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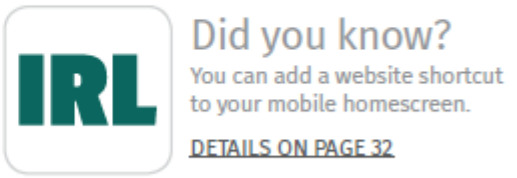

Injuries Resulting From Slips and Trips on a Construction Site

By Angela DiDomenico

The construction industry is one of the largest sectors of the U.S. economy, employing over 6.5 million people in 2016, according to the Bureau of Labor Statistics. Although worksite safety has improved over the years, accidents continue to occur, causing numerous fatalities and injuries to construction workers and the public. According to the Occupational Safety and Health Administration (OSHA), one in five worker deaths in private industry occurs in construction, and falls are the leading cause of death in the construction industry. Many of these fatalities are due to falls from an elevation, such as a ladder or scaffolding. Slips and trips, resulting in falls predominantly on the same level, also occur with a high frequency on a construction site. Slips and trips may result in less severe injuries than falls from elevations, but the frequency of these events make it a critical issue.

Housekeeping on a construction site is paramount to reducing the risk of slips and trips since the work being performed is transient and there is generally a significant amount of materials being stored on the site. For example, slips and trips can occur due to stray tools and materials or uneven ground or holes in the working surface. Unfortunately it is impossible to eliminate all accidents on a construction site, but it is possible to investigate the causal relationship between a claimed injury and an event. Biomechanical research has investigated human gait and determined the mechanisms for many injuries, including those which commonly occur due to slips, trips, and falls.

Slip and Trip Kinematics

The human gait cycle is divided into two separate phases. The period of time when the foot is in contact with the ground is the stance phase and the period of time when the foot is not in contact with the ground is the swing phase. A typical slip and fall event during normal ambulation occurs when the heel of the forward/swing leg contacts the ground surface to begin

stance phase and the foot slides forward due to an inadequate level of available friction. As the leading foot moves forward, the body's center of mass (i.e. torso) moves in a rearward direction towards its boundary of stability. If balance recovery strategies, including reflexive arm responses and the placement of the non-sliding foot behind the slipping foot, are not successful, a rearward fall will occur as the body's center of mass moves rearward beyond its base of support. A typical trip and fall event occurs when the foot, during swing phase, interacts with an obstacle or some structure of the surface that protrudes above the walking surface. The obstacle or structure must have sufficient dimensional attributes to cause a perturbation during ambulation. A trip and fall occurs when the obstacle has sufficient dimensional attributes to impede the forward progress of the lower extremity, causing the body's center of mass to unexpectedly move forward beyond its base of support to an extent that it compromises the body's dynamic equilibrium. During a slip or trip, if balance recovery strategies are not successful, including reflexive arm responses and repositioning of the lower limbs, a fall will occur.

An examination of the movements or kinematics involved in a slip or trip provides an indication of which injuries would likely result from the event. In a slip and fall, it is likely that the posterior (back) aspects of the body will make contact with the ground. Additionally, the hands and shoulders may be susceptible to injury as arm movements are elicited to assist in balance recovery and/or to protect the body during the fall. (Figure 1) In a trip and fall, it is likely that the anterior (front) aspects of the body will make contact with the ground. Similar to a slip event, the hands and shoulders may be susceptible to injury as arm movements are elicited to assist in balance recovery and/or protect the body during the fall. (Figure 2)

Figure 1. Schematic indicating the potential for contact between the ground and the posterior side of the body during a slip and fall event

Figure 2. Schematic indicating the potential for contact between the ground and the anterior side of the body during a trip and fall event

Injury Mechanisms

The relationship between an event and an injury is analyzed by assessing the presence or absence of an injury mechanism. An injury mechanism is the fundamental mechanical process that leads to tissue failure. The scientific community refers to an injury mechanism investigation as a "Failure Analysis." Biomechanical analyses focus on the loads (direction and magnitude) responsible for injury. Loads applied in the proper manner and with sufficient magnitude create the injury mechanism responsible for causation. Without the appropriate injury mechanism, causation between the event and the injury cannot be established and the injury or condition may be due to the normal aging process (i.e. degeneration). Based on the kinematics of each of the events, slip and trip events are typically linked to injuries of the lumbar spine, shoulder, knee and ankle. The injury mechanisms for some typical injuries are described below.

The lumbar spine is comprised of five intervertebral bodies that are separated by intervertebral discs. The injury mechanism for acute intervertebral disc herniation involves a combination of flexion/extension or lateral bending with an application of a sudden compressive load. As described above, rearward fall kinematics associated with a slip event often lead to contact of the posterior aspect of the body with the ground, which may induce a significant compressive load on the lumbar spine. Conversely, the forward fall kinematics associated with a trip event are unlikely to induce significant compressive loads on the lumbar spine.

The rotator cuff is comprised of four muscles that stabilize the shoulder joint and provide the forces required for volitional arm movements. The injury mechanism for acute rotator cuff injury is indirect loading of the shoulder while the arm is abducted. As described above, the fall kinematics for a slip and trip may result in an outstretched arm and loading of the shoulder joint.

The knee is comprised of bones, ligaments, muscles and cartilaginous structures. The cartilaginous structures in the knee joint that typically tear are the medial and lateral menisci. The typical mechanism for a meniscus injury is twisting of the knee while the knee is flexed and weight-bearing. During a slip event, the slipping leg is typically unloaded so the forces on the knee joint would be smaller than those that occur during normal walking. However, knee joint loading of the non-slipping leg would be highly dependent upon the kinematics of the slip event and a biomechanical analysis would be required to determine if the injury mechanism was present for a meniscus injury. After perturbation of the tripping leg, one method for recovering balance is to place the non-tripping leg in front of the body to establish a new base of support. Thus, it is possible for direct loading of the knee joint to occur during attempts to recover balance after a trip and fall event. As with the slip event, a biomechanical analysis would be required to analyze the kinematics in detail to determine if the injury mechanism is present for a meniscus injury.

The ankle is comprised of many bones, and fractures, particularly those of the lateral malleolus, are common during fall events. The injury mechanism for a lateral malleolus fracture is typically loading of the foot during eversion. This movement is commonly linked to rolling the ankle and in minor cases results in a sprained ankle. It is possible for the injury mechanism to be present during a slip and trip event, although a biomechanical analysis would be required to analyze the kinematics in detail.

Summary

Slips, trips, and falls occur on a regular basis on construction sites and in the rest of the world. There are many aspects of a construction site that raise the risk of slips, trips, and falls. Good housekeeping practices and a materials storage plan are two ways to minimize the risk of falls. It is also important for workers to be aware of their surroundings and avoid walking in areas, when possible, that may encompass slip and trip hazards. As described in this article, there are a number of injuries that may occur due to a slip or trip; however, a biomechanical analysis of the fall kinematics can be employed to determine if a specific injury mechanism is present and if a causal link is present between the event and the claimed injury.

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Dr. DiDomenico is a Senior Biomechanist and Certified Professional Ergonomist at ARCCA (a national forensic engineering firm), specializing in the study of human factors, forces and mechanics associated with human injury.

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Dr. DiDomenico's academic and professional experience represents a unique combination of knowledge in slips, trips, and falls, occupational biomechanics, human factors, construction, general worksite safety, live subject kinematic and kinetic testing, and human anatomy. She has published in the areas of postural control, gait analysis, occupational biomechanics, safety, human factors, and ergonomics. Currently, she specializes in slip/trip/fall analysis, construction safety, human factors and ergonomics, and biomechanical and injury causation analysis. She is also involved in accident and mishap investigation involving workplace injuries, ladder safety, falls from scaffolding and the biomechanics of injury, and her work includes site and equipment inspections, applicable code compliance, testing, injury causation and tolerance analysis.