$]. Comparisons between the scatterplots in Figures 3A and 3B highlight the compression of the participants' ratings in the outdoor lighting condition. High-gloss ratings for both shine and slip were nearly a point lower in the outdoor lighting condition.

Although the similarity between shine and slip ratings suggests that the participants based their judgments on the same visual information, their differential treatment of color for shine and slip judgments suggests that they may have implicitly compensated for less shine on the white surfaces when gauging slip. Regardless, the findings indicate that shine is affected by extraneous factors, such as surface color, viewing distance, and overall lighting conditions.

Variability of judgments. A complementary set of analyses on the variability of the participants' ratings provided additional evidence that visual information for shine and slip may not be reliable. We indexed the trial-to-trial reliability of the participants' judgments by computing the coefficient of variation (standard deviation normalized by the mean) for each pair of ratings in each condition. A general rule of thumb for interpreting coefficients of variation (CVs) is that values greater than .10 signify unreliable or unstable behaviors.

Figure 5 shows CVs for each participant in each condition of Studies 2 and 3. Across the shine and slip conditions for the indoor judgments, CVs for individual pairs of trials ranged from .00 to .85. Averaged across the 27 pairs of trials for each participant, CVs ranged from .01 to .34 ($M = .16$). Across the shine and slip conditions for the outdoor judgments, CVs for individual pairs of trials ranged from .00 to 1.06. Averaged across the 27 pairs of trials for each participant, CVs ranged from .10 to .40 ($M = .22$). A 2 (shine/slip judgment types) × 2 (indoor/outdoor lighting conditions) ANOVA revealed a main effect for lighting condition [$F(1,46) = 5.93$, $p < .02$]. Average CVs were lowest for indoor shine ($M = .14$, $SD = .07$) and highest for outdoor slip ($M = .25$, $SD = .10$). To summarize the results, the participants' judgments were not reliable from trial to trial in any of the conditions, and ratings were most unstable under outdoor lighting conditions.

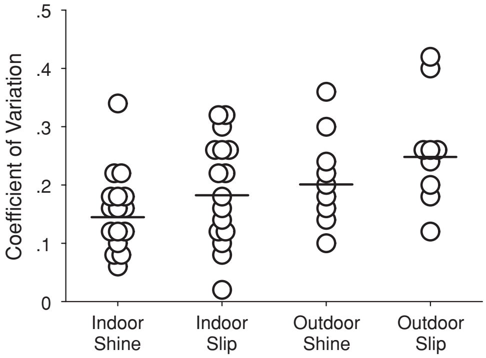

Figure 5. Trial-to-trial reliability for slip and shine ratings under indoor and outdoor lighting conditions in Studies 2 and 3. Symbols represent the coefficients of variation for individual participants. Horizontal lines denote the group means for each condition.

STUDY 4
Gauging Whether Ground Surfaces Are Safe for Walking

Findings from Studies 1–3 provided converging evidence that walkers rely on shine to predict slip. In Study 4, we tested the functional consequences of walkers' reliance on shine in a visual forced-choice task. The participants viewed pairs of surfaces and chose the one that they would walk over if they wanted to avoid slipping. The surfaces were identical to those used in Studies 2 and 3. One set of forced-choice pairings involved comparisons between low-, medium-, and high-gloss levels with paint color and viewing distance held constant. A second set of pairings involved comparisons between black, blue, and white paint colors with gloss level and viewing distance held constant. We tested the participants under the indoor lighting conditions used in Study 2—diffuse, overhead, fluorescent lights. The participants provided their judgments at the 4- and 0-step viewing distances to simulate functional slip perception as walkers approach potentially slippery surfaces from several steps away and just prior to stepping onto the surfaces. We expected that if walkers rely solely on shine to predict slip and if shine is a reliable functional cue for slip, then the participants should select the lower of two gloss levels in the first set of pairings, color choices should be at chance in the second set of comparisons, and viewing distance should not moderate their choices.

Method

Participants. Eighteen New York University undergraduate and graduate students participated for course credit or on a voluntary basis (8 men, 10 women; *M* age = 24.02 years, *SD* = 4.81). The participants were Caucasian (*n* = 8), Asian (*n* = 7), Hispanic (*n* = 2), and other (*n* = 1). Eight participants wore glasses or contacts during the session. One participant had previously experienced a serious slip-induced fall that resulted in a broken clavicle; the others had no serious slip-related falls. The participants were between 1.57 m and 1.85 m tall (*M* = 1.72 m).

Apparatus, Stimuli, and Procedure. All materials, viewing surfaces, and lighting were identical to those used in Study 2. Instead of making visual judgments of single surfaces on a 7-point scale, however, the participants selected one of two target surfaces placed side by side with the long axis parallel to their line of sight. The participants viewed the surfaces from 4 steps in front of the target surfaces or with their toes at the edge of the surfaces. The 2-step viewing distance, used in Studies 2 and 3, was excluded from the present study because most judgments made from 4- and 2-step viewing distances were similar.

As they became available for study, the participants were assigned one of the two viewing distances (0 or 4 steps) and one of two presentation orders within each viewing distance condition. Each observer provided a total of 36 judgments blocked into two sets of 18 pairs of surfaces, composed of three gloss-level comparisons (high/medium, high/low, medium/low) for each of the three colors (black, blue, white) and three color comparisons (black/blue, black/white, blue/white) for each of the three gloss levels (high, medium, low). The participants responded "left" or "right" to the question, "Which surface would you rather walk over if you did not want to slip?" Between trials, the participants turned their backs to the target area while an experimenter arranged the two surfaces for the next trial. A video camera recorded the participants' choices and behaviors from a frontal view.

Results and Discussion

Paired comparisons between the three gloss levels validated the finding from Study 1 that walkers rely on shine to make functional judgments about slip. In fact, in a short debriefing interview after the session, 17 of the 18 participants reported using shine to determine which surface would be least likely to induce slipping, and 1 participant reported using visual information for surface texture. However, shine was not equally effective across the three colors at both viewing distances. As shown in the left panel of Figure 6, when the participants stood at the edge of the target surfaces, they chose the lower gloss level on 89%–100% of trials with the black and blue surfaces and on 78%–100% of trials with the white surfaces. As shown in the right panel of Figure 6, when the participants stood 4 steps before the target surfaces, they chose the lower gloss level on 94%–100% of trials with the black and blue surfaces but only on 45%–67% of trials with the white surfaces. Logistic regression confirmed that the percentage of trials on which the participants chose the lower gloss surface was significantly lower for the white surfaces than for the black and blue surfaces [$\chi^2(2, N = 324) = 35.82$, $p < .01$].

Paired comparisons between the three paint colors showed that the participants' judgments were affected by extraneous information of surface color (Figure 7). Although the COF was similar across paint colors for each gloss level, the participants did not select colors at chance levels. Rather, preference for the lighter surface in each pair increased over gloss levels, especially at the farther viewing distance. Reading across the top panel of Figure 7, preference for the blue surface over the black surface doubled from the low-gloss level (22%) to the medium-gloss level (44%) at the 4-step viewing distance. Reading across the middle panel, preference for the white surfaces over the black surfaces increased from 6% to 56% at the 0-step viewing distance and from 0% to 94% at the 4-step viewing distance. Reading across the bottom panel, preference for the white surfaces over the blue surface in-

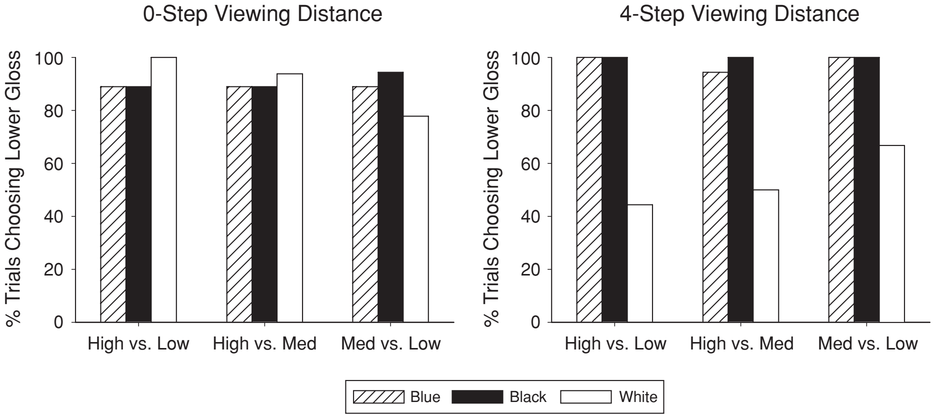

Figure 6. Percentage of trials on which the participants chose the lower gloss surface for high-/low-, high-/medium-, and medium-/low-gloss level pairings at the 0- and 4-step viewing distances in Study 4.

creased from 28% to 72% at the 0-step viewing distance and from 22% to 89% at the 4-step viewing distance.

Unlike in Studies 2 and 3, the participants' choices were relatively constant over the two presentations of each pairing in Study 4. Reliability ranged from 61% to 100% across participants (*M* = 84.57%). Higher levels of reliability may have resulted from the participants' tendency to apply a simple "rule" for choosing one of two test surfaces: In a short debriefing interview after the session, 17 of the 18 participants reported choosing the surface with less shine to determine which of the two test surfaces would be less likely to induce slipping. The participant with the lowest reliability (61%) reported switching rules—from relying on shine to surface texture—midsession.

GENERAL DISCUSSION

Visual information is crucial for controlling locomotion prospectively. To plan a course of action, walkers need accurate visual information to alert them of upcoming threats to balance. Reliable visual cues are especially important under low-friction conditions because slip-induced injuries are frequent and serious. Study 1 showed that most walkers believe that shine (and visual cues for contaminants that increase shine) is the primary source of visual information for identifying slippery ground surfaces. Study 4 confirmed the functional consequences of walkers' beliefs: They rely on shine for selecting a less slippery path. Studies 2 and 3 provided converging evidence that walkers use shine to predict slip: The overall patterns of ratings between the shine and slip conditions were similar.

However, the findings from Studies 2–4 also revealed that shine is not a reliable visual cue for specifying slippery ground. In Studies 2 and 3, shine and slip ratings were not reliable over repeated presentations of the same surface in identical conditions. CVs (normalized measures of variability) over repeated trials were highest for slip ratings under outdoor conditions but were unstable (*M*s $>$ .14) for both shine and slip ratings under both indoor and outdoor lighting conditions.

Although the participants' mean ratings generally varied according to the gloss levels of the test surfaces, both shine and slip ratings were affected by color, viewing distance, and lighting conditions—factors that do not affect the actual COF. Judgments were most sorely affected by the white surfaces, and ratings of the white surfaces were most affected by viewing distance and lighting conditions. Under indoor lighting conditions, the participants' shine and slip ratings of the high-gloss white surface were uniformly low until the viewing distance was so close that they were virtually standing over it. Unfortunately, a 0-step viewing distance would not be large enough to allow participants sufficient time to modify their walking patterns (e.g., Patla, 1991, 1997). The participants did not differentiate the low- and medium-gloss white surfaces at any distance, despite a larger change in the COFs relative to the low- and medium-gloss black and blue surfaces (Table 2). In Study 4, the participants erroneously assumed that high-gloss white surfaces were less slippery than high-gloss black and blue surfaces, especially at farther viewing distances. Lack of perceptual sensitivity to white surfaces has important implications because white is the typical color of ice and snow.

Why Is Shine Not a Reliable Visual Cue for Low-Friction Conditions?

Shine may fail to provide reliable information for slip due to perceptual, functional, and biomechanical factors. From a perceptual standpoint, shine perception is extremely complex and variable. Even under controlled laboratory conditions, shine is more difficult to study than other sources of visual information for surface perception. Shine perception is affected by multiple subject variables (prior knowledge about the viewing surfaces, awareness of lighting conditions, differential weighting of intensity, clarity, distinctness of the reflected image, and the like), multiple environmental variables (surface color, texture, and illumination conditions), and variations in the observer/environment interface (viewing distance, viewing angle, and observer movement; see Braun & Braun,

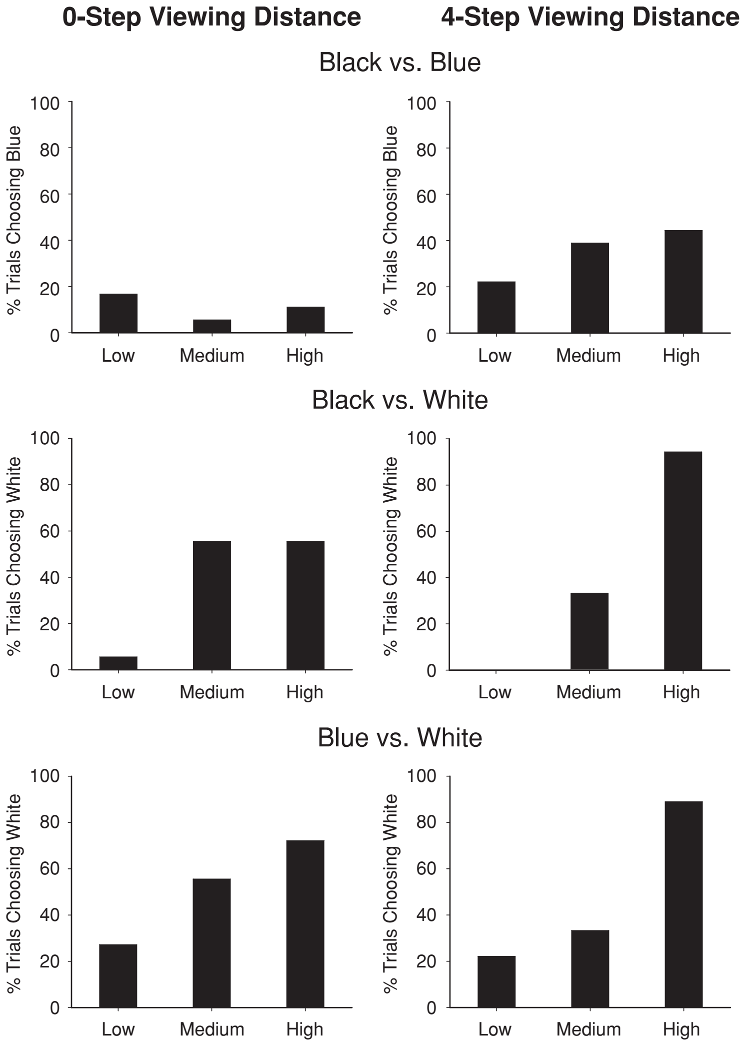

Figure 7. Percentage of trials on which the participants chose the lighter colored surface for black/blue, black/white, and blue/white color pairings at the 0- and 4-step viewing distances in Study 4.

1995; Cohen & Cohen, 1994a, 1994b; Nishida & Shinya, 1998; Pfund, 1930; Sève, 1993).

From a functional standpoint, shine may fail to provide a helpful cue for friction because differentiation of gloss levels occurs too late in the walking sequence for prospective control. Each step brings walkers closer to the target surface in time and space. Perceptual information—shine or any other source of visual information—must become available at a sufficient distance to allow walkers enough time and space to gather and process the information and to implement an appropriate antislip strategy (Adolph & Berger, 2006; Adolph et al., 2000). Walkers cannot stop, veer slightly, or shorten, lengthen, or widen their steps to avoid a slippery obstacle without at least one step of advance notice. They cannot slow down, reduce velocity at heel contact and toe-off, minimize dorsiflexion at the ankle, shorten their steps, or maintain a straight-up body position to minimize slip at the foot–floor interface without three to four steps of advance warning. Thus, in the optimal case, walkers should obtain visual cues several steps ahead (Patla, 1991, 1997). However, Studies 2 and 4 revealed that shine is best perceived at a 0-step viewing distance when walkers are nearly on top of the potentially slippery surface.

Moreover, the lag is further exaggerated between the moment when requisite visual information becomes available and the moment when walkers detect it because walkers only visually sample the ground surface intermittently. In natural settings, walkers do not maintain their gaze on the floor. Rather, on even, regular terrain, studies using head-mounted eye-tracking devices show that walkers look at the floor only 10% of their travel time (Assaiante, Marchand, & Amblard, 1989; Patla, Adkin, Martin, Holden, & Prentice, 1996). Most of their visual exploration involves “travel fixations,” where the eyes are parked in front of the body to sample optic flow information for controlling body sway and balance. In Studies 2–4, we asked the participants to direct their visual attention at the test surfaces. However, even when walkers know that their foot placement is constrained because of irregular terrain, walkers' looks to the floor increase to only 30% of their travel time (Assaiante et al., 1989; Patla et al., 1996).

Finally, from a biomechanical standpoint, friction may simply be impossible to specify via visual information. Contrary to our commonsense intuitions that low-friction conditions look a particular way and that high-friction conditions look another way, any visual cue may be a poor candidate for perceiving friction conditions. Friction is not a property of the ground surface. It is an emergent force that is created only when the foot and the floor come into contact. Consequently, shoes do not cause slips and neither do floors; instead, particular shoe–floor pairings create slippery conditions that cause slips and falls. Because friction is emergent, small changes in one of the two contacting surfaces can create large changes in friction. The frictional forces arising from the same shoe–floor pairing can vary depending on the wear and tear of the shoe soles, the presence of contaminants on the floor, the angle at which the shoe strikes the floor, the contact velocity, the distribution of walkers' center of mass, and so on (Cham & Redfern, 2002; Marigold & Patla, 2002). Thus, visual information may fail to specify slipperiness because we cannot foresee resultant forces before the constellation of relevant factors has coalesced.

In sum, despite walkers' reliance on shine to predict slippery ground surfaces, shine is, at best, a probabilistic cue for low-friction conditions. The complicated nature of shine (and shine perception) makes it an unreliable visual cue. The emergent nature of friction suggests that changes in friction will not always be accompanied by changes in shine. The sequential nature of locomotion requires visual information for low friction to be available from a distance.

Why Do Walkers Continue to Use Shine?

Why, then, do walkers continue to use shine as their primary visual cue for predicting slippery ground? One possibility is that walkers do not know that shine is unreliable. None of the participants in Study 1 indicated uncertainty, difficulty, or impossibility of perceiving slipperiness in response to the question, "By only looking at it, how would you tell if the floor was slippery?" A second, related possibility is that walkers do not fully understand the sorts of factors that affect shine and various exploration strategies that might increase the likelihood of detecting shine. The participants in Studies 2–4 did not appear to display increased head-bobbing, lateral rocking of the torso, or other exploration strategies that might have maximized detection of specular reflectance at the greater viewing distances. Although the participants may have "corrected" their ratings on the basis of lower expected shine for the white surfaces, they erroneously rated the white surfaces as less slippery than the darker surfaces with the same COF and gloss level.

A third possibility is that walkers do not fully understand friction. Despite their various antislip strategies for coping with low-friction conditions, infant and adult walkers do not appear to understand the range of conditions in which antislip strategies should be implemented. For example, neither infant nor adult walkers demonstrate understanding that sloping ground decreases the COF and increases the likelihood of slipping (Adolph, Eppler, Joh, Shrout, & Lo, 2006; Lo, Avolio, Massop, & Adolph, 1999; Narayanan, Joh, Adolph, & Eppler, 2004). The problem is not a lack of experience: Walkers cope with frictional forces with every step on every surface.

An alternative possibility is that walkers do the best that they can under complex and unfavorable conditions. Most adult walkers have slipped and fallen, and most of us have ruefully noted our failure to detect the offending slippery surface prospectively. Indeed, 8 of the participants in Studies 2–4 had incurred slip-related injuries requiring medical attention, and, presumably, others had experienced falls with less severe consequences (Joh, 2006). Nonetheless, the dearth of potential visual cues for friction may leave walkers with few options. Although cues are reliable only to the extent that they exhibit constancy across different contexts, shine may prove better than nothing. Rather than walk around in a state of constant high alert—gingerly pressing their weight onto each new surface they encounter and feeling for slipperiness—walkers may choose to rely on shine and take their knocks.

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