According to published research by the Liberty Mutual Research Institute for Safety, same-level slips and falls represent nearly 11% of all workers’ compensation claims and more than 13% of all claims costs (Murphy & Courtney, 2000). This is second only to manual material handling, which represents 37% and 40%, respectively. In most industry groups, slips and falls represent the highest or second highest type of workers’ compensation claim. In addition, 11% of low-back-pain-related claims and 12% of low back pain-related claims costs are attributed to slips and falls (Leamon & Murphy, 1995).

The Liberty Mutual Workplace Safety Index ranking of the 10 leading causes of workplace incidents and the initial Liberty Mutual Executive Survey of Workplace continued on page 14
Prevention Through Design: Slips, Trips & Falls
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Safety in 2001 revealed some interesting statistics about the direct and indirect costs of workers’ compensation slips and falls and the perception among business executives about the extent of the problem. In reality, the direct cost of falls on same level represents $8.61 billion (16.9% of claims), second behind over-exertion or back injuries. From 1998 to 2010, falls on same level showed a 42.3% increase, but, according to the 2001 executive survey, most executives perceived falls on the same level to be much less of a problem—the seventh most important cause overall (Liberty Mutual Workplace Safety Index, 2001).

Why the difference between the reality and the perceived importance of slips and falls? Why do same-level falls continue to represent one of the most costly safety problems today? The reason might be a lack of understanding as to how slips, trips and falls occur, as well as a lack of a managed safety process that targets those complex causes.

CAUSES OF SLIP, TRIPS & FALLS

To understand slips, first consider human bipedal gait. Bipedal gait is characterized by two phases: the stance phase and the swing phase. The stance phase begins with a heel strike or the initial contact with the floor at the rear edge of the heel. The heel rocks forward to bring the foot into full contact with the walking surface and to support the body as the other foot enters the swing phase. When the swing phase is completed, the supporting foot rocks forward leaving only the forepart of the foot contacting the walking surface. This is called “toe off.” Body weight is then shifted onto the other foot, and the original foot enters its swing phase.

A slip occurs when the heel contacts the floor and the weight is shifted to the heel, potentially resulting in loss of balance and stability and a fall. Slips may result in the person falling posterior or backward (Grönqvist, Chang, Courtney, et al., 2003).

A trip occurs when the foot strikes a near-ground obstacle that abruptly arrests the foot’s movement when the body’s center of gravity is in motion. This causes the center of gravity to rapidly move out of the area of the body’s support base (the planted foot), resulting in loss of balance and stability and potentially a fall. Trips may result in the person falling forward.

Factors that contribute to falls are not well appreciated. Human error is too often blamed for causes of falls (e.g., the person was not watching where s/he was going, was rushing, was careless). Because falls are embarrassing events, slips without a fall or slips and trips that result in a fall without injury are rarely reported or recorded. Prevention strategies are often reactive or are only implemented after an expensive lawsuit or when workers’ compensation claims frequency and severity are significant enough to attract risk managers’ attention.

Preventing falls requires being proactive, which requires an understanding of human behavior and other scientific disciplines that explain why slips, trips and falls occur. These disciplines include ergonomics, biomechanics, psychology and tribology.

Tribology is the study of the interaction of sliding surfaces. The word is derived from the Greek tribos, meaning rubbing. The field of tribology includes the analysis of friction, wear, lubrication and application of these principles to mechanical design, manufacturing processes and machine operation. Historically, tribology, a mechanical engineering discipline, has been associated with the electronics, metalworking and medical industries, but more recently, tribology has been applied to slips and falls.

In slips and falls, tribology can describe causes of slips and falls and prevention of such incidents. Friction is associated with the interface between the floor and shoe sole, wear of the shoe sole material and floor surface material and lubrication with contaminants, such as grease, water and dirt.

Most same-level falls are the result of slipperiness caused by faulty housekeeping or floor surface defects. Faulty housekeeping is defined by the presence of dirt, grease, water or other contaminants on the floor. Defective floors include those having slippery floor waxes and finishes, inappropriate floor surface materials for the environment, excess surface wear and uneven or damaged surfaces.

Rough floor surfaces offer more slip-resistant characteristics by providing sharp peaks, which contact the shoe sole material thereby increasing friction or traction. However, grease, dirt or other contaminants can reduce that benefit by filling in the voids, and the peaks can wear over time, thus reducing the slip-resistance benefit.

Ergonomics is involved in slips, trips and falls in several ways. Tasks performed have a direct effect on the force characteristics associated with a person’s behavior, movement patterns and gait. Slips and falls occur most frequently among the elderly for two reasons. First, as one ages, reaction time slows. When younger people sense or perceive a heel slip, they recover quickly. Older people recover more slowly, and that split-second delay is the difference between recovery and a fall (McCarter, 1990).

Second is muscular strength. Many different muscle groups are employed to recover from a slip, and people take for granted how strong these muscles must
be to recover. The elderly have less strength in these muscles and, again, are less physically able to recover from a slip.

Third, vision deficits and corrective lenses, loss of contrast sensitivity, less color sensitivity, poor dark adaptation (slow/incomplete) and reduced glare recovery can make it difficult to see potential hazards on the walkway surface and, therefore, increase likelihood of a potential fall (Crassini, Brown & Bowman, 1988). This is especially important for detecting height transitions on stairways, sidewalks, curbs and parking stoppers. For this reason, U.S. Access Board (2000) research recommends safety yellow for detectable warnings, as it is most visible to older pedestrians.

Ergonomics is the design of work to fit people, which includes jobs, tasks, workstations, tools and equipment. Ergonomic design means accommodating as many people as possible. The same is true of facility design to prevent slips, trips and falls. Ergonomic facility design includes recognizing individual differences, such as the aging population, and eliminating or reducing as many slip, trip and fall hazards as possible.

Biomechanics is the human factor element of slips and falls and involves the study of body mechanics and how people walk and interface with surfaces as they walk. Biomechanics research in slips and falls provides an understanding of required or utilized coefficient of friction during the gait cycle and how it varies by the person’s age, gait pattern, walking speed, footwear and other factors. Force plates are used to capture ground reaction forces with 3-D motion-tracking technology (cameras and reflective markers) to identify position and motion of the lower extremity, foot and heel.

Biomechanics is helpful in understanding the dynamics of slipping and at what point a fall might occur. For example, research in the early 1990s concluded a microslip of 0 to 3 cm is generally undetected, while a slip of 3 to 10 cm may result in corrective action taken usually without a fall. A slipping distance of more than 10 cm most often results in a fall (Leaman & Li, 1990). Liberty Mutual Research Institute for Safety research showed considerable variation in human perception of heel slip, slip distance and ranking of floor slipperiness (DiDomenico, McGorry & Chang, 2007).

Determination of required or utilized coefficient of friction (COF) is helpful for understanding the probability of slips and falls. For example, if available friction measured with a tribometer or slipmeter is lower or more slippery (0.2) than required friction (0.6), then theoretically the probability of a slip and fall is higher (Burnfield & Powers, 2003). A statistical model published by Liberty Mutual Research Institute for Safety can be used to calculate probability of slips and falls (Chang, Chang, Matz & Lesch, 2008).

Psychology relates to how one perceives and responds to slippery conditions. Slips and falls happen when one least expects it. For example, when a person perceives a slippery condition (e.g., walking on ice), s/he will adjust his/her gait to prevent a slip. A problem often occurs when a person does not perceive a slippery condition, does not adjust his/her gait, slips unexpectedly, fails to recover and falls. Examples include when water or grease is left standing on a floor and when one reaches a transition point from a non-slippery floor to a slippery floor, such as from carpet to a glazed ceramic tile or vinyl-composition tile floor.

Liberty Mutual researchers have studied human perception of slipperiness with regard to friction, heel displacement and visual cues, and while there is good correlation to perceived slipperiness with friction and visual cues, there is less with heel slip (Lesch, Chang & Chang, 2008). People do not usually look at floors when they walk, so selection of flooring is important.

Other factors that increase the likelihood of same-level falls include personal factors such as the use of certain medications and certain illnesses that affect cognition and balance.

Physical factors that increase the likelihood of slips and falls include slippery walkway surfaces (inside and outside), inadequate footwear, poor lighting and transitions from nonslippery to slippery conditions, such as carpet to tile, concrete to tile, hot environments to cold and dry environments to more humid conditions.
slipperiness is affected by the presence of water and contaminants such as grease, oil, dust and particulate soil. Most dry/clean floors are slip-resistant and safe. Outside slips and falls can occur due to slippery walkways at building entrances, sidewalks, curb ramps, parking areas and parking garages.

Physical factors that increase the likelihood of trips include walkways that are too rough, high surface texture, too high of a COF and transitions in height. Most state, local and federal codes and standards describe changes in elevation of one-quarter in. or higher in the course of travel as a trip hazard. Trip hazards can be present anywhere inside and outside a facility, including sidewalks, curbs, curb ramps and parking areas. Evaluating floor slipperiness requires baseline knowledge of friction and the interface between the shoe outsole and floor surface. The higher the friction, the higher the traction between the walkway surface and the footwear.

**A Managed Slip, Trip & Fall Process**

Managing slip and fall exposures is challenging and requires participation by everyone in the organization. Stakeholder groups in a slip and fall prevention process include architects, design and construction, facilities management, operations management, risk management, safety, purchasing, occupational health, maintenance, and housekeeping. Figure 1 describes the elements of a managed slip and fall prevention process (Gielo-Perczak, Maynard & DiDomenico, 2006).

Facility design, including selection of floor surface materials, is key to this process. If a walkway surface is slippery by design or a trip exposure exists by design, then it is only a matter of time before a pedestrian could fall victim to the exposure. Installing the wrong floor for the expected environment, unforeseen transition issues, inadequate cleaning or repairing of defective floors, trip and slip exposures in parking lots and sidewalks are common problems.

**Facility Design Guidelines**

International Building Codes, Americans with Disabilities Act (ADA) Accessibility Design Guidelines and other design standards describe the importance of slip resistant flooring and stair tread material in design but allow the designer to decisions regarding materials selection. The Building Code Commentary provides additional information on slip-resistant surfaces but does not specify standards or performance levels for slip resistance.

ASTM F1646-2012, Standard Terminology Related to Safety and Traction of Footwear, defines slip resistance as the relative force that resists the tendency of the shoe or foot to slide along the walkway surface. Slip resistance is related to a combination of factors, including the walkway surface, the footwear bottom and the presence of foreign materials between them (ASTM International, 2012).

ASTM F1646-2012 defines slip resistant as the provision of adequate slip resistance to reduce the likelihood of slip for pedestrians using reasonable care on the walking surface under expected use conditions (ASTM International, 2012). In its simplest sense, a slip-resistant surface is one that will permit an individual to walk across it without slipping.

Many designers choose flooring on the basis of aesthetics and/or cost rather than slip-resistance performance and durability over time. Installing the right floor the first time can potentially save millions of dollars in costly floor treatments, repairs or even replacement.

Many different types of flooring exist, including various tiles, carpeting, epoxy floors, terrazzo and concrete. Determining factors for floor selection should be to install slip-resistant floor surface materials for the expected traffic load and environment. If the floor is expected to be wet with contaminants present, then those factors should drive the decision about what floor surface to install. When choosing a floor used mostly in dry conditions, one has more flexibility because most dry, clean floors are slip resistant.

Slip-resistant qualities of a new floor may be altered due to high traffic, especially if the floor offers few durable qualities. What might seem inexpensive today could be more expensive over time if the floor needs to be replaced due to excessive wear sooner than expected. Wet or
contaminated conditions determine whether the floor offers the best slip-resistant qualities.

Surface roughness affects friction; selection of floor surfaces with adequate roughness characteristics may potentially reduce slip and fall incidents (Chang, 2004). The higher the COF, the more slip resistant the surface. For example, 0.1 is very slippery while 0.8 is relatively nonslippery. Most studies show that people can walk comfortably and safely on surfaces with a COF greater than 0.4, but 0.5 offers an additional safety factor (Miller, 1983). This is called a slip-resistant surface. Measurement of slipperiness using tribometers is beyond the scope of this article.

Flooring selection should also consider transition areas. A transition from a carpeted floor or nonslippery floor to a glazed tile or more slippery walking surface could increase the likelihood of a slip and fall due to the individual’s lack of detection of the transition (change in slip resistance) and appropriate gait adjustments. In general, flooring should have similar slip-resistant properties when transitioning between different types of flooring, especially when liquid contaminants may be present.

Entrance design and use of matting are also important for slip and fall prevention. Mats can improve overall floor maintenance by absorbing moisture and scraping soil particles from footwear, thereby keeping the floor in a clean, dry condition and protecting the floor from soil particles from footwear, thereby keeping the floor in a clean, dry condition and protecting the floor from unnecessary wear and can remove water between the shoe and floor.

**Stairway Design**

Types of missteps on stairs include oversteps, understeps and airsteps. In all cases, should a stumble occur on a stairway, especially when descending, the presence of a properly designed and installed handrail system is the only thing separating the pedestrian from serious injury. Most public accessibility guidelines on stairway design, including the international building codes, NFPA 101, ADA and ANSI, are fairly consistent on riser and tread dimensions and handrail installations. These same guidelines mention the importance of slip resistant treads, and the guidelines for walkway surfaces selection apply to stair treads as well. What is or is not a slip-resistant tread depends on whether the stairway is inside or outside and whether it is exposed to contaminants, such as grease, oil, particulate soils, water or any combination.

One- and two-step stairway designs are the most difficult to control and should be avoided whenever possible. Controls are limited but can include remodeling the elevation to a ramp or installing handrails. Riser and tread dimensions should follow those of standard stairways. Check building codes for requirements.

**Preventing Trips & Falls**

Trip hazards should be eliminated through facility design or maintenance if possible. However, if elimination is not possible, then other options include:

- For changes of level 0.25 to 0.5 in. (6 mm to 13 mm), bevel the edge with a slope no greater than 1:2. Slope is the angle of incline usually given as a ratio of the rise (or vertical height) to the run (or horizontal length). The larger the run, the more gentle the incline angle.

- For level changes greater than 0.5 in. (13 mm), install a ramp with maximum slope 1:12.

- A third but less desirable option is to make hazards visually noticeable through appropriate detectable warnings.

**Outdoor Falls**

Slips, trips and falls in outdoor environments can be caused by rain, sleet, ice, snow and particulate soil that cause surfaces to become slippery or produce poor traction. While environmental conditions that increase slipperiness of outdoor walkway surfaces cannot be controlled, the likelihood of falls can be reduced through improved design of exterior sidewalks, curbs, parking areas, improved lighting and improved maintenance to increase awareness and eliminate hazards.

**Sidewalks, Curbs & Parking Lots**

A business owner may not be responsible for injuries resulting from a fall on a public sidewalk located outside his/her property. However, some courts may impose liability for injuries on a sidewalk used exclusively by customers coming to and from a business. Consult with legal counsel regarding questions on liability.

However, a parking lot owner can be responsible for maintaining the parking lot to be reasonably safe for people using it. This includes:

- filling and patching cracks and holes;
- repairing and eliminating raised areas due to tree roots, settling, cold weather (frost heaves) and ordinary wear and tear;
- reducing surface water by directing roof drainage away from sidewalks and parking areas;
- clearing sidewalks/parking areas of snow/ice before employees and guests arrive;
- centering and securing parking stoppers;
- painting or staining parking stoppers near entrances safety yellow to improve visibility.

**Curb Ramps & Handicap Ramps**

State, local and national codes specify guidelines/requirements for curb ramps and handicap ramp design. For example, ramp slopes 1:15 minimum to
1:12 maximum with slip resistant surfaces are often cited. As mentioned, no specific guidelines exist on what slip resistant means, but some codes specify grooving or other alterations of curb ramps to improve slip resistance. Check state and local codes for requirements on ramp slip resistance guidelines. Handicap ramps and curbs are colored safety yellow. In some state or local codes, curbs or fire lanes in front of buildings are required to be painted red, so be familiar with code requirements before giving recommendations.

COLOR, CONTRAST & VISIBLE WARNINGS

As mentioned, recent U.S. Access Board (2000) research recommends safety yellow as the preferred color for persons having low vision. Yellow or yellow-orange warning surfaces are preferred over black warning surfaces. Therefore, safety yellow is a color most often used for visible warning in the pedestrian/highway environment.

OUTDOOR LIGHTING

Inadequate lighting may also lead to incidents involving falls in parking lots, trips over curbing, falls on a step or stairs from a parking lot to a store and trips and falls due to holes, cracks and uneven surfaces.

CONCLUSION

Fall prevention programs need to be proactively managed. Prevention strategies include selecting the right floor surface, maintaining floors through good housekeeping programs and conducting periodic inspections for defects. A slip and fall prevention strategy with design focus includes entrance design and proper installation and design of matting systems. Like other safety and health systems, preventing slips and falls requires an integrated approach that includes everyone in the organization, especially those associated with facility design, such as architects, design and construction personnel, and facility and property managers. Education and training for these key stakeholders as well as communication between all stakeholders are essential to the success of prevention efforts.

REFERENCES


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