Reducing Slip, Trip and Fall Accidents on Walkways and Stairs

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Introduction

The leading cause of accidents in the home and the workplace is slipping, tripping and falling. According to the 2007 Edition of the National Safety Council, Injury Facts, the leading cause of non-fatal unintentional injuries is still falls. The leading cause of injury-related Hospital Emergency Department visits is still accidental falls, and in the category of principal types of unintentional-injury deaths is motor vehicles, but still second is falls. Mechanically speaking a fall occurs when the center of mass (weight) of the individual is no longer balanced over their support (feet/legs). When balance is lost, for whatever the reason, the individual will fall. During ambulation, walking on walkways or stairs, this principally occurs when the individual's gait is disturbed. This can occur is several ways, by slipping, by tripping or by an unexpected or non-occurrence of their step (foot) location. In this discussion, I would like to first discuss what is human gait, what affects it and thereby what causes individuals to fall during ambulation. From that knowledge, we can discuss and learn how to prevent these falls.

Discussion

<u>How we ambulate (simple bio-mechanics in layman's terms).</u>
Walking is initiated, from a static standing position by moving the center of mass of the body forward (or backward) creating an unbalanced condition, then swinging one leg/foot forward (backward) and landing it ahead of the body's center of mass. The body's center of mass, then passes over the forward now landed foot, and continues forward (backward) creating another unbalanced condition. The trailing foot is then swung forward (backward) and landed ahead of the body's center of mass, to catch the body and preventing it from falling. The body's center of mass then continues moving forward (backward) and the trailing leg is then swung forward and lands continuing in this fashion until the motion is stopped by not allowing the center of mass from passing forward (backward) of the legs or vertical support position.

This results in three critical positions:
1. Landing the forward (swinging) foot commonly referred to as: "Heel Strike."
2. Swinging the trailing foot.
3. Lifting the trailing foot commonly referred to as "Toe Off" or "Push Off."

The most critical factor in the heel strike and toe off positions is the slip-resistance of the walkway surface. The individual determines what the slip-resistance of the walkway surface is by, first visually observing the walkway surface and optically calculating what they expect the slip-resistance to be. They then cautiously place their foot forward and test or confirm that the actual slip-resistance is what they had calculated. Then after the individual has determined and confirmed the slip-resistance, they will set their gait (step length) accordingly and proceed to walk on that surface. When the individual reaches a spot or area where they have visually determined that the slip-resistance of the surface may be different, they will go through this process again, recalculate, re-test and reestablish their gait. For safety purposes, this requires that the individual can see that there is something different on the walking surface, such as a variation in color or texture of the walking surface. If the pedestrian encounters a change in the slip-resistance of the surface, and does not recognize that there is a change, then their heel or toe is likely to slip, if the slip-resistance is lower than they expected or stumble if it is greater than they expected. Pedestrians adjust the distance they move or swing their foot and move their center of mass, depending on what they determine the slip-resistance to be. On ice, they expect a low slip-resistance and take short steps. On brushed concrete, they expect a high slip-resistance and take longer steps.

The most critical factor during the swing phase of ambulation is the vertical elevation of the ground. When the leg is extended behind the individual, the trailing ankle and foot is also stretched. This makes the trailing leg longer than the forward leg. The individual then bends the knee and/or ankle in order to shorten the trailing leg. This requires additional energy of the pedestrian. Since the homosapien believes in the conservation of energy, particularly their own, they will lift this foot only has high as they need to, usually about one-quarter (¼) inch above the walkway surface as this foot swings under their body. Therefore, it is critical that the individual recognizes exactly how flat or how much of an obstruction is in or on the walkway surface as they walk on it. When there is a vertical change in the walkway surface or an obstruction, greater than one-quarter of an inch, the toe of the swinging foot is likely to catch this obstruction and prevent the swinging foot from being placed under the moving center of mass. An unbalanced condition will result in a fall unless the pedestrian is able to regain their stability or balance during their stumble.

How we ascend and descend stairs (simple bio-mechanics in layman's terms).

When ascending a stairway, the pedestrian will approach the stairs, visually examine the stairway in order to determine the riser height, tread depth, pitch, slope and tread slip-resistance. After the pedestrian has optically made these observations, the pedestrian will calculate how high they must lift their foot, based on the riser heights, and how far forward they need to place it, based on the tread depths, and how far forward (bend over) they need to move their center of mass, which is usually based on the slip-resistance. They will then take a test step or two to confirm their optical observations and calculations, and establish a gait. They will then continue up the stairs using this gait unless or until they see or determine that, there is a change in the stairway configuration, such as a landing or a foreign substance on the treads, or a change in the riser height.

When descending a stairway the pedestrian will approach the stairs and visually examine it to determine the riser height, tread depth, pitch, slope and tread slip-resistance. Having optically made the calculations as to how far they must lower their foot; how far out or in they need to place their foot; where the ball of their foot must be in order to slide over and off of the tread nosing, this is both tread depth and slip-resistance. Sometimes the pedestrian must descend sideways if the tread depth is too short for the length of their foot. How far backward (bend back or stay straight up) they need to keep their center of mass (body). They will then take a test step or two to confirm their optical calculations and establish their gait. Then they will continue down the stairs using this gait unless or until they see or determine a change in the stairway configuration, such as a landing, or a foreign substance on the treads or a change in the riser height.

Since, the homosapien believes in conservation of their energy, they will lift their foot only as far as necessary, no more than one-quarter of an inch above the next riser. If the riser heights are uneven, and the succeeding riser is more than one-quarter of an inch higher than the preceding riser, they will stub their toe on the nosing of the succeeding step. If the next higher riser height is less than the preceding riser height, they will place their weight onto the higher foot at a location above the tread and their foot will appear to fall until it strikes the tread. Both scenarios will disrupt their gait and their balance. If they are unable to regain their balance, a fall will result.

Similarly when descending, the pedestrian determines how far to lower their descending foot and where to place it on the next lower tread. If the next lower riser is greater than the previous riser, they will feel that they are falling as their foot continues to lower past where they believe the tread to be. If the next lower riser is less than the previous riser, then their foot will strike the tread, sooner than they expect it to and their foot will come to a sudden stop. Both scenarios will disrupt their gait and their balance. If they are unable to regain their balance, a fall will result.

In many cases the pedestrian may not feel comfortable when moving up and down and seek additional support such as holding on to a handrail or a wall. Many times due to the shape of the pedestrian's body, the clothes they are wearing or something that they are carrying, they cannot see the individual tread and tread nosing. In these circumstances, they must rely on an optical or tactile clue as to any change in the stairway such as a landing. The position and shape of the handrail is used to provide this tactile or optical information to the pedestrian. Therefore, if the handrail turns from an angle, parallel to the stairway, to the horizontal before or after the last tread, they will continue to step either up or down, and suddenly find that there is no tread where they expect it to be. This will disrupt their gait and their balance. If they are unable to regain their balance, a fall will result. If the handrail is not parallel to the stairway nosings, then the pedestrian will expect the risers to be higher or lower as they ascend or descend the stairway. If the risers are not equally greater or equally lesser than the pedestrian expects them to be, then the pedestrian will misstep and loose their gait. Both scenarios will disrupt their gait and their balance. If they are unable to regain their balance, a fall will result.

Basic requirements for human ambulation on walkways and when ascending and descending stairways.

Based on the forgoing basic explanation of walking and ascending and descending stairs, the most important and critical requirement is **"UNIFORMITY"** in construction and maintenance and in keeping the walkway & stairway treads clean and free from foreign objects and maintaining slip-resistance. Since the pedestrian will subconsciously establish a gait, it is critical that they have the necessary information available to them to establish their gait and that the walkway or stairway remain as they calculated it, which requires **uniformity** in all factors of the walkway surface and the stairway surfaces and configuration, such as:

- The slip-resistance of the entire walkway and all of the treads and nosings is the same (uniform).
- There are no changes in vertical elevation greater than ¼ (one-quarter) of an inch.
- That any changes in vertical elevation between ¼" (one-quarter) and ½" (one-half) of an inch are beveled at a 45-degree angle.
- Any changes in elevation greater than one half an inch be sloped at a slope no greater than 1 in 12 (rise: run), some codes allow a slope as great as 1 in 8 (rise: run).
- That the color or patterns on the surface are uniform and not confusing or conflicting.
- Uniform cleanliness is maintained to maintain a uniform slip-resistance.
- That there are no obstacles or obstructions.
- The riser heights are uniform in a stairway.
- The nosing shape (radius) is uniform in a stairway
- The nosing slip-resistance is uniform in a stairway.
- The tread depths are uniform in a stairway.
- The handrail height above each stair nosing and landing is uniform so that the handrail is parallel to the tread nosings.
- The handrails are parallel to the tread nosings and change direction with the tread nosings such as at a landing.
- There are no riser heights less than 4 inches in vertical elevation.

ASTM F-1637-02 - Standard Practice for Safe Walking Surfaces, covers design and construction guidelines and minimum maintenance criteria for new and existing buildings and structures. This practice is intended to provide reasonably safe walking surfaces for pedestrians wearing ordinary footwear. These guidelines may not be adequate for those with certain mobility impairments.

All building codes and NFPA 101, the life safety code include provisions for walkway surfaces, stairways and changes in elevation, so that a person can safely walk over that surface and in particular egress from the structure or area safely and competently during an emergency. These requirements are most important to be followed, since these codes expect the pedestrian to be impaired during or because of the emergency and their need to safely egress is a matter of life or death.

These codes and standards include such requirement as:

- The slip-resistance of the entire walkway and all of the treads and nosings will be uniform and greater than 0.5.
- There are no untreated changes in vertical elevation greater than ¼ of an inch in a walkway.
- Changes in vertical elevation between one-quarter and one-half of an inch in a walkway shall be beveled at a 45-degree angle.
- Changes in elevation greater than one half an inch in a walkway surface shall be sloped no greater than 1 in 12 (rise: run) some codes allow a slope as great as 1 in 8 (rise: run).
- The color or patterns on the walkway surface are uniform and not confusing or conflicting.
- The walkway surface shall have a uniform cleanliness to maintain a uniform slip-resistance.
- There shall be no obstacles or obstructions on a walkway surface.
- The riser heights in a stairway are uniform (to within three-sixteenths of an inch).
- The nosing shape (radius) shall be uniform in a stairway.
- The nosing slip-resistance shall be uniform in a stairway.

- The tread nosings shall be readily discernible, slip resistant, and adequately demarcated. Random, pictorial, floral, or geometric designs are examples of design elements that can camouflage a step nosing.
- The tread depths are uniform in a stairway (to within three-sixteenths of an inch).
- The treads of a stairway shall be maintained in a clean and uniform condition. The slip-resistance of the tread surfaces shall be uniform.
- There shall be no distractions on a stairway.
- The handrail height above each stair nosing and landings shall be uniform so that the handrail is parallel to the tread nosings.
- The handrails shall be parallel to the tread nosings and change direction with the tread nosings such as at a landing.
- The height of the top of the handrail shall be between 32 inches and 36 inches above the tread nosing.
- No riser height shall be less than 4 inches in vertical elevation.

Measuring a Walkway or a Stairway

I have found several simple measuring tools, which can easily and accurately measure a stairway or walkway. Several of these tools are as follows:

- To measure the vertical height of a riser or a change in elevation, I recommend a machinist's square. This device has a head, with a ninety-degree edge, a level bubble and a clamping screw in it, which slides on a ruler, or scale. Simply place the scale end on the base surface to be measured and slide the head down to the higher surface being measured keeping the bubble in the center of the glass vial (level). When the head is level and in the position of the desired measurement, turn the locking screw, in the head, to secure the head on the scale, then pick up the machinist square and read the bottom edge of the head against the scale. This instrument can also be used to measure the tread depth.
- To measure pitch, slope or angles, an electronic level is most helpful. It can be placed on a walkway or tread surface to measure the angle of the surface and it can be placed on a handrail or tread nosings to measure the angle of the handrail and stairway and determine if they are parallel. The electronic level can also be placed against the edge of a scale or ruler to insure that the scale is measuring vertical distances.
- To measure distance, a tape measure, rolling wheel measurer or a laser beam ruler can be used. I frequently use the laser beam, but it requires a vertical surface to bounce the beam back to the instrument. It can be very useful for such measurements as stairway widths.
- Measuring radiuses reasonably accurately requires a radius gage.
- Measuring thickness or small distances, I like to use a dial caliper.
- When it comes to measuring slip-resistance, there is still much confusion in the world. The term of interest to us is "slip-resistance" not coefficient of friction. ASTM F-1645-05, Standard Terminology Relating to Safety and Traction for Footwear defines "slip resistance," *n* – 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. Many individuals confuse this with the classic laws of friction, formulated in the 17th century, that the coefficient of friction is the ratio of the normal force acting on a body to the force parallel to the plane of contact between the bodies necessary to move the bodies relative to one another which is described by the equation

$F=\mu N$. These laws are not obeyed by either the materials commonly used as shoe bottoms (tread materials) or by the materials commonly used in today's flooring.

Our area of interest during human ambulation is the ability of the walkway, tread or nosing surface to keep the foot of the pedestrian in place as the pedestrian pushes their body forward or backward. The amount of time that the pedestrian's foot (shoe) is in contact (dwell time) with the walkway surface, the rate and magnitude of the load and time of contact are important factors. In terms of coefficient of friction, we are interested in the static slip-resistance, which is the force that will keep the pedestrian's heel or toe in place as they walk or move. Once the static slip resistance has been exceeded and the pedestrian's foot is slipping, we are not interested in the dynamic slip resistance because it is too late and the accident (slip) is in progress.

One phenomenon, most particularly associated with drag sleds, is the dwell time between the drag sled test surface and the floor test surface. This results in a contact force known as "stiction". Stiction is a combination of mechanical sticking of the two surfaces and the exclusion of air from between the two surfaces something similar to suction. It does not occur in normal ambulation, and therefore will cause readings from a drag sled not related to human ambulation.

A recent paper, "Assessment of Walkway Tribometer Readings in Evaluating Slip Resistance: A Gait-Based Approach, *by Christopher M. Powers, PhD.; John R. Brualt, M.S.; Maria A. Stefanou, M.S.; Yi-Ju Tsai, M.S.; Jim Flynn, P.E.; and Gunter P Siegmund, PhD., P.Eng.* published in the Journal of Forensic Science, March 2007, Vol. 52, No. 2, compared the readings of nine (9) slip-meters on six (6) surfaces [three (3) materials, wet and dry] as to the slipperiness rankings of these materials by human subjects. Their results indicate that the traditional drag sled, both manual and powered, do not reflect the rankings of the human subjects.

There are several instruments, tribometers, which were tested, which accurately measure the slip-resistance of importance to ambulation. One is the English XL, which is gas operated and manufactured, distributed, calibrated and certified by Mr. William English of Alva, Florida. Two others are the Mark II, which is gravity operated and the Mark III, which is spring operated, both are manufactured and distributed by Dr. Robert Brungraber, Slip-Test, Spring Lake, New Jersey. Fourth is the universal walkway tester, manufactured by the National Floor Safety Institute, Southlake, Texas. There are several differences between them, primarily in their size and weight. The English XL is a smaller lightweight tribometer, which utilizes a small carbon dioxide cartridge, such as used in mixed drinks, to actuate the tribometer. The Mark II is a larger and heavier instrument, which utilizes gravity as the force actuating the instrument and the Mark III utilizes a spring to operate the instrument.

The English XL, the Mark II and the Mark III instruments use a strut, which is inclined from the vertical and successively operated at increasing angles from the vertical to determine the greatest angle of the test foot contacting the walkway surface without sliding on the walkway surface. This is the slip resistance of that floor surface. Both instruments can be operated with contaminants on the walkway surface, however careful cleaning and preparation of the test foot is required. The English XL can be operated on non-level surfaces since it is powered by the carbon dioxide gas under pressure. The Mark II must be operated on a level surface, since it relies on gravity to operate.

There are currently several standards on the books relating to walkway and stairway safety. First, most all building codes have requirements relating to stairs and walkways. These should always be reviewed and adhered to in every jurisdiction to which they specifically apply. There are also several general standards, such as ASTM F-1637, Standard Practice for Safe Walking Surfaces. ANSI/ASSE A1264.2, American National Standard for the Provision of Slip Resistance on Walking/Working Surfaces. ANSI A117.1 American National Standard for Buildings and Facilities–Providing Accessibility and Usability for Physically Handicapped People. ASTM F-802, Standard Guide for Selection of Certain Walkway Surfaces When Considering Footwear Traction. ASTM E-303, Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester. ASTM F-1677, Standard Test Method for using a Portable Inclinable Strut Slip Tester (PIAST) [Mark II]. ASTM F-1678, Standard Test Method for using a Portable Articulated Strut Slip Tester (PAST) [Mark I]. ASTM F-1679, Standard Test Method for using a Variable Incidence Tribometer (VIT) [English XL].

As you have noted, there are several different devices, which can be used to measure the slip-resistance of a given surface. An experienced well-trained operator is required to produce consistent, repeatable and reliable test results. However, in my experience in walkway safety, the most important factor is a change in the slip-resistance on the walkway or tread surface, which the pedestrian does not see or realize, and therefore walks onto that different slip-resistance not expecting it, thereby disrupting their gait.

Currently, to my knowledge, only William English has a program for users of the English XL Tribometer whereby he provides instruction and operation to qualified tribometer operators and a certification CXLT (Certified X L Tribometrist) to those who pass the written and practical test.

Summary

The safety professional can insure that the walkway surface and the stairway are safe by insuring that they are constructed in conformance with the applicable building codes and standards. That they have a uniform slip-resistance and are maintained free from foreign substances, which can change the slip-resistance and from obstructions, obstacles or other foreign materials, which can confuse or interfere with the pedestrian’s gait.