

# THE STATE OF SCIENCE ON OCCUPATIONAL SLIPS, TRIPS AND FALLS ON THE SAME LEVEL

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This paper summarizes the state of science on occupational slips, trips and falls on the same level. The paper is divided by the subject areas in epidemiology, biomechanics, human-centered approaches, tribology and injury prevention and practices. The summary reveals that slips, trips and falls on the same level are complex problems that require multi-disciplinary approaches. Despite the current progress in recent decades in understanding the mechanisms involved, research and prevention practices remain insufficient given the risk. We urgently need to develop systematic approaches to understanding the mechanisms involved, and to evaluate and implement preventive interventions in the field.

## Introduction

Slips, trips and falls (STF) are a serious problem. Substantial losses due to slip, trip and fall injuries are reported worldwide, including Europe and the United States (Buck & Coleman, 1985; Kemmlert & Lundholm, 1998; Communauté Européenne, 2008; Liberty Mutual Research Institute for Safety, 2012; Nenonen, 2013). Data from the Liberty Mutual Workplace Safety Index (Liberty Mutual Research Institute for Safety, 2012) show that the costs for disabling workplace injuries in 2010 due to falls on the same level in the U.S. were estimated to be approximately 8.61 billion US dollars or 16.9% of the total cost burden. The same data also show that the cost of falls on the same level increased by 42.3% between 1998 and 2010 after adjusting for inflation, while the overall costs of disabling workplace injuries decreased 4.7% over the same period. Falls on the same level continue to be a serious problem in occupational injuries.

## Epidemiology

‘Occupational Slips, Trips and Falls on the Same Level’ (OSTF on SL) assumes that the accident genesis lies wholly within the operation of a socio-technical system. The accident process, starting with a slip or a trip, for example, is determined by accident factors related to safety management (Bentley & Haslam, 2001), equipment usage (Kines, 2003), work organisation (Leclercq & Thouy, 2004) or work system design (Derosier *et al.*, 2008). Each factor revealed by analysis of an accident, notwithstanding its positioning in the accident genesis, is necessary to its occurrence and, therefore, represents a possible lever for its

prevention. Studies of OSTF on SL involve focusing analysis either on the accident process close to the injury event, without referring to the whole socio-technical system involved, or on factors more further upstream in the accident genesis. In the latter case, the identified accident factors are often specific to the activities or organisations, as revealed by the OSTF on SL studies conducted in specific areas of activity.

The notion of same level leads to at least excluding falls from heights. However, this notion is not operationally defined. This would suppose answering the question ‘What set of accidents is it coherent to consider from the occupational safety standpoint?’ Lortie and Rizzo (1999) proposed a categorisation for all loss of balance accidents. Based on a similar wish to embrace the diversity of occupational accidents, Leclercq *et al.* (2010) proposed an operational definition for a set of so-called ‘accidents with movement disturbance’. While accurate distinction of ‘slipping’ or ‘tripping’ events is effectively necessary in the case of prevention that focuses on such events, it may be helpful to consider a larger set of accidents sharing explanatory factors within the framework of a systemic approach.

Whatever the set of accidents considered, the importance of the issue represented by OSTF on SL prevention is indisputable. The European Commission report (Communauté Européenne, 2008) effectively shows that 19% of the 3,983,881 non-fatal accidents at work, which led to more than 3 days lost in 2005, were either slips or trips with a fall on the same level or when walking heavily, or else slips or missteps with no fall. The data from Bureau of Labor Statistics (BLS, 2012) show that, among 1,181,290 non-fatal occupational accidents and diseases recorded at private companies and government agencies in the USA in 2011, 15.5% were falls on the same level and 4.1% were slips or trips with no fall, causing a median number of 10 days lost.

All workers are exposed to the risk of an OSTF on SL since this risk can manifest itself when walking at work. The floor characteristics and the movement disturbance energy are enough to cause an injury in the event of a fall on the floor. Walking is a feature of many accident-causing situations, but loss-of-balance occurrences are also very frequent during materials handling operations (Manning *et al.*, 1984). While all employees are exposed to this risk, in-company activity sectors and their workers are not equally affected by these accidents (Buck & Coleman, 1985; Leclercq *et al.*, 2004).

Findings of several studies investigating the relationship between age and OSTF on SL are sometimes contradictory (Buck & Coleman, 1985; Kemmlert & Lundholm, 1998; Bentley & Haslam, 1998; Leclercq *et al.*, 2004). This could be explained notably by the scale of the study, i.e. the more or less integration of the variability in occupational situations.

Thus, knowledge of the activity sector, occupation or age can lead to formulating hypotheses concerning factors influencing OSTF on SL. However, they are insufficient for developing in-company operational prevention strategies. Conditions in which tasks or, more generally, movements, are performed at work, must be considered in order to explain the differences in OSTF on SL occurrence from one work situation to another.

## **Biomechanics**

Human bipedal locomotion (walking) provides a challenging balance task to the central nervous system (CNS). During a single support period which accounts for 80% of a gait cycle, the body is in a continuous state of falling down because the body’s center of mass is outside the foot, the base of support (Perry, 1992). The only way that recovery is achieved is to position the swing limb so that during double support the CNS can make any re-balancing adjustments. As such, stability is lost and recovered in a gait cycle during normal walking. This recovery is a challenging balance task which requires complex interplay of neural and motor control mechanisms. Motor control is directly linked to the central nervous system’s processing of sensory inputs (vision, vestibular and proprioceptive systems). The sensory systems send inputs to the CNS to make an adjustment in real time. In essence, we use the inverse pendulum model to modify our walking behavior. Additionally, the internal model is used to predict and adapt

into the next step. It is clear that 'EXPECTANCY' is required to walk safely. There will be a motion perturbation if expectation and reality do not match. If not controlled, this perturbation could grow into miss-steps, slips, trips, and falls. Extrinsic and intrinsic factors that can contribute to fall-related injuries are outlined by Gauchard *et al.* (2001).

### *Slips*

Falls initiated by slips are the most prevalent level floor accidents (Courtney *et al.*, 2001). A slip occurs at the shoe and floor interface when the friction required to support human walking exceeds the friction available at the shoe and floor interface.

To reduce slip and fall incidents, steps can be taken to improve identification of individuals prone to have this type of incident and the related risk factors such as anticipation, available coefficient of friction, and human reaction to a slip event. Furthermore, fall prevention training programs using the 'kinetic learning' principle and a slip-simulator facilitated safety training and reduction of falls in the workplace (Lockhart, 2010).

Historically, most of the literature on the biomechanical aspects of slips has investigated human responses to unexpected contamination on floor surfaces. Some of the research focus was on kinematic measurements related to human slips before a slip incident and bodily responses to a slip event. Parameters measured included displacements, velocities and body part positions. For kinematics before a slip event, research focused on identifying parameters associated with the required friction coefficient measured (Kim *et al.*, 2005) or slip outcomes (Moyer *et al.*, 2006). More recently, accelerations and joint moments calculated from the kinematic measurements have been shown to be promising parameters (Beschoner & Cham, 2008). Whole body responses to a slip incident were summarized by Cham *et al.* (2007).

More recently, nonlinear dynamics was used to investigate walking stability measured with accelerometers on a treadmill (Liu & Lockhart, 2007). Body movements for several consecutive steps were analyzed to quantify variations in the temporal domain. The maximum Lyapunov exponent was identified as a measurement of stability.

### *Trips*

Statistical distributions of the minimum foot clearance during mid-swing of repeated walking of the same participant were investigated by Begg *et al.* (2007) and the probability of a trip event at different obstacle heights could be calculated from the statistical distributions.

For trips that occurred in early swing and late swing phases, common responses were an elevating strategy of the swing limb to clear the obstacle and a lowering strategy to shorten the step length, respectively (Eng *et al.*, 1994). The results from Grabiner *et al.* (1993), Owings *et al.* (2001) and Pijnappels *et al.* (2005) indicate that a recovery from a trip depended on factors such as the lower extremity muscular power, ability to restore control of the flexing trunk, reaction time, step length and walking speed. Strength training for the lower limbs might help reduce fall risk.

## **Human-centered approaches**

Human-centered approaches include the psychophysical and organizational. Psychophysics involves perception of slipperiness with visual and tactile cues, while organizational approaches could include macroergonomics and safety climate.

### *Perception of slipperiness*

Perceptions, based on factors such as visual cues and proprioceptive feedback, can be used to assess slipperiness and can supplement objective measurements of slipperiness. When potentially hazardous conditions are perceived through visual and tactile sensation, or are expected to exist in a walking person's perceptual field, walking gait is adjusted accordingly (Capellini *et al.*, 2010).

The visual field is an important psychophysiological parameter involved in gait regulation.

Studies of the human visual mechanism have indicated that only a small part of the effective visual field is attended to. Therefore, if a slippery condition is not detected within one's effective visual field (usually 10-15 feet ahead), the likelihood of fall accidents is significantly increased (Zohar, 1978). Visual control of locomotion has been classified into both avoidance and accommodation strategies (Patla, 1991).

Joh *et al.* (2006) reported that people rely on 'shine' information in forming judgments of slipperiness despite variations as a function of surface color, viewing distance, and lighting conditions. Lesch *et al.* (2008) found perceived 'reflectiveness' to be the strongest predictor of visually-based ratings of perceived slipperiness, but that visually-based judgments of texture and traction were also highly predictive of perceived slipperiness.

Perceived slipperiness can be quantified on a psychophysical scale using foot movement or postural instability as the physical stimulus. One is often not fully aware of the slip between the footwear and the floor on contaminated surfaces, and even on dry non-slippery surfaces, in the very beginning of the heel contact during walking (Perkins, 1978). The results reported by Leamon and Li (1990) indicated that any slip distance less than three cm would be detected in only 50% of the occasions, and that a slip distance in excess of three cm would be perceived as a slippery condition.

Objective measures of slipperiness include kinematic measurements of gait and may also include ground reaction forces obtained with force plates. Results of subjective rating or ranking have been correlated with the static or dynamic coefficient of friction (COF) and slip distance as summarized by Chang *et al.* (2008). The results from Cohen and Cohen (1994) showed that the sense of touch by bare feet, under the conditions of the study, agreed best with the measured ACOF compared with that of seeing the tiles and hearing fingernails dragging across them.

### *Organization approaches*

The roles of macroergonomics in reducing slip, trip and fall incidents were outlined by Maynard and Robertson (2007) who proposed a continuum based on socio-technical system approaches. Key elements in this continuum included management leadership, education and training, hazard surveillance, floor slipperiness assessment, incident and injury reports, floor surface selection, floor surface treatments, mats, housekeeping and maintenance, warning signs and instructions, and slip-resistant footwear.

Safety climate, which is a multilevel factor, is defined as employees' shared perceptions of their organization's safety policies, procedures, and practices regarding the relative value and importance of safety (Zohar, 2003). Safety climate has been demonstrated to predict safety behavior and safety-related outcomes, such as incidents and injuries, in the workplace and could be related to workers' perceptions of injury risk (Huang *et al.*, 2007; Mearns & Flin, 1996). Safety climate has been linked to overall injury outcomes in general, but not to particular injury types. However, Kaskutas *et al.* (2010) reported that safer work climate scores had significant links with safer crew behavior scores and fall injuries.

## **Tribology**

Correlation between the level of friction and subjective perception of slipperiness was shown to be statistically significant as summarized by Chang *et al.* (2006). The potential for slip and fall incidents can be increased by local variations in friction due to unexpectedly encountering an abrupt reduction in friction across floor surfaces (Strandberg, 1985). Chang *et al.* (2008) reported that two friction reduction variables evaluated could have a slightly better correlation with the perception rating score than the mean COF of each working area based on the results obtained from a field study.

Surface texture of nominally flat floors and shoe surfaces has been shown to influence friction at the shoe and floor interface under liquid contaminated conditions (Chang *et al.*, 2001b). Surface roughness and waviness parameters that had strong correlations with the

measured friction were identified (Chang *et al.*, 2004).

Tread patterns on shoe surfaces also affect friction, especially when surfaces are contaminated with solid particles or liquid. SATRA published guidelines, without supporting scientific data, for selecting proper tread patterns on shoe soles (Wilson, 1990). The results obtained by Li and Chen (2005) and Li *et al.* (2006) showed that the measured COF was significantly affected by the tread depth, width and orientation.

Wear development and characteristics of shoe and floor surfaces remains a critical issue. Kim *et al.* (2001) reported that progressive wear on the shoe sole was initiated by plowing, which was followed by simultaneous plowing and abrasion.

Although human movements during slip incidents have been reported in the literature (Perkins, 1978), when slip measurement devices to measure various types of friction at the shoe and floor interface were constructed, design and reproducibility issues necessitated some simplifications in shoe movements. More drastic simplifications were made with portable slipmeters than with laboratory-based devices due to constraints of weight and portability. These simplifications resulted in significant differences in the results measured with various devices. The measurement conditions of these devices are still far from perfect and are inconsistent across various devices (Chang *et al.*, 2001a).

Friction modelling has been widely used in tribology. Beschoner *et al.* (2009) developed a friction model for steady sliding between the shoe and floor interface and their results were confirmed by experimental data.

Scientific investigations on the operating protocols and performance of slipmeters focused on surfaces with liquid contaminants. Solid contaminants such as sand, sugar or flour particles are an understudied potential slip hazard. Friction measurement on surfaces covered with sand particles was investigated by Li *et al.* (2007).

A statistical model was introduced by Chang (2004) to estimate the probability of slip incidents by comparing the stochastic distributions of the required and available friction coefficients. In contrast to typical biomechanical experiments in which human participants are asked to walk on a walkway on which a section is covered with contaminants, this statistical model is an alternative way to investigate slip incidents when unexpectedly encountering a low friction coefficient area with a reduced gait bias. With this approach, human participants walk on only dry surfaces for the required coefficient of friction measurements, and the available friction coefficient is measured with a slipmeter.

Floor cleaning has received very little attention despite the efforts by Underwood (1991) and Quirion *et al.* (2008). Underwood (1991) developed a procedure to produce realistically fouled tiles in a laboratory environment with which cleaning procedures and products could be evaluated. Cleaning procedures observed at work sites were used to evaluate their effectiveness on different quarry tiles and porcelain tiles in a laboratory environment by Quirion *et al.* (2008) and improved procedures were identified.

## **Injury prevention and practices**

The causes of occupational falls on the same level are well understood, but fall and injury prevention is another matter. Attention has been given in the literature to specific hazards and controlling of risks. For example, the use of proper slip-resistant footwear and floor surfaces can increase the friction at the foot-floor interface (e.g. Aschan *et al.* 2009; Verma *et al.* 2011). There remain notable gaps in our knowledge on occupational falls prevention. For example, knowledge about floor cleaning, the level and character of lighting, and the effectiveness of training, education and improved awareness to reduce fall related injuries is underdeveloped. Moreover, only limited research has adopted an ergonomics systems approach that addresses the ‘...important latent failures or the upstream organisational and cultural contexts within which workplace STF occur’ (Bentley, 2009). Another, perhaps surprising, aspect is the paucity of prospective studies and evaluated occupational fall prevention intervention programs.

For occupational falls, however, our evidence base of evaluated, multi-factorial



interventions is formed of the sole, important study by Bell *et al.* (2008) who applied a comprehensive package of interventions to three hospitals in the United States which were based on analysis of the historical accident reporting data and on-site risk assessment. Their results showed that the overall workers compensation STF injury claims rate for the hospitals declined more than 50% during the post-intervention time period. A major success of the intervention showed that a comprehensive and sustained intervention can have a major effect in reducing occupational fall-related injuries. However, the study was unable to reveal the relative effect or interdependency of the intervention components.

Without evidence from evaluated interventions, a structured risk management approach to occupational falls reduction is needed with three overarching components: primary prevention, residual risk reduction, and measures to maximise individual capability (Haslam & Stubbs, 2006).

### *Primary prevention*

The purpose of primary prevention is to eliminate fall hazards at source, through the design of the built environment and work/activity systems. Flooring should offer appropriate slip resistance for the different conditions. Walkways and walking areas should be designed and constructed to avoid trip hazards. In addition, primary prevention involves attention to the equipment used (e.g. to avoid spillages and other walkway contamination), the manner in which equipment is arranged and stored, the tasks workers need to perform, and the extent to which each of these might affect the risk of falling. Provision of sufficient, accessible storage is a measure to reduce trip hazards. The provision of sufficient lighting is important to allow monitoring of the walking surface. Walking surfaces and pathways will need to be properly designed and installed, then cleaned and maintained. In addition, installations should be durable and resistant to damage.

### *Risk reduction*

Even with primary prevention, fall hazards will still be present in the environment. Risk reduction aims to reduce the likelihood of injuries arising from these hazards. An important starting point is to raise awareness of the problem and, through education, promote understanding of risk factors for falling and how they can be improved with proactive risk assessment and management.

It is important that adequate procedures are implemented to detect slip or trip hazards and to remedy the situation. During the floor cleaning process, fall hazards might be introduced. Routine inspection programs should be arranged for walking areas. In all cases, housekeeping procedures should be designed to be sustainable, so that initial good practices do not deteriorate.

Where fall hazards cannot be removed immediately, signage warning of a slip risk should be used. Both carrying items and hurrying should be discouraged in circumstances where other fall risk factors are present. Poor weather with ice or snow is frequently accompanied by an increase of falls, unless appropriate precautions have been taken.

### *Maximise capability*

A third strand of the fall prevention process is to maximise individual ability to negotiate the workplace environment. Use of footwear commensurate with underfoot conditions is a measure that can reduce slipping. Protective clothing, such as respirators and hearing protection, can restrict movement and cause sensory impairment. Protective eyewear can distort vision. Thus, consideration needs to be given to safety from falls when specifying and managing the use of workplace apparel.

Promoting regular eyesight testing among workers, along with encouragement to use spectacles appropriately, could reduce the risk of falling. Encouraging exercise can help improve balance. Certain medications that may be prescribed for individual workers for health conditions can cause drowsiness, dizziness, unsteadiness and blurred vision, all undesirable from a falls prevention perspective. Tiredness, as may arise among shiftworkers, can affect concentration and attention. Although the effects of alcohol on coordination and balance are

well known, there is a particular need to avoid the existence of fall hazards in workplace locations where alcohol is consumed regularly (e.g. in bars and clubs).

## Conclusions

This paper summarized the state of science on occupational slips, trips and falls on the same level. The summary revealed the complexity of these problems that would require multi-disciplinary system approaches. Despite the current research progress in recent decades, we still urgently need to develop systematic approaches to understanding the mechanisms involved, and to evaluate and implement preventive interventions in the field.

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