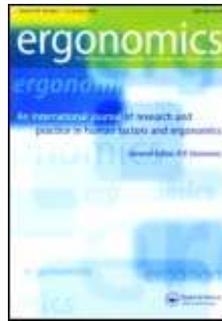


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K. Beschorner; R. Cham. *Impact of joint torques on heel acceleration at heel contact, a contributor to slips and falls.* S. 1799–1813.

Slips/falls are a health burden in the workplace. Previous research has implied a relationship between foot dynamics at heel contact and slips/falls; however, heel acceleration has received little attention. Heel acceleration as the heel contacts the ground is the result of the combined effort of the leg joint torques to control motion of the foot. This study aims to examine the association of heel acceleration with fall risk, and explore the main joint torque determinant of heel acceleration at contact. Sixteen young and eleven older adults walked on known dry floors and in slippery environments expected to be dry. Heel acceleration at heel contact in the direction of motion, i.e. anterior/posterior, was compared between slip-recovery and slip-fall outcomes. Results showed that subjects that recovered contacted the floor with a greater heel deceleration ($p < 0.05$) than fall subjects. Knee torque alone explained 76% of the heel acceleration variability ($p < 0.01$). These data suggest that walking with reduced knee flexion torque at heel contact results in a reduced heel deceleration, a potential risk factor for slip-initiated falls.

- **Keywords:** slips; falls; gait; joint torque; heel dynamics

Sharon S. Chiou; Christopher S. Pan; Amit Bhattacharya. *Kinematics and kinetics of gait on stilts : identification of risk factors associated with construction stilt use.* S. 1814–1829.

This study investigated kinematics and kinetic strategies and identified risk factors associated with gait on stilts. A six-camera motion-analysis system and two force platforms were used to test 20 construction workers for straight walking or turning, with or without carrying tools while wearing safety shoes or stilts at different heights. The results indicated that gait on stilts is characterised by increases in stride length, step width and the percentage of double support period, decreases in cadence, minimum foot clearance and a weaker heel-strike and push-off. Stilts place greater joint loadings on lower extremities to compensate for the added weight and limitation in joint mobility. Smaller foot clearances found for gait on stilts constitute an increased risk for tripping over obstacles. Workers may need to avoid prolonged use of stilts to alleviate stresses on the joints. This study was conducted to determine to what extent stilts alter the gait strategies and to explain the compensatory movements. Prior to this study, there has been little substantive research to evaluate the stresses and potential injuries associated with stilts.

- **Keywords:** gait; stilts; construction; balance; tripping

Daniel Tik-Pui Fong; Youlian Hong; Jing-Xian Li. *Lower extremity preventive measures for slips - joint moments and myoelectric analysis*. S. 1830–1846.

This study investigated the lower extremity preventive measures for slips on simulated slippery surfaces in construction worksites. A total of 15 harnessed Chinese males walked without slips on a 5-m walkway in 16 simulated conditions 10 times at their natural cadence. Joint moments were calculated from kinetics, kinematics and anthropometric data recorded from a force plate, a Novel Pedar system and a motion analysis system. Data were evaluated from footstrike to mid-stance at 10%-stance intervals. Electromyography signals from tibialis anterior, gastrocnemius, rectus femoris and biceps femoris in one stride were evaluated in four phases, including early/late stance and swing. Results showed that lower extremity preventive measures for slips included prolonged ankle plantar flexion moments from 25% to 92% stance, increased ankle plantar flexion moments from 30% stance to mid-stance, and diminished knee extension moments from 10% to 30% stance. Higher activity of rectus femoris and gastrocnemius were found in the late stance and the swing phase respectively.

- **Keywords:** electromyography; kinetics; biomechanics; slips and falls; fall prevention; joint torque

Jeremy James Houser; Leslie Decker; Nicholas Stergiou. *Stepping over obstacles of different heights and varied shoe traction alter the kinetic strategies of the leading limb*. S. 1847–1859.

This study aims to investigate the effects of shoe traction and obstacle height on friction during walking to better understand the mechanisms required to avoid slippage following obstacle clearance. Ten male subjects walked at a self-selected pace during eight different conditions: four obstacle heights (0%, 10%, 20% and 40% of limb length) while wearing two different pairs of shoes (low and high traction). Frictional forces were calculated from the ground reaction forces following obstacle clearance, which were sampled with a Kistler platform at 960 Hz. All frictional peaks increased with increases in obstacle height. Low traction shoes yielded smaller peaks than high traction shoes. The transition from braking to propulsion occurred sooner due to altered control strategies with increased obstacle height. Collectively, these results provided insights into kinetic strategies of leading limb when confronted with low traction and high obstacle environments. This study provides valuable information into the adaptations used to reduce the potential of slips/falls when confronted with environments characterised by low shoe-floor friction and obstacles. It also provides the necessary foundation to explore the combined effects of shoe traction and obstacle clearance in elderly people, more sensitive to slippage.

- **Keywords:** shoe traction; gait kinetics; obstacle clearance; slip and fall

Thurmon E. Lockhart; Jian Liu. *Differentiating fall-prone and healthy adults using local dynamic stability*. S. 1860–1872.

Variability in kinematic and spatio-temporal gait parameters has long been equated with stability and used to differentiate fallers from non-fallers. Recently, a mathematically rigorous measure of local dynamic stability has been proposed based on the non-linear dynamics theory to differentiate fallers from non-fallers. This study investigated whether the assessment of local dynamic stability can identify fall-prone elderly individuals who were unable to successfully avoid slip-induced falls. Five healthy young, four healthy elderly and four fall-prone elderly individuals participated in a walking experiment. Local dynamic stability was quantified by the maximum Lyapunov exponent. The fall-prone elderly were found to exhibit significantly lower local dynamic stability (i.e. greater

sensitivity to local perturbations), as compared to their healthy counterparts. In addition to providing evidence that the increased falls of the elderly may be due to the inability to attenuate/control stride-to-stride disturbances during locomotion, the current study proposed the opportunity of using local dynamic stability as a potential indicator of risk of falling. Early identification of individuals with a higher risk of falling is important for effective fall prevention. The findings from this study suggest that local dynamic stability may be used as a potential fall predictor to differentiate fall-prone adults.

- **Keywords:** local dynamic stability; falls; gait; risk assessment; slips and falls; locomotion; elderly falls; fall accidents

Prakriti Parijat; Thurmon E. Lockhart. *Effects of lower extremity muscle fatigue on the outcomes of slip-induced falls. S. 1873–1884.*

Slip-induced fall accidents continue to be a significant cause of fatal injuries and economic losses. Identifying the risk factors causing slip-induced falls is key to developing better preventive measures to reduce fall accidents. Although epidemiological studies suggest localised muscle fatigue may be one of the risk factors for slip-induced falls, there has been no documented biomechanical study examining the relationship between fatigue and fall accidents. As such, the overall objective of the current study was to investigate the effects of localised muscle fatigue of the quadriceps on the slip initiation and slip recovery phases of slip-induced falls. Sixteen healthy, young participants were recruited to walk across a vinyl floor surface in two different sessions (fatigue and no fatigue). Kinematic and kinetic data were collected using a 3-D motion analysis system and force plates during both sessions. Results suggest that localised muscle fatigue of the quadriceps affected various kinematic and kinetic gait variables that are linked with a higher risk of slip-induced falls. Additionally, the results indicated that localised muscle fatigue of the knee extensor muscle caused a delayed response in producing an effective joint moment and base of support using the trailing limb to recover from a fall. The findings from this study indicate that localised muscle fatigue is a potential risk factor causing slip-induced falls.

- **Keywords:** localised muscle fatigue; locomotion; fall accidents; slips and falls

Peter Simeonov; Hongwei Hsiao; John Powers; Douglas Ammons; Alfred Amendola; Tsui-Ying Kau; Douglas Cantis. *Footwear effects on walking balance at elevation. S. 1885–1905.*

The study evaluated the effects of shoe style on workers' instability during walking at elevation. Twenty-four construction workers performed walking tasks on roof planks in a surround-screen virtual reality system, which simulated a residential roof environment. Three common athletic and three work shoe styles were tested on wide, narrow and tilted planks on a simulated roof and on an unrestricted surface at simulated ground. Dependent variables included lateral angular velocities of the trunk and the rear foot, as well as the workers' rated perceptions of instability. The results demonstrated that shoe style significantly affected workers walking instability at elevated work environments. The results highlighted two major shoe-design pathways for improving walking balance at elevation: enhancing rear foot motion control; and improving ankle proprioception. This study also outlined some of the challenges in optimal shoe selection and specific shoe-design needs for improved walking stability during roof work. The study adds to the knowledge in the area of balance control, by emphasising the role of footwear as a critical human-support surface interface during work on narrow surfaces at height. The results can be used for footwear selection and improvements to reduce risk of falls from elevation.

- **Keywords:** virtual reality; height; walking balance; footwear; construction; roof

Evaluation of a comprehensive slip, trip and fall prevention programme for hospital employees. S. 1906–1925.

In 2007, the Bureau of Labor Statistics reported that the incidence rate of lost workday injuries from slips, trips and falls (STFs) on the same level in hospitals was 35.2 per 10,000 full-time equivalents (FTE), which was 75% greater than the average rate for all other private industries combined (20.2 per 10,000 FTEs). The objectives of this 10-year (1996-2005) longitudinal study were to: 1) describe occupational STF injury events in hospitals; 2) evaluate the effectiveness of a comprehensive programme for reducing STF incidents among hospital employees. The comprehensive prevention programme included analysis of injury records to identify common causes of STFs, on-site hazard assessments, changes to housekeeping procedures and products, introduction of STF preventive products and procedures, general awareness campaigns, programmes for external ice and snow removal, flooring changes and slip-resistant footwear for certain employee subgroups. The hospitals' total STF workers' compensation claims rate declined by 58% from the pre-intervention (1996-1999) rate of 1.66 claims per 100 FTE to the post-intervention (2003-2005) time period rate of 0.76 claims per 100 FTE (adjusted rate ratio = 0.42, 95% CI: 0.33-0.54). STFs due to liquid contamination (water, fluid, slippery, greasy and slick spots) were the most common cause (24%) of STF claims for the entire study period 1996-2005. Food services, transport/emergency medical service and housekeeping staff were at highest risk of a STF claim in the hospital environment. Nursing and office administrative staff generated the largest numbers of STF claims. STF injury events in hospitals have a myriad of causes and the work conditions in hospitals are diverse. This research provides evidence that implementation of a broad-scale prevention programme can significantly reduce STF injury claims. Preliminary results from this study were previously presented in brief at the 2007 IEA International Conference on Slips, Trips and Falls.

- **Keywords:** injury epidemiology; slips; trips; falls; healthcare workers

C. Derosier; S. Leclercq; P. Rabardel; P. Langa. Studying work practices : a key factor in understanding accidents on the level triggered by a balance disturbance. S. 1926–1943.

Accidents on the level (AOL) rank second amongst the most numerous and serious occupational accidents with days lost in France and are a major health and safety problem in every sector of activity. The case study described in this paper was conducted at a metallurgical company with 300 employees. The aims of this work were dual: 1) to extend the general knowledge required for preventing these accidents; 2) to propose prevention measures to this company. Existing data on company occupational accidents were gathered and analysed to identify a work situation that appeared likely to cause AOL. This work situation was analysed in detail. Several risk factors were identified within this work situation, by way of interviews with 12 operators. These risk factors concerned various dimensions of the work situation, particularly its physical dimension (e.g. templates structure) and organisational dimension (e.g. parts availability). Interviews were conducted, focusing on risk factors perceived by operators and involving all-confrontations based on accounts of four AOL occurring in this situation. All-confrontations were interviews confronting operators with a risk occupational situation that was accidental for one of their colleagues, the latter being absent from the interview. Results highlighted the fact that the work practices implemented are key factors in understanding these accidents. This study underlines the role of work practices in AOL causality and prevention. It also provides explanations associated with various work situation dimensions involving adoption of more or less safe work practices. AOL are serious and frequent in occupational situations. Injury claims analysis and interviews in an industrial company emphasise the specific characteristics of an occupational situation and of prevention actions forming the basis of an intervention. The need for a better understanding of factors affecting work practice is highlighted in relation to

research.

- **Keywords:** injury prevention; occupational accident; accident on the level; slips, trips and falls; accident analysis; work practices

Tiina E. A. Slip, trip and fall injuries in potato, sugar beet and open field vegetable production in Finland. S. 1944–1959.

STF injuries are common in agriculture. The purposes of this study were to assess the magnitude of STF injuries, to identify contributing factors and to propose preventive actions to reduce injuries in potato, sugar beet and open field vegetable production in Finland. The material consisted of 1648 injury claim records and 22 interviews. The analysis showed 45% (n = 740) of the non-fatal injuries were STFs or jumps. Phrase analysis of injury descriptions provided further insight into the characteristics of STF injuries. The current findings suggest interventions should focus on making access paths (e.g. stairs, ladders, platforms) safer, minimising the need for mounting and dismounting equipment, decreasing manual material handling, improving contamination control and housekeeping in working areas and improving the safety of traffic areas and farmyards.

- **Keywords:** slip, trip and fall injuries; agriculture; horticulture; phrase analysis

Santosh K. Verma; David A. Lombardi; Wen-Ruey Chang; Theodore K. Courtney; Melanye J. Brennan. A matched case-control study of circumstances of occupational same-level falls and risk of wrist, ankle and hip fracture in women over 45 years of age. S. 1960–1972.

This study examined the association between circumstances of occupational same-level falls and the risk of wrist, ankle and hip fracture in women over 45 years of age. Cases of fractures and matched controls who suffered non-fracture injuries, all from same-level falls, were selected from workers' compensation claims data. Cases and controls were matched on age, season of fall, industry and state. Information was obtained about manual material handling, fall hazard, initiating event and fall location. Falls during pushing/pulling were associated with increased wrist fracture risk. Falls due to tripping were associated with increased wrist fracture risk, but decreased risk of ankle fracture. Falling outdoors was associated with increased wrist and ankle fracture risk. Increasing age was associated with increased injury risk from tripping-initiated vs. slipping-initiated falls. Few circumstances increased risk of fracture at multiple sites, indicating that they affect risk of fracture by primarily affecting point of impact. The proportion of female workers over 45 years of age, who are at increased risk of fracture, is increasing in developed countries. This study examined the associations between circumstances of falls and wrist, ankle and hip fracture risks among these workers and found that the associations differed by fracture sites.

- **Keywords:** falls; fracture; women; manual material handling; ageing

Mary F. Lesch; Wen-Ruey Chang; Chien-Chi Chang. Visually based perceptions of slipperiness : underlying cues, consistency and relationship to coefficient of friction. S. 1973–1983.

If walkers can anticipate surface conditions, they can adjust their gait to help reduce the risk of a slip. This study investigated visual cues to slipperiness. Thirty-one participants made visually based judgements about 37 different floor surfaces. These judgements included ratings of slipperiness, reflectiveness, texture, traction, light/dark, likelihood of slipping, cautious intent as well as relative slipperiness. Correlational and regression analyses indicated that while reflectiveness is the predominant visual cue in forming judgements of slipperiness ($r = 0.73$; $p < 0.05$), texture and traction were also highly correlated with perceived slipperiness. Furthermore, participants were consistent in

slipperiness judgements over time ($r = 0.76$; $p < 0.05$) and response measures and a significant relationship was observed between visual cues and coefficient of friction (COF) (r ranged from 0.16 to 0.58; all $p < 0.05$). Subjective ratings and measured COF, taken as a composite measure of slipperiness, may provide safety professionals with an improved indicator of 'higher risk' surface conditions. The results indicate that people rely on visual cues to judge slipperiness, that they do so consistently and that subjective ratings are related to measured COF. These results have implications for the measurement of slipperiness as well as the design of floor surfaces to be protective against slips and falls.

- **Keywords:** perceived slipperiness; visual cues; coefficient of friction; slips

Wen-Ruey Chang; Mary F. Lesch; Chien-Chi Chang. *The effect of contact area on friction measured with the portable inclinable articulated strut slip tester (PIAST)*. S. 1984–1997.

A portable inclinable articulated strut slip tester (PIAST) measures friction at the shoe and floor interface. The squeeze-film effect with the PIAST is excessive in representing a human strike. The goal of this study was to investigate the effect of the contact area size on friction for reducing the squeeze-film effect. The footwear pad area of this slip meter was sequentially reduced from 7.62 cm square to 2.54 cm square. Five walkways were constructed. Friction was measured on each walkway under three surface conditions. Thirty-five participants rated their perceptions of slipperiness. The results indicated that the friction increased and plateaued as the size of the contact area was reduced. The effect of the pad size on the friction coefficient was statistically significant. The correlation coefficients between the friction and perception rating did not give a clear indication of what pad size might have a better correlation with human perception. Friction measurement at the shoe and floor interface is a critical issue in assessing potential interventions and identifying potentially dangerous locations for slip and fall incidents. This paper addresses a potential improvement in measuring friction on liquid-contaminated floor surfaces.

- **Keywords:** contact area; squeeze-film effect; PIAST

Wen-Ruey Chang; Kai Way Li; Alfred Filiaggi; Yueng-Hsiang Huang; Theodore K. Courtney. *Friction variation in common working areas of fast-food restaurants in the USA*. S. 1998–2012.

Friction variation has been related to employees' perception of slipperiness in a field study conducted in fast-food restaurants. However, details of friction variation in actual workplaces have not been reported in the literature. This field study investigated friction variations in 10 fast-food restaurants in the USA. The results indicated that friction reductions in a step exceeding 10% were proportional to the ages of the floor tiles in most restaurants. There were more friction reductions exceeding 10% in the sink areas than the other five areas measured, but all the areas had more than 10% friction reductions in at least one of the restaurants. As expected, significant relative friction reductions are common on older floors. A small portion of the newer tiles had significant relative friction reductions, despite their overall higher friction levels. Therefore, slip and fall preventions should not be overlooked in restaurants with newer floors. Friction variation is speculated to be a significant contributor to slip and fall incidents. However, friction variation has not been quantified in the literature. Understanding of potential friction variations in field environments helps identify potential issues for interventions. This field study investigated friction variations in fast-food restaurants in the USA.

- **Keywords:** slip and fall incidents; friction measurement; friction variation; fast-food restaurants

F. Quirion; P. Poirier; P. Lehane. *Improving the cleaning procedure to make kitchen floors less slippery*. S. 2013–2029.

This investigation shows that, in most cases, the floor cleaning procedure of typical restaurants could be improved, resulting in a better cleaning efficiency and a better floor friction. This simple approach could help reduce slips and falls in the workplace. Food safety officers visited ten European style restaurants in the London Borough of Bromley (UK) to identify their floor cleaning procedure in terms of the cleaning method, the concentration and type of floor cleaner and the temperature of the wash water. For all 10 restaurants visited, the cleaning method was damp mopping. Degreasers were used in three sites while neutral floor cleaners were used in seven sites. Typically, the degreasers were over diluted and the neutrals were overdosed. The wash water temperature ranged from 10 to 72°C. The on-site cleaning procedures were repeated in the laboratory for the removal of olive oil from new and sealed quarry tiles, fouled and worn quarry tiles and new porcelain tiles. It is found that in 24 out of 30 cases, cleaning efficiency can be improved by simple changes in the floor cleaning procedure and that these changes result in a significant improvement of the floor friction. The nature of the improved floor cleaning procedure depends on the flooring type. New and properly sealed flooring tiles can be cleaned using damp mopping with a degreaser diluted as recommended by the manufacturer in warm or hot water (24 to 50°C). But as the tiles become worn and fouled, a more aggressive floor cleaning is required such as two-step mopping with a degreaser diluted as recommended by the manufacturer in warm water (24°C).

- **Keywords:** fat; floor cleaner; friction; oil coverage