2010 International Conference on Fall Prevention and Protection

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Research and Practice for Fall Injury Control in the Workplace:

Proceedings of International Conference on Fall Prevention and Protection

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Foreword

Falls represent a serious hazard to workers in many industries. Workers who perform tasks at elevation—workers in the construction, structural metal working, and tree trimming industries, for example—are at risk of falls from heights, with frequently grave or even fatal consequences. Many more workers, in nearly every industry, are subject to falls to floors, walkways or ground surfaces. These falls, characterized as fall on the same level, are responsible for well over half of nonfatal injuries that result in days away from work.

The etiology of falls as injury-producing events is multi-factorial, and encompasses multiple mechanisms of exposure. Working at heights involves completely different fall risks than those found on workplace surfaces and floors. The different exposures represent serious safety risks in both cases, resulting in fatal and serious nonfatal injury. To address the various causes of multi-factorial events such as these, there needs to be wide-ranging and multidisciplinary injury-mitigation approaches provided to practitioners based on a wide variety of research methods.

To advance our knowledge of occupational fall injuries, the International Conference on Fall Prevention and Protection (ICFPP), held in May of 2010, was convened to provide a forum for researchers from NIOSH, its stakeholders, and the community of fall-prevention specialists and experts to present research findings, recommendations and expert advice on the latest tools and methods to reduce the incidence of injury from falls. At the conference, a wide variety of research approaches and methods were presented, and these approaches reflected the multidisciplinary orientation of the different stakeholders in attendance, as well as the individual interests and expertise of participating researchers.

NIOSH is pleased to present the findings from this conference in these proceedings. This document represents a wealth of knowledge from experts and informed stakeholders on the best way to understand, prevent, and control fall-related risk exposures.

It is anticipated that these presentations will serve to bring together the communities of interest that attempt to prevent and ameliorate fall-related injuries, and will spur efforts that will continue in the form of joint and supported research investigations, research consortia, and informed dialogue in support of a common goal. NIOSH hopes to continue to sponsor forums for the presentation of methods and findings related to occupational fall injury protection and prevention in the future.

It is gratifying and exciting to be a part of this research effort, which exemplifies some of the best efforts to advance work-related fall injury prevention. It is an approach that calls on the national and international community of interest—representing academic researchers, workers and worker advocates, safety and health practitioners, laboratory directors, manufacturers , and the entire range of concerned stakeholders—to achieve research that is directed toward a goal that benefits both workers and the Nation: safe and healthful working conditions for every working man and woman.

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A Commentary on Global Strategic Goals

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In a plenary session on global strategic goals, national leaders of occupational safety research organizations from five countries came together to share and discuss strategies for preventing work-related fall incidents from a global perspective. Presenters representing Japan, the Netherlands, Korea, the United Kingdom, and the United States (from the National Institute for Occupational Safety and Health and from the Liberty Mutual Research Institute for Safety), described their nations' priorities and strategies for occupational fall prevention.

Many commonalities in priorities for fall prevention emerged from these discussions. In all countries represented, falls from elevations, particularly in the construction industry, are a high priority for prevention efforts. In this industry, specific foci in common include prevention of falls from scaffolding, ladders, roofs, and openings and edges. Another high-risk priority in several countries, that crosses multiple industry sectors, is falls from motor vehicles, particularly trucks and industrial vehicles. These falls occur during ingress and egress, as well as during loading, unloading, and maintenance.

There is also substantial variation between countries in methodological approaches for reducing falls from elevations. Research foci range from the need to collect data to better understand fall risks, to using digital modeling of human fall dynamics to evaluate protective technology. Approaches in common described by some presenters include research focusing on risk assessment and human factors, and prevention-through-design strategies – taking working conditions into consideration in the design process and employ engineering solutions in building design to minimize injury risks. Others described approaches including development of accident analysis tools and safety hazard assessment instruments, conducting epidemiologic studies to identify modifiable risk factors, investigating the role of stability and balance, and developing new personal protective technologies.

Intervention efforts to prevent falls from elevations also vary among the countries. Strategies range from training, informational campaigns, risk assessment tools, and increased inspections, to new policy, regulations, design standards, and protective technology.

Although falls from elevations, with the high risk of fatal injury, is a primary research target in all of these countries, prevention of Slip, Trip and Fall (STF) injuries is also a priority research area in some countries. While STF injuries have a lower case mortality rate than falls from elevations, they are a leading cause of injury – and cost of injury - in many industries.

The US, UK and the Netherlands include STF injuries among their fall prevention priorities. Research activities aimed at STF prevention focus on measuring slipperiness, stability, and friction to predict STF potential, examining footwear performance, and conducting epidemiological studies of risk factors and intervention effectiveness. Prevention strategies include informational campaigns, risk assessment approaches, and developing, evaluating and promoting comprehensive best practices programs aimed at reducing STF injuries, particularly in the healthcare and food services industries.

In all of the nations represented at this symposium, and most other countries as well, falls is one of the leading cause of injury and death of workers. The commonalities between countries in goals and strategies to prevent occupational fall injuries reinforce a global priority for occupational fall prevention efforts, especially for falls from elevation and in construction. The common aims also suggest an advantage of working together to advance a global strategy.

The differences in methodological approaches and prevention strategies for reducing falls likely reflect, in part, differences between countries in work practices and safety policies. But they also suggest differences between countries in the longevity and maturity of national-level attention to and action towards occupational fall research and prevention. This variation also reinforces the need for sharing of knowledge and experiences in fall prevention strategies, for learning from each other about successful and promising approaches, as well as failures to avoid repeating.

Both the similarities and distinctions in priorities and approaches for occupational fall prevention presented in this plenary session further strengthen the need for international communication and collaboration to advance work-related fall prevention worldwide. This forum provided the opportunities to begin this international dialog. Now it is up to all of us to ensure that it continues.

NIOSH Strategic Goals to Reduce Fall Injuries In The Workplace

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Fall-prevention research has long been recognized as one of the most critical areas of occupational safety research. Over the past 15 years, the National Institute for Occupational Safety and Health (NIOSH) has recognized fall prevention as a strategic research priority and has conducted a program of laboratory- and field-based research to identify fall risks and develop prevention strategies and technologies. Recently, NIOSH has made a concerted effort to develop and update strategic research goals to systematically address the national occupational fall burden. This paper summarizes the NIOSH priority goals for research to prevent workplace falls.

Introduction

The U.S. Bureau of labor Statistics reported a total of 5,657 fatal work injuries for calendar year 2007 [BLS 2009]. Of the fatality cases, 847 were associated with falls. In addition, of the 1,078,140 nonfatal occupational injuries and illnesses involving days away from work in 2008, there were 260,610 cases associated with slips and falls [BLS 2010]. The National Safety Council [2002] estimated that compensation and medical costs associated with employee slip and fall incidents were approximately $70 billion/year. The U.S. construction industry continues to suffer the highest rate of fall-related fatalities, while the health services and wholesale and retail industries experience the highest frequency of non-fatal fall injuries.

Historically, NIOSH biannual meetings with Occupational Safety and Health Administration (OSHA) to discuss research needs for safer workplaces consistently included the subject of fall prevention. NIOSH's National Occupational Research Agenda (NORA) also has identified reducing fall injuries as a primary strategic goal for the Construction Sector and the Traumatic Injuries Cross-Sector. Recently, NIOSH has undertaken a concerted effort to work with stakeholders to develop and update strategic goals to address this national occupational burden. This paper describes the current NIOSH priority research goals for occupational fall prevention. Through this effort, we hope to increase communication among ourselves and with key stakeholders, to more effectively advance a common research agenda, and to facilitate the implementation of research findings to prevent falls in the workplace.

The Process

The strategic plan for the NIOSH effort in reducing fall injuries in the workplace was developed to (1) focus program activities in directions that are likely to have the greatest impact on preventing fall injuries and deaths,(2) ensure a systematic approach from risk factor identification to implementation of results in the workplace, (3) provide guidance to NIOSH intramural and extramural scientists in conceptualizing and planning research projects and activities, (4) assist leadership in balancing programmatic direction and resource management, and (5) facilitate coordination of research programs within the NIOSH portfolio.

The Goals

Based on the magnitude and severity of fall injury data, stakeholders' input and the above mentioned process criteria, 5 strategic goals are proposed; each with 1 to 3 intermediate goals.

Strategic Goal 1 - Reduce Fall Injuries in the Construction Industry

Intermediate Goal 1: Construction organizations, engineers, architects, and employers in the construction industry will implement effective, evidence-based fall prevention and protection designs, technologies, programs, and communications materials for their structure design and at their work sites.

Intermediate Goal 2: Safety research organizations, trade associations, insurance companies, and employers will identify, characterize, and reduce fatal and serious injuries associated with construction falls to a lower level among Hispanic construction workers.

Strategic Goal 2 - Reduce Fall Injuries in the Health Services Industry

Intermediate Goal 1: The health services industry will implement comprehensive slip, trip, and fall (STF) prevention programs.

Strategic Goal 3 - Reduce Fall Injuries in the Wholesale and Retail Trade (WRT) Industry

Intermediate Goal 1: Engineers, WRT trade associations, and employers in the WRT industry will implement effective, evidence-based fall prevention and protection designs, technologies, programs, and communication materials for the handling, storage and retrieval of merchandise.

Strategic Goal 4 - Reduce Fall Injuries in the Public Safety, Services, Manufacturing and other high risk Industries

Intermediate Goal 1: Government agencies, vehicle and equipment manufacturers, standards committees, and occupational safety professionals will work together to improve the designs of ambulances, fire trucks, and heavy trucks to reduce the risk of injuries and fatalities associated with falls from these vehicles.

Intermediate Goal 2: The food services industry and other high risk industries will implement comprehensive slip, trip, and fall (STF) prevention programs.

Strategic Goal 5 - Reduce fall injuries through research on human characteristics and on biotechnology-based fall control measures.

Intermediate Goal 1: Researchers will identify biomedical information of humans to design out fall risk or craft engineering solutions to control worker fall risk.

Intermediate Goal 2: Manufacturers will produce and market new, improved fall protection devices and systems that effectively reduce the forces to the human body during fall arrest and fall termination.

Intermediate Goal 3: Researchers, safety professionals, and safety investigators will use comprehensive digital models of human fall dynamics to evaluate new fall prevention and protection technologies, products, and methods and conduct fall injury investigations to recommend solutions.

Summary

Fall-prevention research has long been recognized as one of the most important and needed areas of occupational injury prevention research. This paper presents current NIOSH priority strategic goals to reduce fall injuries in the workplace, including the construction, health services, wholesale and retail trade, public safety, and manufacturing industries. These priorities include research on human characteristics and biotechnology-based fall control measures. Targeted research priorities also address areas of surveillance and technology assessment, among others. Although not presented here, detailed "Activity/Output Goals" have also been developed for these strategic goals to guide project planning. Through this presentation, we hope to increase communications among ourselves and with key stakeholders, to more effectively advance a common research agenda, and to facilitate the implementation of research findings to prevent falls in the workplace. The findings and conclusions are those of the authors and do not necessarily represent the views of NIOSH or imply the policies of NIOSH.

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MHLW and NIOSH Strategic Goals to Reduce Fall Injuries in the Workplace in Japan

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Fall-prevention research has been recognized as one of the most critical areas of occupational safety research. Over the past 40 years, the National Institute of Occupational Safety and Health, Japan (NIOSH) has recognized fall prevention as a strategic research priority and has conducted a program of laboratory- and field-based research to identify fall risks and develop prevention strategies and technologies. This paper introduces the Ministry of Health, Labour and Welfare (MHLW) and the NIOSH priority goals for activity and research to prevent workplace falls.

Introduction

The Ministry of Health, Labour and Welfare reported a total of 1,268 (construction 430) fatal work injuries in 2008. Of the 1,268 fatality cases, 311 (construction 172) were associated with falls. In addition, of the 119,291 (construction 24,382) fatal accidents and nonfatal occupational injuries involving four or more days away from work in 2008, there were 22,379 (construction 6,629) cases associated with falls.

Occupational Accident Trends in Japan

There has been a long-term decline in the number of casualties due to occupational accidents from the peak of 1.72 million in 1968. However, 604,139 workers are still suffering from occupational accidents and injuries. Those requiring absence from work for four or more days account for about 119,291 of the workers affected in 2008. Moreover, the number of fatalities peaked at 6,712 in 1961, and has gradually declined since this peak. The number nearly halved in the four years from 1972, after the Industrial Safety and Health Law came into force. It has continued to decline steadily since going below 2,000 in 1998. However, 1,268 (311 due to falls) workers were victims of fatal occupational accidents in 2008.

11th Industrial Accident Prevention Plan

The Japanese Government (Ministry of Health, Labour and Welfare) has promulgated an "Industrial Accident Prevention Plan" every 5 years. The 11th plan is a five-year plan commencing in fiscal 2008 and ending in fiscal 2012.

Targets of the Plan

(1) The plan aims to reduce the overall number of fatal occupational accidents during the term of the plan by more than 20%.

(2) The plan also aims to reduce the overall number of occupational accidents (injuries requiring absence from work of four or more days) during the term of the plan by more than 15%.

Targets of the fall accidents prevention plan

(1) Promotion of the "Guardrail-first erection method" and the "Precedent scaffolding erection method."

The plan will promote the method of erecting (dismantling) scaffolding that requires installation of the handrails prior to going to the next level in the construction work.

(2)Precedent scaffolding erection Method

The plan will continue to advocate the dissemination and consolidation of the "precedent scaffolding erection method" for the construction of low-rise buildings, such as wooden houses.

(3)Enhancement of prevention measures for fall accidents from scaffolding

The plan aims to publicize and promote new regulations and measures for scaffolding.

(4)Enhancement of prevention measures for the non-construction industry

The plan aims to review prevention measures for falls from vehicles during cargo handling operations in the land freight transportation industry.

Issues in relation to the Promotion of the Prevention of Occupational Accidents

(1) Construction Industry

The number of workers in the construction industry represents about 10% of all workers. However, the industry accounts for over one third of all fatal industrial accidents and over 20% of accidents resulting in injuries requiring absence from work for four or more days.

By type of accident, falls account for about 40% of fatal accidents and over 30% of accidents resulting in injuries requiring absence from work for four or more days.

(2) Land Freight Transportation Industry

By type of accident, fall accidents account for about 30% of the fatal accidents and 30% of the accidents resulting in injuries requiring absence from work for four or more days in the land freight transportation industry.

Fall Occupational Accident Prevention Strategy by Industry

The plan will put a priority on promoting measures in the construction and the land freight transportation industries, which have a high rate of fall accidents.

Fall accident prevention targets in the construction industry

1) Promotion of the "Precedent scaffolding erection method" for low-rise building construction (wooden houses)

2) Promotion of the "Guardrail-first erection method" for the erection and dismantling of scaffolding

3) Review and implementation of prevention measures for "falls from openings", "falls from beams", "falls from tiled roofs".

Fall accident prevention targets in the Land Freight Transportation Industry

In order to reduce accidents caused by falls during loading and unloading work, and accidents involving loading and unloading machinery, the plan seeks to encourage thorough methods of ensuring safe work practices based on the provision of safe work manuals and training that uses such manuals. Furthermore, the plan will encourage freight shippers to improve the terms and conditions in contract ordering and to establish safe working environments at sites.

Proposals for Measures to Prevent Accidents involving Falls from Scaffolding

NIOSH organized a committee for "Preventing Falling Accidents from Scaffolding" from May 2007. The aim of the committee is to review the prevention measures for accidents that involve falling from scaffolding in view of the incidence of fall accidents from scaffolding and interviews with people working in the field. Based on the committee's proposals, the related Ordinance on Industrial Safety and Health was amended by 1 June 2009.

Views on Strengthening Measures for the Prevention of Falls from Scaffolding

Expand and strengthen the provisions covering scaffolding guardrails, etc., and to prevent danger from falling objects of the current Ordinance on Industrial Safety and Hygiene as given below.

For preventing falls

(a) Tube and coupling scaffolding, etc.

Require guardrails (height of at least 85 cm) and rails (position height of 35 cm to 50 cm) (including equivalent measures).

(b) Prefabricated scaffolding

Require that a rail (position height of 35 cm to 50 cm) or a toe-board (height of at least 15 cm) be installed in the cross bracing (including equivalent measures).

For preventing objects from falling

Require the installation of toe-boards (height of at least 10 cm) and safety nets or scaffolding mesh.

Views on the State of Scaffolding Erection Methods

Revision of the Guidelines for the Guardrail-First Erection Method

Together with revision of the measures for preventing falls from scaffolding, the Guidelines should also be partially revised in the Views on Strengthening Measures for the Prevention of Falls from Scaffolding.

Views on Strengthening Safety Inspections

Inspections are indispensable for ensuring the safety of scaffolding, and since it is effective to record and preserve the results of scaffolding inspections, the inspections after scaffolding erection or modification should be strengthened and pre-work inspections should be required.

For fall accidents from scaffolding, the data, including that for injury accidents, should be compiled and analyzed annually and the results disclosed. After three years, the results of these strengthened measures should be studied, and, if necessary, measures should be implemented based on the results.

Summary

Fall-prevention research has long been recognized as one of the most important and needed areas of occupational injury prevention research. This paper presents the current strategic goals of the Ministry of Health, Labour and Welfare (MHLW) and the National Institute of Occupational Safety and Health, Japan (NIOSH) to reduce fall injuries in the workplace.

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Research and Practice on Fall Prevention of OSHRI, KOSHA

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According to the workers' compensation data, fall from the height (fall) is one of the major causes of occupational injuries in Korea. Approximately 50% of falls occurred in the construction industry, while the industry accounted for 22% of workforces in 2008. In particular, fatal injuries occurred mostly in the construction industry. The Korea Occupational Safety and Health Agency (KOSHA) has performed technical assistance to workplaces for reducing falls. The Occupational Safety and Health Research Institute (OSHRI), which is an affiliated institute of KOSHA, has selected five major causes of falls and conducted research for the strategy on prevention. This paper summarizes the activities of KOSHA and priority goals of OSHRI in research in order to prevent falls at workplaces.

Introduction

The Ministry of Labor reported 78,306 nonfatal injuries requiring 4 or more days of treatment and 1,161 fatal injuries for calendar year 2008 (Ministry of Labor, 2009). Among the fatality cases, 40% (468 cases) were associated with falls from the height. In addition, out of all nonfatal injuries requiring 4 or more days of treatment in 2008, 17% (13,604 cases) were associated with falls from the height (Ministry of Labor). Seventy percent of fatal injuries (327 cases) and 50% of non-fatal injuries (6,649 cases) occurred in the construction industry. Thus, the construction industry is the primary target for fall prevention. KOSHA, which is a semi-government agency to conduct prevention activities for occupational injuries and illnesses, has conducted various practical activities together with the Bureau of Occupational Safety and Health of the Ministry of Labor (BOSH). BOSH enforces the regulation of Occupational Safety Standard through inspection. OSHRI is a research institute affiliated to KOSHA.

Activities for Fall Prevention Activities

Prevention activities for injuries caused by falls are usually performed by KOSHA through its local branches. OSHRI analyses injuries caused by falls and conducts research to find solutions to reduce them.

KOSHA

KOSHA provides technical supports to construction sites to reduce occupational injuries, including injuries by fall from the height, through its 24 local branches. KOSHA's activities for fall prevention are follows:

1) Support the strategic plan for preventing accidents by reviewing the hazard prevention plan submitted in advance from construction sites of buildings with 31 meters and more in height, and by following the sites whether they are undergoing construction works as the hazard prevention plan states.

2) Improve construction safety in small-scaled construction sites by providing subsidies through construction safety service agencies.

3) Provide support to set up the systemic approach for occupational safety and health by expanding authorization of KOSHA 18001.

4) Encourage and support employers' associations, professional associations, and public ordering organizations to actively join fall prevention activities. Injury rates of public ordering organizations are announced to improve their consideration to fall prevention.

5) Educate workers to improve their awareness in construction safety. Injuries have decreased

significantly among workers who have taken the education for safety work before starting work.

OSHRI

OSHRI has conducted relatively few researches on fall prevention even though fall from the height is one of the major causes of injuries. In 2008, injuries by falls in the construction industry arose from ladder (21.6%),steel frame structure (16.1%), foothold (14.5%), scaffold (14.4%), passage and floor (7.1%), machine and equipment (4.3%), and shores (4.3%).Based on the analysis of occupational fall injuries, OSHRI selected five research priorities for fall prevention. They are open orifice, foothold, scaffold, movable ladder, and sloping roof. Researches on scaffold and movable ladder have been completed by 2009.

Steel pipe scaffolds are still widely used, which can cause more accidents compared to system scaffolds. In 2008, out of all injuries caused by falls from scaffolds, 18% was caused by pipe scaffold, 41% was caused by pipe frame scaffold, and 0.2% was caused by system scaffold. The most common reason for falls from the height is negligence of employers in keeping the guideline of construction safety. In 2000, research on foothold was conducted. Researches on open orifice and sloping roof will be followed.

Summary

Research on fall prevention has been limited to engineering aspects. However, most injuries were caused by improper use of safety equipment or negligence of employers and employees. Actual statistics on the general status of injuries by fall is insufficient so far. OSHRI will focus on the practical aspect about the cause of fall in construction industry.

Fall Prevention Research at the Liberty Mutual Research Institute for Safety

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At the Liberty Mutual Research Institute for Safety (LMRIS), slips, trips and falls represents one of four core research domains. Our approach to fall prevention research is multifaceted, recognizing that an injury event often results from a confluence of several contributing factors. Thus, it is important to integrate the perspectives of diverse disciplines. Our multidisciplinary Approach includes tribological studies (interactions between shoes, contaminants, and floor surfaces),biomechanical studies (human gait, stability, and motion patterns), epidemiology (burden and transient risk factor identification), and cognitive studies (human perceptions and decision-making processes). Our interdisciplinary approach integrates methods and insights from psychology,biomechanics, epidemiology and tribology to gain a better understanding of the underlying causes and mechanisms. This paper summarizes the LMRIS research thrusts aimed at preventing workplace falls.

Introduction

For over 55 years, the Liberty Mutual Research Institute for Safety (LMRIS) has conducted scientific research aimed at preventing occupational injuries and disability. Consistent with Liberty Mutual's core mission to help people live safer and more secure lives, the research performed at the Institute is non-proprietary and research findings are published in the peer-reviewed scientific literature. With staff comprising scientists covering a broad range of disciplines as well as technical, communication and administrative support, the Institute's scientific contributions have received numerous awards. The four research centers specialize in injury epidemiology, physical ergonomics, behavioral sciences and return-to work. In addition to our intramural research program we have extensive extramural collaborations, including joint research with university partners and other research organizations, visiting scholars, and post-doctorate fellows.

The burden of slip- and trip-related falls is alarming, representing one of the leading causes of compensated loss across all industries. According to the Institute's most-recent Workplace Safety Index (WSI), that provides a national snapshot of the direct costs associated with severe occupational injuries, the cost of slips and falls on same level and to lower level in 2007 amounted to $13.9B, representing more than 25% of the total burden (see Figure 1). Together, these two categories of falls have surpassed overexertion injuries in terms of cost burden for the first time in 2007.

Figure 1: 2007 Liberty Mutual Workplace Safety Index

[1]Overexertion – Injuries caused from excessive lifting, pushing, pulling, holding, carrying, or throwing
[2]Bodily reaction – Injuries caused from slipping or tripping without falling
[3]Struck by object – Such as a tool falling on a worker from above
[4]Repetitive motion – Injuries due to repeated stress or strain
[5]Struck against object – Such as a worker walking into a door

Even more alarming is the growth of the burden associated with work-related falls from 1998-2007, the ten years that we published the Index. Although data from BLS (for 1998 and 2007) indicated that the frequency of falls on same level and falls to lower level actually dropped by 1.3% and 12.5%, respectively, during this same period the corresponding cost burden associated with these injuries increased by 36.7% and 33.5%,respectively. In fact, the cost burden associated with falls grew substantially more than any other injury category. The underlying reasons for these trends are not known at this time, though one might speculate that changes in workforce demographics and changes in the nature of work have played a role.

A Rich Legacy of Falls Prevention Research

At the LMRIS, research on slips, trips and falls has been a priority area since the very founding of the Institute. As an example, in 1967, Liberty Mutual researchers developed the first Horizontal Pull Slipmeter™, a portable device that measured the slipperiness of floors and other walkway surfaces. This tool gave safety practitioners and researchers a way to evaluate floor slipperiness and devise prevention strategies. Early slips and falls research included investigations of floor surface testing methods and cleaning protocols. Today, the research program includes tribological studies of the interaction between shoes, contaminants, and floor surfaces;biomechanical investigations of human gait, stability, and motion patterns; epidemiologic studies of potentially modifiable transient risk factors, and cognitive studies of human perceptions and decision-making processes. In 2000, the Institute hosted a two-day international symposium to develop global perspectives on methodological issues on slipperiness measurement and to identify research gaps. This work has greatly influenced the direction of research not only at LMRIS but elsewhere. As a result of this work, we began to examine the relation between actual friction measurements and subjective ratings of slipperiness across working areas in restaurant kitchens, as well as the role of friction variation. The results suggests that while workers' perceptions of floor slipperiness are useful indicators of actual friction individual perceptions of slipperiness may be impacted by factors other than friction (e.g., visual cues, sensory feedback, motor control,and environmental factors, such as lighting, shoe sole condition, and contaminants). This line of research continues, as noted below.

It is worth noting that in 2006, Institute scientists worked to found a new International Ergonomics Association technical committee on Slips, Trips and Falls, which held its first conference in 2007. Key members of this committee also have helped support the success of the current conference. The establishment of international scientific networks will further advance this field.

Current Research Priorities

Perception of floor slipperiness and its influence on gait and UCOF

Following a series of studies investigating factors influencing perception of slipperiness, a major interdisciplinary study is underway that examines visual perceptions of slipperiness and resultant gait changes prior to walking on the surface, as well gait adjustments after stepping onto the walking surface in response to proprioceptive cues. The study utilized surfaces in which there were discrepancies between perceived and actual slipperiness, the selection of surfaces having been based on previous findings that slipperiness is mostly influenced by the reflectance characteristics of the surface.

Epidemiology investigations of risk factors for fall injuries

The purpose of a series of epidemiological studies is to identify modifiable risk factors associated with injuries that result from falls. For example, a large-scale case-crossover study being conducted with collaborators at the Harvard School of Public Health, the U.S. Consumer Product Safety Commission, the

National Institute for Occupational Safety and Health, and the CPWR Center for Construction Research and Training focuses on transient risk factors associated with falls from portable ladders, which account for the majority of disabling ladder injuries. Study participants were patients who had been treated at hospital emergency departments across the United States for ladder fall-related injuries. Another example is a prospective cohort study that examines factors that contribute to the risk of slipping in limited-service restaurants. This landmark field study will quantify the relative role of modifiable risk factors such as surface characteristics, cleaning protocols, and slip-resistant footwear.

A third example is a 10-year collaborative study involving NIOSH, BJC Healthcare, the Finnish Institute of Occupational Health, Johns Hopkins School of Public Health, and the Washington University School of Medicine to evaluate a comprehensive slip, trip and fall prevention programme for hospital employees. This study received the 2006 NORA Partnering Award from CDC and the 2009 award for the best paper in Ergonomics from the Ergonomics Society.

Stability-related research

This line of research investigates the role of stability (in particular, identifying factors that disturb worker stability), as a proximate factor in falls. A number of studies currently underway include investigations of stability while working on stepladders (e.g., as it may be affected by lateral reach) and stability following postural transitions (e.g., standing after bending or kneeling).

Falls from trucks during ingress/egress

The current research focuses on behavioral issues associated with commercial vehicle ingress/egress to better understand the reasons for drivers' apparent non-compliance with safe methods. In particular, the study explores drivers' perceptions, beliefs and preferences regarding methods of ingress and egress.

Tribology

Current studies in the area of tribology focus on methodological improvements to the measurement of slipperiness and estimate of slip or fall probability. Examples of current studies include using a statistical model to estimate the probability of slip or fall incidents, modeling the stochastic characteristics of COF, and determining `the role of the transverse shear force in deriving a more valid measure of Required Coefficient of Friction.

Summary

The LMRIS program comprises a rich mixture of field studies to identify risk factors for falls as well as experimental investigation in laboratory settings to gain a better understanding of the underlying mechanisms. We also leverage our resources by collaborating with partners such as NIOSH and the Harvard School of Public Health in joint research involving large-scale studies. Findings from these studies provide a scientific basis for the development of cost-effective interventions and strategies that can reduce the likelihood of work and non-work related slip-, trip- and fall-related injuries.

Slips and Falls, the Health and Safety Executive Approach

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Slips and falls are the biggest class of accidents reported to the United Kingdom's Health and Safety Executive (HSE). In addition, many other accidents reported, as falls from height or workplace transport accidents, are often initiated by simple underfoot events. This paper will discuss the HSE Watch Your Step campaign in 2004 and the Shattered Lives campaign in 2008 and 2009 to raise awareness of these accidents. The Slips Assessment Tool (SAT), the Slips and Trips e-learning package (STEP) and a training package will all be described.(s)We will also describe ongoing Health and Safety Laboratory (HSL) work on behalf of HSE, which helps understand the reasons behind many of these accidents, and identifies possible solutions. A number of cross cutting issues will be discussed. Laboratory and site based work has highlighted the need for robust methods of test for both flooring and footwear. These will be discussed in detail. Test data needs to be complemented with other information to help the end user understand the issues and make better informed decisions. Examples of successful intervention will be outlined and illustrated with case study material.(s)

Introduction

Statistics show slipping and tripping to be the most common causes of injuries in UK workplaces. Provisional statistics for 2008-09 show that slips and trips resulted in 10,626 major injuries (37% of major injuries), and 24,000 over 3 day injuries (23% of over 3 day injuries) reported to HSE(www.hse.gov.uk/slips/statistics.htm). In addition, slips and trips are often initiators of accidents attributed to different causes, including falls from height and workplace transport accidents. Last year 35 workers died following a fall from height and 4,000 were seriously injured (www.hse.gov.uk/falls/). In the same period there were 2 fatal, 861 major and 1,205 over 3 day workplace transport injuries attributed to people falling from vehicles (www.hse.gov.uk/workplacetransport/statistics.htm).

Campaigns, tools and supporting materials

HSE launched the Watch Your Step campaign in 2004, the first big HSE publicity campaign on slips and trip accidents. This was followed by Shattered Lives in 2008-9 (www.hse.gov.uk/shatteredlives). This campaign included falls from heights as well as slips and trip. The first phase of Shattered Lives received a number of accolades including the 'Best National Newspaper campaign'; the campaign website attracted more than 800,000 visitors. There were almost 200 press articles published, none of which were negative.

A second phase of the campaign in 2009 was focussed around the launch of the Slip and Trips e-learning Package (STEP) (www.hse.gov.uk/slips/step/index.htm) and this attracted almost 60,000 visitors to the website in the first few weeks. Visitors spent on average 23 minutes looking at the STEP tool. The STEP tool includes a general course suitable for a wide range of industries and four other courses specifically designed for food manufacturing, hospitality and catering, education and health and social care. There are introductory, intermediate and advanced levels depending on the amount of detail required. The tool includes easy to follow guidance, case studies, videos, animation and quizzes, designed to give the user the information needed to set up and maintain a safer way of working. The third phase of Shattered Lives in 2010/11 includes the new Work at Height Access equipment information Toolkit(www.hse.gov.uk/falls/wait/index.htm). This is a simple tool for people who occasionally work at height. It gives practical advice and guidance on the factors to consider when selecting access equipment for planned work at height and on some of the different types of access equipment available.

Phase three also includes recent case study material outlining some success stories from real workplaces.

Supporting material includes downloads, industry specific posters, a hazard spotting checklist and the Slips Assessment Tool (www.hse.gov.uk/slips/sat/index.htm) a downloadable software package which allows an immediate assessment of the slip potential of pedestrian walkways. It does this by gathering information on the floor surface, contamination, cleaning regimes, footwear and environmental factors. People who leave their e-mail details are sent regular slips, trips and falls from height e-mail alerts with up to date news and advice on keeping the workplace and staff safe. Over 37,000 people have subscribed to date.

The material outlined above has been central to the development of training and awareness raising packages delivered to a wide range of different stakeholders in recent years. At the core of this training is the slip potential model (www.hse.gov.uk/pubns/web/slip01.pdf) for assessing the slip resistance of flooring. A technical information sheet). We use this model to promote a holistic, risk assessment based approach to tackling slip accidents. The main features of the model are described in more detail below.

Required Friction

To help reduce the number of slip accidents, we need to understand the friction requirements of people using pedestrian surfaces. Data published by the UK Building Research Establishment [Pye and Harrison 2003] summarizes an experiment they carried out to measure the required coefficient of friction. The data gathered showed that people have different requirements, which can be analyzed and related to risk. The relationship between friction and risk is reproduced in Table 1. The data relates to level surfaces only.

Table 1: Coefficient of friction vs. risk

Risk 1 in:	Straight Walking	Turning left foot	Turning right foot
1 000 000	0.36	0.40	0.36
100 000	0.34	0.38	0.34
10 000	0.29	0.34	0.33
200	0.27	0.31	0.32
[redacted]			

Sloping surfaces will require a greater level of friction for a given level of risk. The friction requirements listed under straight walking assume that the pedestrian is moving at a moderate pace while not turning,carrying, or pushing or pulling a load. These factors would again result in a higher friction requirement for a given level of risk.

Measuring Friction

When measuring the available friction on surfaces it is vitally important that a valid method is used. HSL's work over several years has concluded that only two test methods provide reliable friction data. The first of these is the pendulum Coefficient of Friction (CoF) test used according to the protocols detailed in the UKSlip Resistance Group Guidelines [UKSRG 2005]. This test methodology can be applied to samples inthe laboratory and can also be used on site. Data generated by HSL [Hallas et al. 2008] using this method in accident investigations supports the friction requirement data published by BRE. The second method is a laboratory based ramp method. HSL's basic methodology uses trained operators walking at a controlled constant pace with standardised footwear soling materials and potable water as the contaminant. The test can also be used to assess bespoke combinations of footwear, flooring and contaminant relating to specific work place environments. The data generated is reported as coefficient of friction to allow easy interpretation and direct comparison with pendulum data. Our work has also identified a complementary measurement of surface micro roughness found to be useful in many situations, especially when used with the SAT. Surface micro roughness measurement can also be used as a simple monitoring tool to identify changing characteristics of surfaces in service.

The data generated by these methods requires careful interpretation and a lot of good advice is contained in the references provided. The Construction Industry Research and Information Association (CIRIA) have recently published further useful information [Carpenter et al. 2006]. The document will be updated in 2010. Technical specifications for various ramp methods and the pendulum method are currently being developed in a European Standards Committee group (CENTC/339/WG1).

Cleaning

Cleaning is the obvious link between flooring and contamination. Cleaning can help reduce the likelihood of slip accidents by keeping floors free of contamination but it is important to remember that the cleaning process itself often introduces contamination to the surface (water or detergent solution). The process needs to be properly thought through and carefully managed. Research has shown that where cleaning is carried out effectively, it can make the difference between a floor being an unacceptably high slip risk or an acceptably low slip risk (www.hse.gov.uk/pubns/web/slips02.pdf). There are several case studies highlighting the various aspects of cleaning on the HSE website.

Footwear

Using flooring surfaces we have characterized using the pendulum method, HSL have recently utilized a ramp based method to evaluate footwear. This has identified several pieces of footwear that perform well in terms of slip resistance [Loo-Morrey and Houlihan 2007]. HSL currently believe that this ramp based method of test generates more relevant data than the CEN method of test [BSI 2007]. As mentioned previously, bespoke combinations may be evaluated and careful selection of footwear can help significantly in reducing the likelihood of slip and fall accidents. However simply relying on footwear, which has achieved a particular threshold in a standard test, is not enough to ensure a reduction in slip accidents. This is exacerbated by the low threshold values in the current CEN test. Test data should be complemented with other information including details of tread pattern, the number and length of square leading edges and the micro roughness and hardness of soling compounds. However even with all this information the best that is likely to be achieved is improving the odds of selecting an appropriate product.

It is also important to remember that the overwhelming majority of footwear that is tested is new and that it may change significantly in terms of slip resistance even with little wear. This is especially true if the footwear has fine detail on the tread surface, which is quickly lost in use. Ultimately the best test for footwear is for it to be trialled in real workplace environments. An Informative Annexe to the recently published CEN method has been prepared and will be published in 2010.

It is very important to remember that slip resistance is only one aspect of the performance of safety footwear. Other features such as toe caps and protective insoles are more likely to be prominent in the minds of prospective purchasers. The statistics detailed earlier are a powerful case for slip resistance to be given much higher priority. At present slip resistant footwear and safety footwear are not the same thing!

Barefoot

The ramp-based method described above can also be used to generate barefoot data. In our experience the method is less precise than the shod version of the test but nevertheless provides useful data. Surfaces that perform well under test perform well in service.

Profiled Surfaces

Ramp methods can also be used to determine the slip resistance properties of profiled surfaces. Different orientations of the profile need to be tested to establish any directional effect. The complementary measurement of surface micro roughness is also useful in building up a fuller picture of how these surfaces are likely to behave.

Recent work has raised questions about the slip resistance properties of such surfaces [Thorpe et al. 2007]. Laboratory and anecdotal data suggests they do not necessarily provide the user with greater friction than their unprofiled equivalents. The choice of footwear appears to be far more important. Profiled surfaces can also change very quickly [Houlihan 2008] with some significant changes observed on some surfaces just from the wear incurred by the process of testing. All observed changes resulted in a reduction in the slip resistance as measured, with obvious implications for their performance in use. These surfaces are often encountered in external environments exposed to a wide range of contamination.

They are routinely used on ladder treads, mobile work platforms and on various forms of workplace transport including tail lifts and steps into vehicle cabs. Anecdotal evidence also suggests that profiled surfaces can be a problem for barefoot users. This is an area which is less well researched and further work is ongoing.

Conclusions

Slips and falls are the most frequent accident type reported to HSE. In addition they are the initiators of many other types of accidents. They create a serious burden on the UK economy and beyond in terms of the injuries and deaths they cause and the consequent costs. Better tests and clear data with supporting information will help all stakeholders, giving them a better understanding of the challenges they face. This in turn will lead to better decision making, which will ultimately lead to fewer accidents, injuries and fatalities in the workplace. Recent work described in the paper has developed various tools, in particular the STEP tool, and a great deal of information to help address the problem of slips, trips and falls in the workplace. Effort must be maintained to ensure it becomes properly embedded.

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Dutch Approach to Reduce Accidents in Construction Industry

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Introduction

Arbouw was set up in 1987 by employers' and employees' organizations to improve working conditions in the construction industry and to decrease absence resulting from sickness. The board of Arbouw consists of representatives of employers and employees organizations.

Arbouw is a small Non Governmental Organization; we cannot enforce changes by law. We can persuade employers and employees to make an agreement on working conditions. Beside this we inform construction workers and firms via the internet and a magazine about their influence on working conditions.

Working in the construction industry means being involved with safety issues. Arbouw has estimated that there were 9.370 work-related accidents in 2007 among 217.000 construction workers. Furthermore, both employers and employees have noticed over a period of many years that there are too many accidents in the construction industry.

Following the life cycle of a construction there are moments of intervention. According to this moments of intervention this paper describes the problems and if possible the opportunities to change.

Design Stage

There is a saying 'rubbish in; rubbish out'. This can be translated to construction industry. A wonderful design that is hard to construct leads to unsafe working conditions.

The architect and the structural engineer are largely responsible for health and safety in the execution phase. The choices these disciplines make about design and the use of materials are major factors in determining the possibility of safe building practices.

Since 1994, building designers have had to take the working conditions during execution, maintenance and demolition work into account in their designs. This obligation is contained in "Directive 92/57/EEC," a Directive that has been incorporated into national legislation in all EU countries. In the Netherlands, the obligation is implemented via the Arbo-besluit (Working Conditions Decree), which forms part of the Arbo-wet (Working Conditions Act).

Most of the publications on this subject have offered solutions that can be directly implemented or checklists to monitor the design afterwards. This type of precise advice inhibits the designer's creative process and hampers the usual design process. Designers are used to a methodical approach, which is one of the reasons for suggesting that a method would be the best way to turn safe construction practices into a standard part of the regular design process. Designers must reduce foreseeable hazards to a minimum and this must be done in a systematic way [Bluff, 2003].

In an attempt to solve this, Arbouw developed a method for safety assessment in design phase [Frijters and Swuste 2008]. This method can be incorporated into the design process for building elements and construction methods.

The method works on the basis of building elements and comparisons with alternative construction forms, and comparing hazards and exposure to hazards. A building element is a part of a building with an independent function, for example a roof, a wall or a floor.

For these building elements the potential hazards and risks are assessed. The combination with the duration of exposure to these hazards provides insight in construction tasks with high, medium and low risks. The low risk activities are the preferred construction form for that particular building element.

Building Permit 'XL' (check safe design)

Within one year safety maintenance of the outside of the building is a condition to get a 'building permit'. This will be embedded in regulations and the local authorities are pointed out to control the design as a part of their normal procedure.

We, Arbouw, in corporation with other organizations, are asked to provide principals, designers, architects, local authorities and technical universities with knowledge, information and instruments for implementing the new regulation. Those materials need to be developed and produced.

Generally the designer must anticipate on maintenance. He must include the highest level of safety measures for maintenance activities. For instance on a flat roof there must be a railing, cleaning the windows must be done from a position without the risk of falling.

The expectations of this project are high although, we estimate only results on long term.

Selection Guide 'Safe Workplace at Height'

Working on height is dangerous and causes accidents. In 2001 we produced a guideline 'fall protection'. There is a large amount of systems to protect workers falling from height. Not all systems are useful in all occasions. Not all experts are aware of the systems or its restrictions in use. Sometimes the knowledge is limited to the system last seen of what is on stock in the company.

In order to spread the knowledge and to guide companies, the first guideline was set up.

After the implementation of the EU directive 2001/45/EC there was a need to include equipment to facilitate a workplace on height (e.g. mobile scaffolding, MEWP).

In the selection guide 'Safe Workplaces at Height' (www.veiligwerkenophoogte.nl) companies and workers find the best solution to create a safe workplace and find advises to make a choice for equipment. The Dutch delivers with a few questions the best known system or equipment.

Working Conditions Agreement

In the Netherlands governmental regulations are goal setting. This is often too abstract for most companies. This kind of regulations offers opportunities for unintentional measures.

Arbouw has produced the so-called 'A-fact sheets' (A-Bladen), reflecting agreement between employer and employee organizations on preferred solutions. These 'A-fact sheets' fill the gap between abstract regulations and operational needs. Labor authorities respect those agreements and use them to control the H&S situation on construction sites.

On the subject 'falling from height' three 'A-Fact sheets' are relevant to mention; the fact sheet 'working on flat roofs', 'working on steep roofs' and 'scaffolding'.

In those fact sheets working with personal protective fall equipment (restraint of arrest) is limited. For instance scaffold building is no longer permitted without the use of a railing. Work on a roof is not permitted without use of a railing. The use of an PPE is only accepted in case the activities fit a time frame of maximum three work hours. Those agreements were made last year, results are to come.

Safety Level: Dutch Safety Indicator

Managers and workers in construction are not always aware of hazards and risks during construction activities. When pointing out hazards involved they are aware of the required safety measures.

Arbouw has developed the 'Dutch Safety indicator' [Frijters et al. 2007; Frijters et al. 2008]. This instrument is a translation of the Finnish TR Method and provides workers and management with an instrument to recognise safety hazards and risks. Arbouw supports the use of the Safety indicator with a website (www.veiligheidsindicatorbouw.nl). Beginning of April 2010 the instrument was introduced, after a testing period of 4 months on 214 construction sites.

The TR method is an observation and assessment instrument allowing to measure safety by construction site personnel themselves. The measuring method draws attention major accident scenarios and to the quality of barriers to control these scenarios (table 1).

The 'TR safety observation method on building construction', was developed by the Finnish Institute of Occupational Health as an audit instrument for construction site workers. [Laitinen and Ruohomäki 1996; EU-OSHA 2004]. The abbreviation 'TR' is the Finnish acronym for 'construction site'. The Labour Inspectorate in Finland is using the instrument, and resent research findings showed a positive correlation between a high score and a low accident rate [Laitinen et al. 1999; Laitinen and Paivarinta 2010].

Table 1: Safety Indicators observation form

Name of company:			Construction site:	
Address of construction site				
Phase of work: foundations, structural work, completion				
Component	Score 'correct'	Total	Score 'incorrect'	Total
1. work practices				
2. scaffolding and ladders				
3. machines and tools				
4. fall protection				
5. light and electricity				
6. workplace				
	Total number 'correct'		Total number 'incorrect'	
Safety index = total correct / total number observations X 100% =				
Name observer		Signature		Date

Comments

In the years to come the focus will be on 'work practices', 'scaffolding and ladders', 'machines and tools', 'fall protection', 'light and electricity' and 'workplace'.

Story Builder Construction

The construction industry has a high accident rate. Most accidents are the result of only a limited number of accident scenarios. Learning from accidents is difficult in this branch of industry. All companies are investigating accidents in their own way with their own system leading to their own data and their own measurements. Sometimes very sophisticated sometimes very traditional, sometimes reliable and evidence based but more often it looks like a 'jumping to conclusions' method and 'blaming the victim'. Non comparable figures and non comparable, poor prevention measures are the results. Storybuilder is an accident analysis tool developed in the WORM project of the Dutch ministry of Social Affairs [Bellamy et.al, 2007; Ale et.al. 2008]. This tool is used to analyze about 12.500 occupational accidents and it generates scenarios. The scenarios consist of failing barriers leading from the hazard to an event and damage. Storybuilder is a research tool.

Arbouw and RPS, with support of the TU Delft, conducted a research on the methods companies use for the report, registration and analysis of accidents. We also made an inventory of the demands companies puts on accident investigation, certification and legislation.

Based on this study we remodelled Storybuilder for use by companies in construction industry. With the 'StoryBuilder construction industry' it will be possible to make an accident analysis in a very short time. It also offers control measurements to the company to improve safety. The system is facilitated by Arbouw and this organization makes the anonymous results available for bench marking. Our goal is to release the instrument beginning 2011.

What Make Companies Change

Despite all safety initiatives by Arbouw, the number of accidents in the construction industry remains on a plateau, or is decreasing only very slowly. Arbouw and the Technical University of Delft (Safety Science) have started a research project on determinants of the level of safety in construction companies, and whether or not this level can be changed for the better. What makes workers, management and directors in construction companies willing to change, and consider occupational safety as a serious topic?

A pilot study is started among 5 till 10 companies, assessing the company's safety investigations, the use of instruments and information, its safety management, its safety climate and its safety performance. We use the Safety indicator to classify the safety performance and we use the Nordic Safety Climate Questionnaire(NOSACQ) to classify the safety climate. Publications to share our results are foreseen and we hope the results gives U.S. opportunities to develop better accepted and better working instruments.

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A Commentary for Slips, Trips and Falls on the Same Level

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Substantial losses due to injuries caused by slips, trips and falls (STF) are reported worldwide, including Finland, Sweden, the United Kingdom and the United States (Buck and Coleman 1985, Manning et al. 1988, Grönqvist and Roine 1993, Kemmlert and Lundholm 1998, Courtney et al. 2001, Liberty Mutual Research Institute for Safety 2009). As the leading antecedent for unintentional injury-related emergency department visits, STF injuries account for 21% of such visits in the United States [NSC 2008]. According to the Liberty Mutual Safety Index [Liberty Mutual Research Institute for Safety 2009]. costs for disabling workplace injuries in 2007 due to falls on the same level were estimated to be approximately 7.7 billion US dollars or 14.6% of costs, and falls to a lower level were 6.2 billion US dollars or 11.7% of costs. In addition, bodily reaction, which included slips or trips without a fall, accounted for 5.4 billion US dollars or 10.2% of costs for the same period. Moreover, data published by the Liberty Mutual Research Institute for Safety [2009] also showed that falls on the same level and falls to a lower level increased 36.7% and 33.5%, respectively, between 1998 and 2007 after adjusting for inflation, while the overall costs of disabling workplace injuries increased only 5.8% over the same period. STF injuries are a serious problem and pose a significant burden to society.

Anticipation and adaptation are two important elements in determining whether people will be injured due to STF incidents. Anticipation consists of the ability to perceive the floor conditions ahead and to determine the course of action for prevention of an STF incident. Adaptation involves human reactions in order to regain balance and avoid an injury following a loss of balance due to a triggering event, such as a slip or trip. Posture control is determined by neurosensorial afferences that include visual, vestibular, proprioceptive and exteroceptive. Falls are caused by both intrinsic and extrinsic factors as summarized by Gauchard et al. [2001]. Intrinsic factors include aging, alcohol, attention, drugs, experience, fatigue, pathologies and physical status. Extrinsic factors include environmental parameters such as contamination, lighting, maintenance, shoes, and a change in surface height, and task parameters such as activity type and temporal constraint/urgency. STF incidents are a complex problem. Multi-disciplinary approaches involving disciplines such as biomechanics, epidemiology, psychology, tribology and chemistry are needed to understand issues involved in this type of incident and to develop successful interventions.

The papers in the following document were presented at the 2010 International Conference on Fall Prevention and Protection held in Morgantown, West Virginia, USA, May 19-20, 2010. This conference was organized and hosted by the National Institute for Occupational Safety and Health (NIOSH). Slips, trips and falls were one focus of the conference in addition to the global strategic goals, falls from elevation and research practice. There were 21 papers in the area of the slips, trips and falls. The authors came from universities, government agencies, private industries and consultant companies in five different countries. Topics covered by epidemiology papers included STF in nursing home workers, elderly in-patients in acute facilities, limited-service restaurants, and a helicopter manufacturing plant, as well as the effects of limbering up exercises for elderly workers to prevent fall incidents. There were several tribological papers on friction of spheroidal heel, shoe wear and shoe roughness. There was a large proportion of papers in biomechanics that covered the issues of obesity, required coefficient of friction, firefighter boots, walking simulations, balance training, gait and mental workload, and trips. Additional papers dealt with architectural issues, a safety program and fashion footwear related to STF. These papers address a broad range of issues from research to practice. The collection of papers reflects the complexity of STF incidents and how much we have to learn about the causes of these incidents. They also reflect opportunities and provide stimulation for future research.

The contributions from the authors of the papers are greatly appreciated. Special thanks goes to NIOSH for organizing and hosting the conference and for publication of this document which will help bring the issues to the attention of a broader audience than just the conference attendees. The contributions to the conference from members of various committees from a variety of organizations are greatly appreciated.

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Causes, Sources and Costs of Falls in a Helicopter Manufacturing Plant

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Slips, trips and falls (STFs) were evaluated among 4,070 workers employed at a large helicopter manufacturing plant from January 1, 2004 to February 28, 2008. The purpose of this evaluation was to estimate rates and determine the leading causes of STFs in the plant and their associated medical costs. Company records on workers' compensation claims, company physician and nurse first report of injury, and payroll records of the number of hours worked were collected on all workers. Cause and source of all injuries and cause of the first initiating event of STFs were coded for analysis. During the study period, there were 2,378 injuries of which there were 226 STFs, 46 falls to a lower level,117 falls to the same level, 41 from slips, trips, or loss of balance without a fall, and 22 from other events. Of the 226 STFs, 52 were from slippery surfaces, 43 from objects on floor, and 28 from surface irregularities which were all preventable by good housekeeping and maintenance and cost $1,543,946. Recommendations for fall preventions in the plant are discussed.

Introduction

A project was initiated with a helicopter manufacturing company to evaluate the reduction of injuries and return on investment associated with a company safety program of interventions targeted to reduce injuries in one of their plants employing approximately 3,500 production workers. Risks of falls from elevation include working on stands around the aircraft complete with stairs, standing on aircraft for some assembly work, working on ladders, and climbing onto and off of large production equipment and machines for processing parts and machine maintenance. Risks from falls to the same level include slipping on slippery substances including ice and snow in parking lots and outside walkways, tripping on objects such as tools and parts in walk ways, and tripping on irregular surfaces such as grates and holes in indoor stands and on holes and cracks in outdoor walking surfaces.

Bell et al., [2008] used an epidemiologic approach to analyze baseline slips, trips and falls (STFs) in a hospital-based intervention study. They coded the event of STFs using the Bureau of Labor Statistics(BLS) Occupational Illness and Injury Classification Structure (OIICS) [BLS, 1992]. They further categorized the cause of the first initiating event (FIE) and developed a taxonomy of characteristics of the cause of the FIE to supplement the OIICS codes. They reported a high percentage of STFs due to preventable conditions such as slippery substances on surfaces; surface hazards such as holes, cracks, and uneven surfaces; elevated edges of rugs and mats; and falling off chairs. They then implemented a program targeting high risk jobs and areas for hazard evaluation, raising employee awareness to the importance of preventing STFs, housekeeping practices, maintenance and repair, methods of floor cleaning to increase the coefficient of friction, and slip resistant shoes for targeted employees. Employing this approach, STFs were reduced by 50-60%.

The epidemiologic approach used by Bell *et al*. for their baseline analysis of STF risks was applied to data from the helicopter manufacturing plant. Primary questions to be addressed were what were the leading causes of STFs in the plant with respect to plant location and what were the medical and indemnity costs associated with the injury outcomes. Recommendations for fall prevention in this plant are discussed.

Methods

The study population consisted of 4,070 production workers who were employed between January 1, 2004 and February 28, 2008 at a large helicopter manufacturing plant. Data were collected on workers from company records including 1) payroll records on dates and hours worked, 2) personnel records on date of birth, gender, occupation, and department, 3) workers' compensation (WC) records, and 4)company physician and nurse first report of injury records. WC and first report of injury records for each injury were merged to code cause and source of injury.

The event and source of all injuries were coded using the OIICS [BLS, 1992] by a trained OIICS coder. One of the authors (HA) read each injury narrative and verified agreement with the coder. The condition leading to the FIE of STFs was also coded (slip, trip, fall, loss of balance, or unknown) similar to the approach used by Bell *et al*. [2008] to supplement the OIICS event codes. Additionally, the condition causing the FIE of STFs was coded to supplement the OIICs event code and provide specificity peculiar to the plant. Codes on nature of injury were taken from the physician or nurse first report of injury. For the purposes of this analysis, STFs were defined as injuries with OIICS event code1 (falls) and 215 (slip, trip, or loss of balance without a fall).

The company is self insured, and thus, all WC medical and indemnity costs from all claims filed during the study period were used for the cost analysis. For this analysis, total cost of WC claims, cost per injury, and cost per WC claim were calculated. The cost per injury is defined as the total WC cost divided by the total number of injuries (some injuries did not have WC claims filed and some had WC claims filed but no costs associated with them.) The cost per claim is defined as the total WC cost divided by the number of claims which cost $1 or more.

Annual rates of injury per 10,000 full-time equivalents (FTE) in selected subgroups were computed by dividing the total number of injuries in the group by the total number of hours worked times 20,000,000 which is comparable to the method used by BLS [2009]. It was assumed that the total annual number of hours worked was 2,000 hours (50 weeks x 40 hours per week).

Results

From January 1, 2004 to February 28, 2008, there was a total of 2,378 injuries among the 4,070 employees of which 930 injuries had a WC claim costing $1 or more. There were 226 STFs which were the fourth leading injury event among all OIICS single digit coded events (9.5% of all injuries). The leading event was bodily reaction and exertion (40.2%), followed by contact with objects (34.6%) and exposure to harmful substances (11.3%). STFs were the second leading event of lost work day (LWD) injury. Of the 226 STFs, 23 (10.2%) were LWD injuries. The rate per 10,000 FTE of LWD injuries was 14.4 for all falls, 5.8 for falls to a lower level, 8.4 for falls to the same level, and 5.0 for slips, trips, or loss of balance without a fall.

Of the 226 STFs, there were 46 (20.4%) falls to a lower level, 117 (51.8%) falls on the same level, 41(18.1%) slips, trips, or loss of balance without a fall, and 22 (9.7%) from other events. The event associated with the highest number of falls on the same level were to the floor, walkway, or other surface (77 injuries) and onto or against objects (31 injuries). The source associated with the highest number of falls were floors of building, walkways, ground surfaces, steps, and parking lot surfaces (118 STFs, 52% of all STFs). Body motion and posture was the second most prevalent source of STFs (40,17.7%). The most prevalent nature or diagnosis of injury for STFs from first report of injury was due to contusion (75), pain, nature unspecified (69), sprain (24), strain (27),and laceration (12).

With respect to the contributing cause of the first initiating event (FIE), of the 226 STFs, slippery surfaces contributed to 23% (52), slips on ice and snow to 13% (30), objects on the floor to 19% (43), a surface irregularity to 12% (28), chairs to 6% (13), and other causes to 40% (90) including 8% (17) due to climbing in, out of, onto or off of the aircraft and 14% (32) due to bodily reaction involving loss of balance or a misstep while walking or standing on level ground. Patterns of lost work day injuries with respect to causes of the first initiating event due to STFs were similar to that of all injuries. The total WC and indemnity costs for all injuries from January 1, 2004 to February 28, 2008 were $13,836,424.

STFs (OIICs event codes 1 and 215) had a total cost of $2,238,849. Bodily reaction and exertion was the injury event associated with the highest total cost of $8,525,108 (total cost of all bodily reaction and exertion injuries in U.S. the cost of injuries due to slips, trips, or loss of balance without a fall). However, falls (OIICS single digit event code =1) had a higher cost per injury ($10,108) and cost per WC claim ($22,532) than injuries from bodily reaction and exertion ($9313 and $16,941,respectively). Among categories of fall events, falls on the same level had the highest total cost($1,405,302), cost per injury ($12,011) and cost per claim ($26,515).

With respect to contributing causes of a STF, the total cost was highest for STFs on slippery surfaces($856,043) followed by objects on the floor ($522,408), and surface irregularities ($165,495). However, the total cost per injury was highest for STFs on slippery surfaces ($16,462) and objects on floor($12,149). Among causes contributing to slippery surfaces, slipping on ice contributed to 30 (58%) of the 52 STFs in this category and had a total cost of $698,011 (82% of the cost of all STFs due to slippery surfaces), a cost per injury of $23,267, and cost per claim of $53,693.

Rates of STFs were elevated in the blades and composites department, outside walkways and parking lots, gears and transmission, hanger, and final assembly areas. The percentage of all injuries due to STFs on slippery substances was 50% in gears and transmission departments and 20-30% in blades and composite, final assembly, and hanger areas. The percentage of STFs due to objects on the floor was 18-30% in blades and composites, final assembly, gears, and hanger areas. Between fourteen and twenty-six percent of the STFs due to surface irregularities were found in the blades and composites, hanger, and outside walkways and parking areas.

Discussion

STFs were the fourth leading cause of injury and the second leading cause of lost workday injuries for production employees at a large helicopter manufacturing plant. The average annual rate per 10,000 FTE for LWD injuries was 5.8 for falls to a lower level, 8.4 for falls to the same level, and 5.0 for slips,trips, or loss of balance without a fall. Comparable LWD injury rates for the manufacturing industry in 2007 [BLS, 2009] were 5.2, 13.3, and 3.4 per 10,000 FTE, respectively. Thus, LWD STF rates for the helicopter plant were lower than that in the U.S. manufacturing industry.

During the 2004-2008 study period, there were 226 STFs of which 123 STFs due to slippery surfaces, objects left on the floor, and surface irregularities. These 123 STFs could have possibly been prevented by good housekeeping and maintenance practice, and comprised 54% of the total STFs, cost $1,543,946 in WC costs, and comprised 69% of the total cost of STFs.

Although the cost to prevent STF hazards in this plant has not been estimated, it would appear that the cost to prevent many STF events could offset the cost of occupational injury in this plant. For example, spending more money to more aggressively apply ice melting chemicals on sidewalks and walkways could offset a large portion of the $698,011 in workers compensation claim dollars spent on slips on ice and snow on outside walk ways and parking lots. Monies spent to repair floors and walking surfaces throughout the plant could offset the $165,495 in compensation claims related to trips surface irregularities. Finally, dedicating staff time and training to the promotion of awareness to keep walking surfaces clean and dry, objects off the floor, site inspections, and housekeeping could have a large impact on the 1.5 million dollars spent on STFs due to slippery surfaces, objects on the floor, and surface irregularities in this plant over approximately 4 years. Clearly, a STF hazard audit and business case is needed to determine the return on investment of prevention measures.

Results have shown similar patterns of preventable STF injuries due to slips on slippery surfaces and trips over surface irregularities as found by Bell *et al*. [2008] in hospitals. It seems reasonable and appropriate to implement and evaluate a STF prevention program in this helicopter manufacturing plant.

Recommendations are as follows:

1. Conduct an audit of the plant to determine where and why surface contaminants are present, surfaces are in need of repair, and objects are trip hazards on the floor. Focus the audit program plant wide but ensure inclusion of high risk areas such as blades and composites department, outside walkways and parking lots, gears and transmission, hanger, and final assembly areas.

2. Repair surface irregularities including holes or cracks in grates, stands, or other walking surfaces, uneven surfaces, mats and rugs with elevated edges, uneven elevator floor with building floor, etc.

3. Examine drainage from downspouts as well as the process for ice and snow removal on outdoor walkways to identify areas where snow and ice build up on walkways.

4. Increase monitoring of walkways for ice melting chemical applications in walking areas.

5. Increase awareness among workers to immediately clean up spills from slippery substances, place caution cones over the slippery area, and remove parts, tools, and other trip hazards from walkways as soon as possible. Conduct periodic audits by supervisors and safety officials to monitor the work place for these hazards.

6. Implement a plant promotional campaign to increase awareness to slippery substances and objects on the floor.

7. Conduct a business case analysis on the return on investment associated with the cost of these interventions assuming significant reductions in preventable injuries. Results of this epidemiologic analysis indicate that a high proportion of STFs are preventable by housekeeping and maintenance activities, that the cost of these preventable injuries is high and would likely offset much of the cost of interventions. An epidemiologic approach to the analysis of STF risk is a good first step in assessing the STF problem in a manufacturing plant and to estimate the return on investment of STF preventions.

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Slips, Trips and Falls: Bad Design or Careless Behavior?

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The paper and presentation addresses how much comparative negligence is contributed by bad architectural choices and environmental design, as compared to humans not being aware or "unconscious" of their surrounding environment. What is the role of the environment versus behavior? The architectural design process has critical steps in developing design criteria, but human factors and ergonomics are not typically given priority over aesthetics. Egress paths of travel are addressed typically in terms of accessibility and fire resistance, but not in terms of walk-ability, safety, including slip and trip resistance. Various national and state codes, as well as standards of care define what safe paths of travel should be, yet in 2007, more than 21,700 Americans died as a result of falls and more than 7.9 million were injured. Falls are the leading cause of injury related deaths among adults 73 year and older and 2nd leading cause of death of persons 60-72. Over 275,000 occupational injuries were caused by slips, trips and falls in 2008 [NSF 2009]. Recommendations are made for improved architectural awareness and understanding of the human factors and ergonomics in the prevention of slip, trip, and fall accidents.

Introduction

Form follows function. That was a familiar tenet of 20th century architecture, originally expressed by the Bauhaus School of Design and popularized in America by architect, Louis Sullivan and his student Frank Lloyd Wright. Yet, most architecture has focused on form rather than function. It is as if the structure itself, harmony with the site, and integrity of the materials has become the function. Less emphasis has been placed on the activities taking place inside the building. As a whole, the profession continues to be dominated by the view that architecture is a matter of aesthetics, and the form only follows form [Wikipedia, Nov. 2006]. "The intrinsic significance of our craft lies in the philosophical fact that we deal in nothing. We create emptiness through which certain physical bodies are to move - we shall designate these physical bodies for convenience as humans. By emptiness I mean what is commonly known as rooms. Thus, it is only the crass layman who thinks that we put up stonewalls. We do nothing of the kind, we put up emptiness." [Rand 1943].

Most people are familiar with the layout and environmental cues of their home or apartment. When we venture into public spaces such as: malls, airports, hotels, stadiums, etc. there is no familiarity of conditions. The frame of reference that protects U.S. at home offers no protection from unfamiliar level changes, steps, holes, or slippery surfaces in public places. Consequently, falls and injuries often result. This paper will address the perception of level changes, design errors, and prevention strategies.

The identification of existing hazards entails a systematic appraisal or user analysis for all possible safety hazards. Those public use environments have a special duty of care to provide safe and easy access, egress, ingress, and walking surfaces.

The first step in identification of existing hazards is where to look for the hazards. The most logical starting point is observing the design and layout for obvious congestion points, code violations, and what features the architect provided for stairs, ramps, handrails, and floor surfaces. Managers or owners of publicly used spaces should review the history of user patterns. Having a good understanding of human factors and ergonomics provides the clues on where and how people have accidents. A review of maintenance inspection and accident/incident reports is another indicator of where problems exist. The second step in identification of existing hazards is what to look for when looking for hazards. The following list is recognized design and construction failures that are contributing factors in stair fall accidents [Rosen 1983]:

- 1,2, or 3 winders
- Open risers
- Single steps
- Doors opening onto a stairway
- Low headroom
- Lack of intermediate landings
- Irregular riser heights,
- Tread depths of 10 inches or less
- Widths of stairs 60 to 66 inches
- Absence of nosing projections
- High door thresholds
- Excessive riser heights
- Low riser heights 6 inches or less
- Improperly elevated handrails
- Synthetic tread coverings
- Improper cross sectional shape of handrail
- Open railings
- Handrails, which are not continuous
- Poor lighting
- Unmarked brick, terrazzo, waxed treads, and smooth marble surfaces
- Loose attachment of carpet or pad
- Walls or posts intruding into stairwell spaces

Thus, the major areas for conscious observation are changes in elevation, stair and ramp geometry, handrail and guardrail design, lighting, the type of landing area in the event of a fall, physical barriers, and the coefficient of friction of adjacent surfaces. One of the key issues in slips, trips, and falls is the lack of perception by the human brain to detect a change in elevation or a change in surface. The brain programs the human walk based on uniform distance. After the first step the brain knows exactly how far to extend the stride to duplicate the prior movement. Any variations from what the brain has learned to expect will result in improper placement of the foot and could result in a slip and fall. 85% of stair accidents occur on the first or last three steps. A one step level change is particularly deadly as the brain is not expecting or easily perceives the change in geometry.

As a result of the brain seeking uniformity, strong environmental cues must be given to increase awareness. Transition zones from one height to another, or one surface material to another, need visual indicators. This notice may be accomplished architecturally through the use of texture, color, bordering, or signage. People walking are typically looking ahead in their field of vision, and not looking at their feet. Thus, level changes or material changes where there are strong visual distractions, or change in light conditions (i.e. dark hallway into bright outdoor light) can create dangerous conditions for the building user.

Another key issue to look for while scoping the site for hazards understands the physical limitations of the walker. Many public use environments have an architectural feature known as monumental stairways. The Nation's Capital, all of the State Capitals, and most of our downtown urban cities has governmental structures that have grand entrances. Often these monumental stairways have risers that are less than six inches, have few or no handrails, often are a marble material, and are usually taxing to climb. These design features are especially taxing to the elderly or handicapped (those not in a wheelchair). If these features exist they may be grandfathered into compliance with building codes. Arrangements must be made to fully accommodate the elderly or handicapped with compliant accessible ramps.

Weather conditions should be evaluated as another important variable in identifying hazards. The building environment will respond in changing ways to rain, snow, summer heat, ice, and wind. All egress points should be carefully designed to allow for drainage of water and prevention of water from entering the building. Door thresholds are one feature that accomplishes the prevention of water seepage. Most thresholds permit entry without incident. However, door thresholds that are improperly designed or are elevated too high create a significant tripping hazard.

The floor material that transitions the outside to the inside should be carefully considered. Most major office towers, banks, and apartment towers have a concrete or granite outside surface which transitions into marble to terrazzo or some slick, smooth, shiny floor material. On rainy or snowy days shoes, dripping raincoats, and umbrellas create a major safety hazard by bringing in water.

After conducting a safety audit of the public use environment for potential hazards, the next major concern is what to do with these identified hazards. The designated person responsible for building upkeep and safety (guard service, maintenance, property manager, owner, tenant or combination thereof) must notify the building management for corrective action. Once the building management or owners are notified that a safety hazard condition exists, the owners and management are put on notice, and further accidents were thus foreseeable and they could be held legally liable. The contribution of design to the prevention of stairway accidents lie mainly in directing attention to the presence of a stairway, level change, or change in surface materials. Design features can focus attention on the stairs and improve the user perception that the steps are clearly defined. Design can provide suitably dimensioned steps. Design can provide handrails for support and assistance and balustrades to prevent falls from the stairs. Design can avoid features that are likely to lead to misuse of the stairway by children. Design can avoid creating decorating and maintenance hazards above the stairs. Careful planning and design can provide the quality and quantity of light to insure uniform light distribution and no glare to assist in perception.

Injury to the user can be a liability issue to the architect and owner of public use spaces. Preventative steps should be taken to reduce or limit legal exposure. Stairs, ramps, and walkway surfaces should meet applicable building codes and national standards. Architects and owners may need to give more consideration to operational directives regarding how materials specified should be properly used. Even if all foresight and good measure steps are taken, there is no guarantee that it will prevent injury or litigation. However, the issue of negligence and standard of care will be more favorable for the responsible architect and owner.

Results

Thousands of people get injured every year, and some killed, in the built environment by either their careless behavior of not paying attention, or by faulty architectural features that contribute to the causal factors of these accidents. Most people walk in their daily lives, in a swirl of distractions: IPods, cell phones, daydreaming, texting, drinking coffee, eating, carrying packages, or children. Human beings in the 21st Century are unconscious of their surroundings and environment until something bad happens (walking into a street and getting hit by a car for not paying attention to the street lights, misstepping off a curb or step; not observing contaminants on the ground or floor and slipping; tripping over a raised or buckling sidewalk; falling downstairs or steps, and not holding on to handrails, etc.). Accidents are a collateral consequence of behavior or lack of it, and the environment. We have greater potential to control the environment than we do of peoples' behavior.

Summary

In achieving the goal of safe and secure buildings, the architect plays a critical role in making the decisions that impact the selection of fixtures, finishes, and furniture. Most architects are not cognizant regarding the considerations of factors that contribute to slip, trip, and fall accidents. Human factors, ergonomics, and premises liability, are not topics taught in architectural colleges and schools or in continuing education courses for practicing architects. The students and practitioners must be taught and made aware of the consequences their unconscious decisions have on the impact of walking behavior. The field of architecture is evolving because of litigation and development of codes and standards to be more aware and sensitive to the decisions and choices of materials, finishes and circulation patterns of the users of the built environment. Education is critical in the evolution of architecture to be safer for its users. Introducing a course that teaches human factors, ergonomics, and crime prevention though environmental design (CPTED) as part their professional practices development will yield future generations of architects and designers that are better informed and equipped to make a safer living, working, and playing environment.

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Slip, Trip, and Fall Injuries to Nursing Home Workers

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There is a growing body of literature on the injuries incurred by nursing home workers. As overexertion injuries are the most numerous, this is where much of the research focus has been. Very little research has focused on slip, trip, and fall (STF)-related injuries in nursing home workers, even though this is a common source of lost-workday injury in this population. The objective of this research is to describe the STF injury experience and trends in a population of nursing home workers, to identify risk factors, and inform future preventive efforts. Workers' compensation injury claims data and payroll data were obtained from 1996 through 2003 from six nursing homes and used to calculate injury rates. Narrative information was used to describe details of the STF events. There was a total of 86 STF-related workers' compensation claims filed over the eight-year period. STF claim rates showed a marginally significant increase over the 8 year period. Most of the STF events were attributed to hazards that can be mitigated, such as water on the floor or loose cords in a walkway. Nursing home workers have a high rate of STF-related injury claims in comparison to other industries, and preventive programs should be evaluated in this industry.

Introduction

There are approximately 3 million nursing home workers [BLS 2009a], and they incurred almost 17,000 lost workday STF-related injuries in 2008 [BLS 2009b]. Slips, trips, and falls (STFs) account for the second largest proportion of lost-workday non-fatal injuries (~ 24%) in all private industry [BLS, 2009c]. In the healthcare and social assistance sector, STFs are of greater importance, also ranking second but at 28% of lost-workday non-fatal injuries. Of the 88 industry sub-sectors [BLS, 2009c], nursing and residential care facilities (NAICS 623) ranked first overall for both total STF (falls from an elevation, falls on the same level, and slips or trips without a fall) and same-level STFs (falls on the same level, and slips or trips without a fall) with rates of 70.4 and 63.0 lost workdays per 10,000 workers, respectively. These rates surpass the all industry rates for total and same-level STFs of 27.4 and 20.3 per 10,000 workers respectively.

Overexertion injuries among nursing home workers are the most numerous injuries [BLS, 2009c], and consequently, this is where much of the research focus has been. To address the issue of overexertion injuries, improvements upon patient handling methods have been implemented and evaluated in the nursing home environment [e.g. Collins et al. 2004, Miller et al. 2006, Alamgir et al. 2008]. In addition to patient-handling injuries, recent research has also focused on the violence-related and needle stick injuries in healthcare, including nursing home workers [Myers et al. 2007, Trinkoff et al. 2008]. These types of incidents are postulated to contribute to high turnover rates in long-term care staff [Karsh et al.2005]. Although STFs are the second highest cause of lost work-day injuries in nursing home workers, research about the risk factors and prevention of STF injuries in nursing home workers is virtually nonexistent.

In a review of injuries to nursing home employees, Castle et al. [2009] also did not address STF injuries in detail. Given the paucity of STF information, the objective of this research is to describe the STF injury experience and trends in a population of nursing home workers, to identify contributing factors, and inform future preventive efforts.

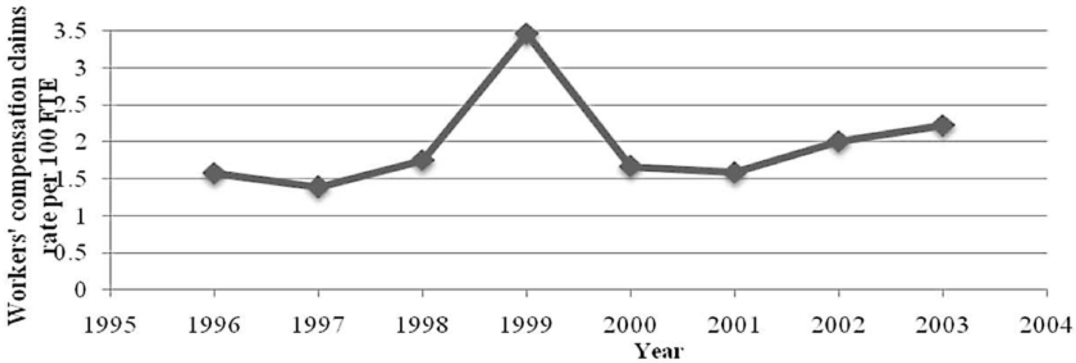

Figure 1. Slip, trip, and fall injury claim rates in nursing home employees, 1996-2003

Methods

Injury and employment data were examined for all employees in six nursing homes from 1 January 1996 to 31 December 2003. All nursing homes belonged to the same non-profit healthcare corporation, covering a total of 552 licensed beds, with facilities ranging in size from 60 to 120 beds. Injuries, hours worked and demographic data were supplied by the healthcare system for all staff employed during the 8-year study period.

Data on worker injuries came from all workers' compensation claims. These records generally included narrative information on the conditions surrounding the injury event. The narrative information for each claim was used to create a detailed coding scheme to identify as many specific details about the circumstances (existing conditions or state of affairs surrounding and affecting the event) of the STF incident as possible to better describe the event.

For denominator data, human resources records were obtained for all nursing home employees and included data on productive hours worked per year, employee date of birth, gender, job title and date of hire. Job titles with similar job tasks were grouped together into larger job group categories. Human resources records were merged with injury records for each employee to calculate rates and were reported as injury claim rates per 100 FTEs per year. Differences between groups of interest and trends in injury rates were assessed using chi-square tests and Poisson regression, using the SAS procedure GENMOD [SAS 1993].

Results

During the eight-year period January 1996 through December 2003, a dynamic cohort of employees worked a total of 8,865,473 productive hours (~4,433 FTEs). Unadjusted STF claim rates showed a marginally significant increase in trend (slope estimate=0.0089, p=0.06) over the eight-year period from 1996 through 2003 (Figure 1).

The 86 STF claims were categorized (based on the information in the claims narrative) to identify the causal factors of the event. The greatest percentage, 33.8%, were attributed to liquid contamination on the floor (water, wet floor, body fluid, grease, wax, gel), 27.9% were STFs, not otherwise classifiable (includes cases where the injury was coded as an STF and the narrative was empty, or the narrative lacked detail, for example "fell while walking", "fell on floor", "slipped and fell"), 10.5% were attributed to tripping on objects (wheelchairs, boxes, open desk drawers, bedspreads, wastebaskets, etc.), 10.4% due to ice or snow, 5.8% due to tripping on electric, phone, and call cords, medical tubing, wires, etc., 4.7% due to outside surface irregularities (holes, curbs, drain dips, etc.), 3.5% due to indoor surface irregularities (mats, carpeting, rugs, etc.), and the remaining 3.6% included falls from elevation (ladder,stairs, into a hole, out of non-moving vehicle) (due to rounding, percentages may not add up to 100.0).The 86 STF events were also grouped into four categories by the first initiating event, slip, trip, misstep,or unknown (not mentioned in the injury narrative). In 44% (n=38) of STF claims, the leading first initiating event was slipping.

Employees were placed into six functional job groupings based on their job title. These were characterized as Nursing, Care Aides (primarily certified nursing assistants and patient care aides), Food Services, Housekeeping, Maintenance, and All Other. Of all six job groupings, the Nursing group had the lowest STF claim rate at 1.19 per 100 FTE and the Care Aide group had the highest STF claim rate at 2.59 claims per 100 FTE. The majority of the claims in the Care Aide group were due to STFs due to liquid contaminants on the floor (34%).

Discussion

National injury data show that nursing home employees are at particularly high risk of an STF injury resulting in days lost from work when their rates are compared to rates found in all private industry [BLS 2009a]. It is not fully known why these workers are at such high risk; it may be that they are exposed to more hazardous conditions, that they have characteristics that make them more likely to fall or sustained injury after a fall, or they are more likely to report injuries. However, Galazzi et al.'s [2010] research shows that many injuries go unreported in the healthcare industry, so it is quite likely that the injury burden sustained by nursing home workers is even greater than it appears. Most of the STF events were attributed to hazards such as liquid contamination on the floor, objects on the floor, or ice/snow that can be mitigated through preventive measures. Previous research identified risk factors and developed and implemented a "best practices" STF prevention program in three acute care hospitals [Bell et al. 2008]. The ten-year longitudinal study demonstrated the effectiveness of the prevention program, and a reduction in STF workers' compensation claims rates by almost 60%. Given the similarities in the hospital and nursing home environments, comparable interventions should be trialed in a nursing home setting.

Drebit et al. (2010) recently performed a large-scale analysis of falls in British Columbia's healthcare sector. In their study, the long-term care sector (nursing home) workers had the highest rate of falls in all of healthcare. Given that Care Aides were also among the highest risk employees within long-term care, evaluation of these workers' specific hazard exposures is warranted so that preventive measures can be better tailored for their work. Bathing and toileting of dependent patients, as an example, may add unique STF hazards to their work. It is hoped that the findings of this paper can direct research towards the high STF risk environment of nursing home workers, with particular focus on Care Aides involved in direct patient care tasks.

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Role of Transverse Shear Force in Required Coefficient of Friction

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The required coefficient of friction (RCOF) represents the minimum friction needed at the shoe and floor interface to support human locomotion. Despite wide use of the RCOF, its extraction from the ground reaction force (GRF) is not standardized. This paper presents a methodology to extract the RCOF. The impact of adding the transverse shear component of the GRF to the instantaneous COF on variables associated with the RCOF were investigated with one participant. The transverse component increased the RCOF in a majority of the successful strikes. The RCOF with the transverse component occurred much earlier than the RCOF without it in a significant portion of the strikes, so the available response time for the human to take reactive actions if a slip incident occurs might be shorter than previously thought.

Introduction

At the shoe and floor interface, required coefficient of friction (RCOF) is the minimum coefficient of friction(COF) needed to support human locomotion, while available coefficient of friction (ACOF) is the maximum COF that can be supported without a slip. When the RCOF for an activity exceeds the ACOF, a slip may occur [Redfern et al., 2001].

The instantaneous COF (ICOF) is calculated by dividing the tangential component of the ground reaction force (GRF) measured with a force plate along the floor surface by the normal component at the same instant. The RCOF is one of the maximums in the ICOF during a step [Redfern et al. 2001]. The GRF consists of three components in the normal, longitudinal (anterior-posterior) and transverse (medial-lateral) directions. An artificially large ICOF might be obtained immediately after heel contact due to a small shear force being divided by a small normal force.

This high COF period is ignored in order to identify the peak COF as the RCOF. Furthermore, there are different ways to obtain the RCOF. One choice is whether or not to ignore the transverse component of the shear force which is usually much smaller than the longitudinal component.

There is no standardized method to extract the RCOF from the GRF despite wide use of the RCOF in the literature. Buczek et al. [1990] extracted the RCOF by identifying the maximum ICOF value obtained by dividing the resultant shear force, a vector sum of the longitudinal and transverse components, by the normal component at each time instant when the normal force exceeded the threshold value of 50 N. Burnfield and Powers [2007] added an additional requirement that the shear force for foot sliding has to point forward. Other methods to identify the RCOF were based on time from heel contact or percentage of the stance phase in a gait cycle. Cham and Redfern [2002] reported that for level walking on a vinyl floor the RCOF occurred at 16.5% (S.D. 2.4%) of the stance phase. Strandberg [1983] reported that the RCOF occurred at 91 ms after heel contact with a standard deviation of 25 ms. The extraction of the RCOF from the same data with different methods could result in very different RCOF values, so the process needs to be standardized in order to compare difference RCOF values across various laboratories.

The objective of the current study was to develop a methodology for extracting the RCOF from the GRF. The impact of including the transverse component of the shear force on the RCOF, the time from heel contact to the instant of the RCOF (variable Time), and the normal force at the instants of the RCOF were investigated.

Methods

A straight walkway approximately 12.2 m long and 1.56 m wide was constructed with three force plates installed midway along the length [Chang et al. 2008]. Quarry tiles, approximately 15 by 15 cm in size, were laid on top of the walkway. The walkway was kept under dry conditions. Data from one male participant is presented. The weight, height and age of the participant were 97.1 kg, 177cm and 45 years old, respectively. The participant, screened to assure no active musculoskeletal disorders, gave written informed consent to participate in a protocol approved by an institutional review board. During the experiment, the participant walked at self-selected normal and fast speeds. Two types of footwear, a leather loafer and a sneaker, were used. Two factorial designs were randomized with 4 walking conditions:loafer-fast (LF), loafer-normal (LN), sneaker-fast (SF) and sneaker-normal (SN).

A sampling rate of 1000 Hz for the force plates was used. The fourth order zero-lag Butterworth low pass filter with a cut-off frequency of 36 Hz was used to process the force plate data. The RCOF values from each successful strike were extracted using two methods. The longitudinal component of the shear force was divided by the instantaneous normal component to obtain an ICOF in the first RCOF method, with an output called RCOF1 in the subsequent analyses. A positive value of the longitudinal component indicates that the shear force is pointing forward. The ICOF for the second RCOF method was obtained by dividing the vector sum of the longitudinal and transverse components by the instantaneous normal component, with an output called RCOF2. The sign of the longitudinal component of the shear force was used as the sign for the resultant shear force for indicating the direction (Buczek and Banks, 1996). When the ICOF has a positive value, the shear force is pointing forward.

The search for the RCOF started with a threshold of the normal force, just like the method used by Buczek et al. [1990]. In addition, the longitudinal shear force must point forward at the instant of the RCOF. To avoid the end of the period with the artificially large ICOF when the normal force reached the threshold value, the RCOF was only considered when the ICOF was increasing with time. Also, a peak COF might exist near the mid stance for the RCOF2 when the normal force decreases, as found in a few cases. A limit of 200 ms after the heel contact was used to eliminate this possibility. The heel contact was defined as the instant at which the normal force reached 10 N [Lockhart et al. 2003]. The maximum ICOF that satisfied these requirements was the RCOF of that strike. If a peak in the ICOF occurred at the instant that the longitudinal component switched direction, this peak would be the RCOF as long as the rest of the requirements above were satisfied. All the contact forces were divided by the body weight of the participant to obtain dimensionless contact forces. The dimensionless normal force at the instant of the RCOF (variable Normal) was identified and also recorded. The RCOF and Normal were compared up to six digits after the decimal point and the Time was compared up to ms. A paired comparison was carried out for each walking condition for each dependent variable (the RCOF, Normal and Time) under both methods for the RCOF (RCOF1 and RCOF2). A regression analysis between the RCOF1 and RCOF2 was also carried out for each walking condition, where the RCOF2 was an independent variable.

Results

The sample sizes for each condition were 151, 167, 154 and 148 for LF, LN, SF and SN, respectively. The normal force threshold was 100 N across all successful strikes. The GRF and ICOF of the first 200 ms after heel contact for a successful strike generated by this participant under the walking condition of LN are shown in Figure 1, in which Fx, Fy and Fz are the dimensionless longitudinal, transverse and normal components, respectively. In this example, the transverse component was small compared with the longitudinal component except shortly after the longitudinal component changed from backward to forward at 24 ms after heel contact. A small local peak existed in the ICOF when the transverse component was ignored (COF1) right after the longitudinal component changed its direction. This local peak was increased further by adding the transverse component to the total shear force (COF2). The RCOF2 in this example was 0.224 at 39 ms after heel contact at the Normal of 0.348, while the RCOF1 was 0.207 at 123ms after heel contact at the Normal of 1.056. In this example, the transverse component also reached its local peak at the instant when the RCOF2 occurred, i.e, the occurrence of the RCOF2 was caused partially by the peak in the transverse direction. The local peak in the ICOF with only the longitudinal component occurred 1ms later than the RCOF2 in this example.

The results of the paired comparisons indicated a statistically significant difference with $p < 0.001$ between RCOF1 and RCOF2, between Normal at RCOF1 and RCOF2, and between Time at RCOF1 and RCOF2 for every walking condition.

the variable Normal at RCOF2 was less than that at RCOF1 with an average difference of 0.321, while 150 strikes had a higher normal force at RCOF2 than at RCOF1, with an average difference of 0.082.

The averages and standard deviations for the variable of Time at RCOF1 and RCOF2 were 92.1 ± 27.2 and 84.9 ± 34.6 ms, respectively.

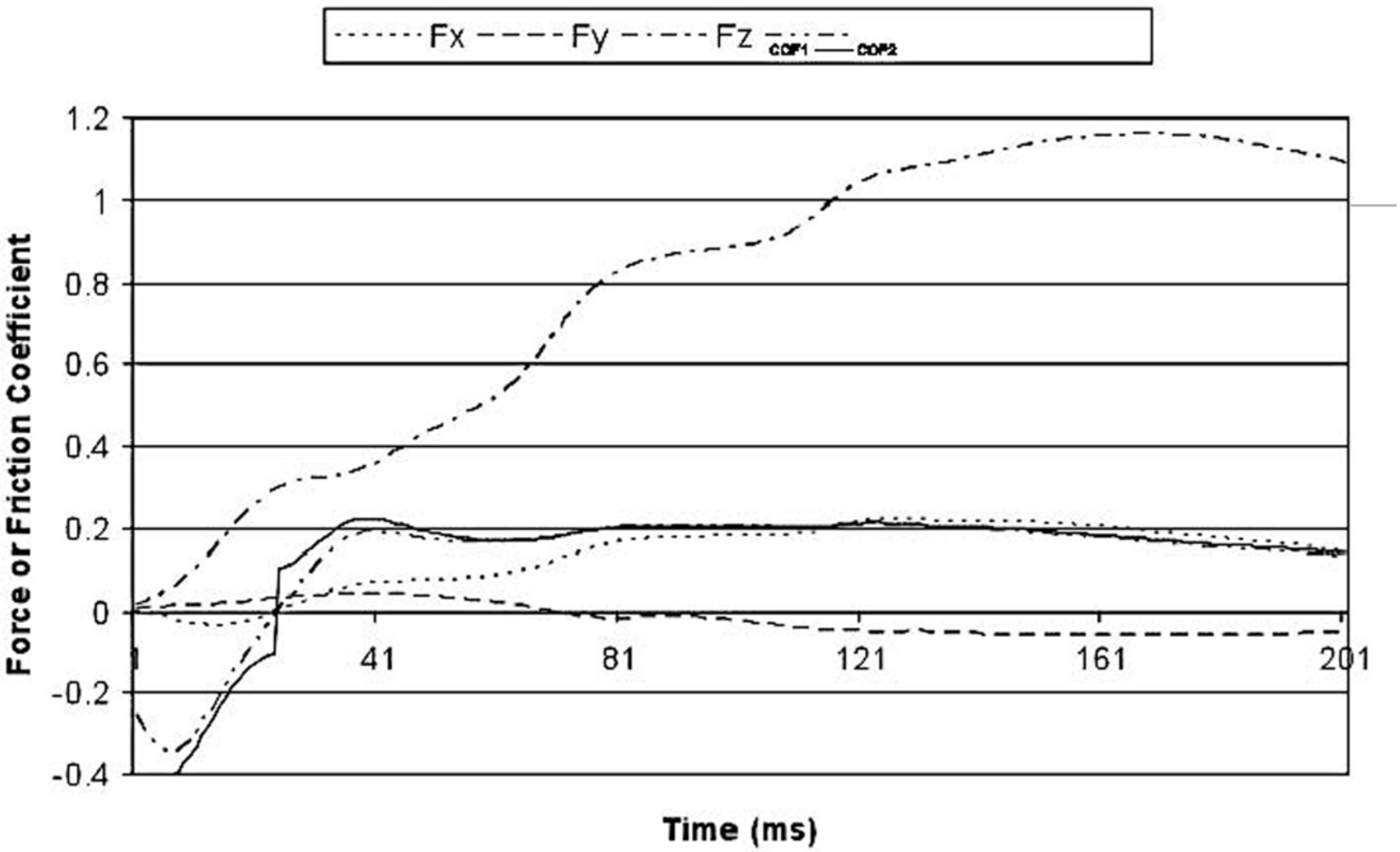

Figure 1. GRF and associated COF values in the first 200 ms after heel contact of a successful strike Note: Fx, Fy and Fz are the dimensionless longitudinal, transverse and normal components of the GRF,respectively.

The averages and standard deviations for the RCOF1 and RCOF2 were 0.205 ± 0.022 and 0.216 ± 0.022,respectively. The RCOF2 was greater than the RCOF1 in all strikes except one. All the regression equations were statistically significant ($p < 0.0001$). The slopes of the regression equations (coefficients for the RCOF2)were 0.73, 0.76, 1.05 and 1.12, and the intercepts were 0.04, 0.04, -0.02 and -0.03 for LF, LN, SF and SN,respectively. The correlation coefficients between the RCOF1 and RCOF2 were 0.92, 0.83, 0.97 and 0.97 for LF, LN, SF and SN, respectively, with $p < 0.001$. The averages and standard deviations of the variable Normal for RCOF1 and RCOF2 were 0.960 ± 0.213 and 0.872 ± 0.291, respectively. There were 208 strikes where

In 207 of 620 successful strikes for Time, the RCOF2 occurred earlier than the RCOF1, with an average difference of 35.7 ms, while 151 strikes had an earlier RCOF1 than RCOF2, with an average difference of 19.5 ms. The numbers of strikes in which the RCOF2 occurred earlier than the RCOF1 were 82, 110, 8 and 7 for the walking conditions of LF, LN, SF and SN, respectively.

Discussion and Conclusions

As one of the important parameters in the research of slip incidents, the RCOF has been correlated with some kinematic measurements [Cham and Redfern, 2002; Lockhart et al., 2003].

It has also been used to compare with the ACOF in the estimate of slip probability [Chang, 2004]. The results presented in this paper indicate that the RCOF actually increased if the transverse component were taken into account. Without the consideration of the transverse shear component in the RCOF, the associated risk can be underestimated. The correlation between the RCOF and kinematic parameters and the estimate of the slip probability could be improved by adding the transverse component.

The RCOF was determined by the magnitudes of several local peaks in the ICOF in the same strike, so the differences might be small; however, there were greater changes in the values of the variables of the Normal and Time. More than half of the successful strikes had the same instant for RCOF1 and RCOF2, but a significant portion of strikes had different instants for RCOF1 and RCOF2. Much larger differences were observed in the values of the Time and Normal variables if the RCOF2 occurred before the RCOF1 rather than vice versa. The results imply that a slip initiation might occur much earlier in a gait cycle than what has been commonly thought and that, without a firm early heel contact with the floor, the available response time for the human to take reactive actions if a slip incident occurs might be shorter than previously believed. One reason why the RCOF2 could occur before the RCOF1 was that the participant could exert a relatively larger transverse shear force compared with the longitudinal component right after heel contact as shown in Figure 1. The results in this study show that this participant had a higher number of strikes with an earlier RCOF2 than RCOF1 for LF and LN, but lower for SF and SN. The differences suggest that the outcomes of the experiment might depend highly on the shoe used.

In summary, this paper presents a methodology for extracting the RCOF from the GRF. Despite a wide use of the RCOF in the literature, the methods used to extract the RCOF have varied across different laboratories based on their empirical experience. This variation makes it difficult to compare the results across laboratories. More objective criteria with certain built-in restrictions were used in the method presented in this paper. The contribution of the transverse component of the shear force to the RCOF, typically ignored in the calculation of the ICOF, was examined. The transverse component actually resulted in a higher RCOF than without it in the majority of the successful strikes.

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Effect of Boot Weight on Gait Characteristics of Men and Women Firefighters in Negotiating Obstacles

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This study investigated the effect of boot weight on gait characteristics of men and women firefighters in negotiating obstacles. Twelve men and nine women professional firefighters, while wearing full turnout gear and different boots of varying weights, walked for five minutes while stepping over two 30-cm and two 15-cm height obstacles. The results indicated that boot weight and task duration affected firefighters' gait characteristics in negotiating obstacles. For each one kg increase in boot weight, there was a 2.8 cm decrease in toe-obstacle clearance when crossing a 30 cm obstacle. Significant decreases in toe-obstacle clearances and increases in lateral displacement of the foot were also found after 5-minute walking tasks compared to the beginning of the task. Based on these findings, firefighters may be more likely to trip over obstacles when wearing heavier boots and after walking for a period of time. Findings of this study provide useful information for firefighters and boot manufacturers in boot selection and design, as well as recommendations for preventing trips and falls.

Introduction

Firefighting is one of the most dangerous jobs in the United States with the work-related injury rate exceeding those of most occupations [Walton et al., 2003]. In 2007, an estimated 80,100 firefighter injuries occurred in the line of duty [Karter and Molis, 2008]. Fall-related injuries were the top leading cause accounting for 27.3% of the total fire ground injuries, followed by overexertion (24.4%) [Karter and Molis, 2008]. In firefighting and rescuing operations, firefighters are exposed to a varied, complex, unpredictable and rapidly changing environment. They are constantly exposed to chemical and physical hazards, such a carbon monoxide, heat, and noise. They also frequently work on roofs and ladders and the walking surfaces are often cluttered or slippery due to the existence of debris, building materials, or contaminants.

Firefighters' personal protective equipment (PPE) is designed to provide a high level of protection against extremely adverse environments. Nevertheless, the use of PPE may pose an additional load on the firefighters, restricting their movements [Adam and Keyserling,1995], impeding job performance [Krausman and Nussbaum, 2007], and increasing the risks for slip-and-fall injuries. Firefighters have traditionally worn heavily insulated rubberized boots as protective footwear, which can add 10 pounds of extra weight to a firefighter. Previous studies have documented the evidence on the effect of PPE on firefighters' postural balance [Punakallio et al., 2004]. The heavy weight of firefighter boots has been shown to significantly increase the physiological stresses of firefighters [Turner et al., in press]. The effects of boot weight and design on firefighters' locomotion efficiency, however, are still unknown. A few articles on the evaluation of military boots were found [DoMoya, 1982;Rosenblad, 1988]. There have been little to no previous attempts to show how boot weight may affect firefighters' gait and might be an important factor in fall injuries.

Method

Subject and Boot Characteristics

The objective of this study was to investigate the effect of firefighter boot weight on firefighters' gait characteristics and risks for fall injuries while negotiating obstacles. Twelve healthy men (28.9±5.0 years) and nine healthy women (35.3±3.1 years) professional firefighters between the age of 23 and 39 years old participated in the study. All subjects provided informed consent and were free of neuromuscular dysfunction, history of dizziness,vestibular disorders, and fall injuries in the past year. Male subjects were recruited from West Virginia, while women participants were recruited from western Maryland, northern Virginia, eastern Ohio and West Virginia.

Four models of firefighter boots conforming to National Fire Protection Association [NFPA]1971 Standards for structural firefighting were selected for the study. These boots were pull up bunker boots that were commercially available. The four models of boots represent two models of leather boots, one model of leather/fabric hybrid boots, and one model of rubber boots. The boot characteristics are shown in Table 1. The sole flexibility was determined by the Longitudinal Stiffness of Footwear Testing based on the TM 194 procedures of the UKSATRA Technology Center.

Test Protocol

The test protocol involved subjects walking along a 6.3-meter path and stepping over two 15-cm and two 30-cm obstacles. The participants, while wearing full turnout gear and randomly assigned boots, walked from one end of the walkway, stepping over four obstacles to travel to the other end. They then turned around and continued walking and crossing obstacles for five minutes at a speed of 0.57 m/sec. The walking speed was paced using a metronome. A 6-camera motion analysis system (Peak Motion Analysis System™, Vicon Inc., Centennial, CO) was used to collect 3D marker trajectory data at 60 Hz and low pass filtered using a fourth-order Butterworth filter with a cutoff frequency of 6 Hz. Two ten-second trials of kinematic data were collected during the five-minute walk, one in the beginning after 30 seconds of walking and the other during the last 30 seconds of walking. Each subject was allowed to select his or her preferred limb for leading over the obstacle. A total of 8 reflective markers were placed on the subjects at the toe, heel, 5th metatarsal joint,and the ankle to monitor gait patterns and rear foot motions for both leading and trailing feet. Two markers were placed on the two ends of each obstacle to define its position in the 3D-space. The obstacles were made of light-weight PVC pipes measuring 3.5 cm diameter and one meter in length. They posed little to no risks of falls if contacted.

Table1. Boot Characteristics by Model

Boot Model	A	B	C	D
Upper material	Leather	Leather	Leather/ Fabric	Rubber
Sole flexibility*	More Flexible	Less Flexible	Less Flexible	More Flexible
Boot wt (men)	3.1 (0.1)	2.9 (0.1)	2.5 (0.1)	3.8 (0.1)
Boot wt (women)	2.5 (0.1)	2.4 (0.1)	2.0 (0.1)	3.3 (0.04)
Boot length (men)	31.2 (0.9)	31.2 (0.8)	30.9 (0.9)	30.7 (1.0)
Boot length (women)	27.1 (0.9)	27.0 (0.8)	26.5 (1.0)	26.8 (0.6)
Boot width (men)	10.8 (0.2)	10.1 (0.2)	10.6 (0.2)	11.1 (0.3)
Boot width (women)	9.6 (0.2)	9.0 (0.2)	9.6 (0.2)	10.1 (0.2)

Note: standard deviations are shown in parenthesis; * SATRA TM 194 Testing performed Boot weights are in kg and boot length and width are in cm.

Results

The motion data were analyzed from the toe-off of the trailing foot before stepping over the first obstacle to the heel strike of the trailing foot after crossing the second obstacle. Swing foot trajectories were assessed through the examination of crossing step length, toe obstacle clearance, lead foot heel strike distance, and trail foot approach distance. The cross step length was the distance from the trailing toe-off to the leading heel contact. Toe obstacle clearance was defined as the vertical distance between the toe and the top of the obstacle at the instant when the toe was directly above the obstacle. The heel strike distance was the distance from the lead heel to the obstacle, while the trailing foot Approach distance was the distance from the trailing toe to the obstacle. During testing it was observed that subjects tended to displace their crossing limb laterally when clearing the obstacle. Therefore, the lateral position of the lead foot was quantified, which is the horizontal position of the lead toe from the stance foot at the time when it crossed over the obstacle. Data from successful trials for which the subjects stepped over the obstacle without contacting the obstacle were included in the analysis. Of all 168 trials collected, 19 (11.3%)tripping incidents occurred. All tripping over obstacles occurred with the trailing foot. Repeated Measure Analyses of Variance (ANOVAs) were performed to test the effect of gender, boot weight, boot sole flexibility, and time period (beginning vs. end of 5-min walk)on the temporal-distance variables. The effect of boot weight and time period was found to be significant on trailing foot toe-obstacle clearances for both high and low obstacles ($p < 0.02$). As the boot weight increased, the toe-obstacle clearances decreased. For each one kg increase in boot weight, there was a 2.8 cm decrease in toe-obstacle clearance for the taller obstacle. Subjects were able to maintain a toe-obstacle clearance of 23.5 cm in the beginning of the walk (Figure 1); however, the clearance was decreased to 21.9 cm near the end of the 5-minute walk over the high obstacle ($p < 0.05$). In addition, significant differences were observed for lateral toe position by gender ($p < 0.01$) and time period ($p < 0.03$). On an average, the lead toe was initially 42 cm to the right of the stance foot when crossing the high obstacle, but it was increased to 46 cm near the end of walk. Women firefighters were found to displace the toe farther away from the stance foot than the men firefighters (Fig. 2).

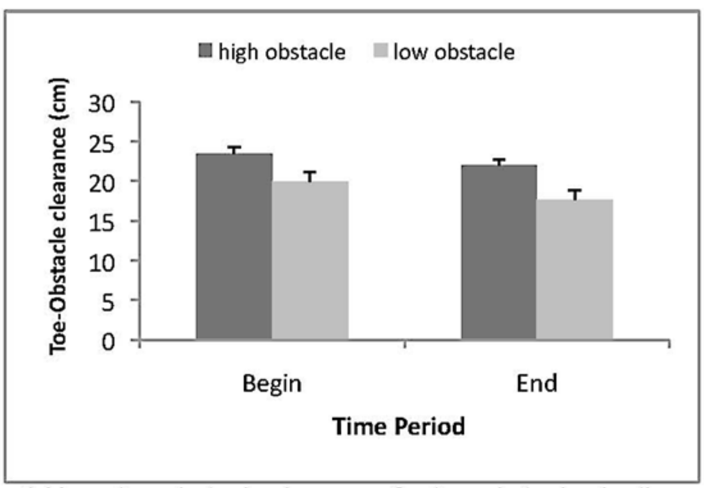

Figure 1 Mean toe-obstacle clearance for two obstacles by time period

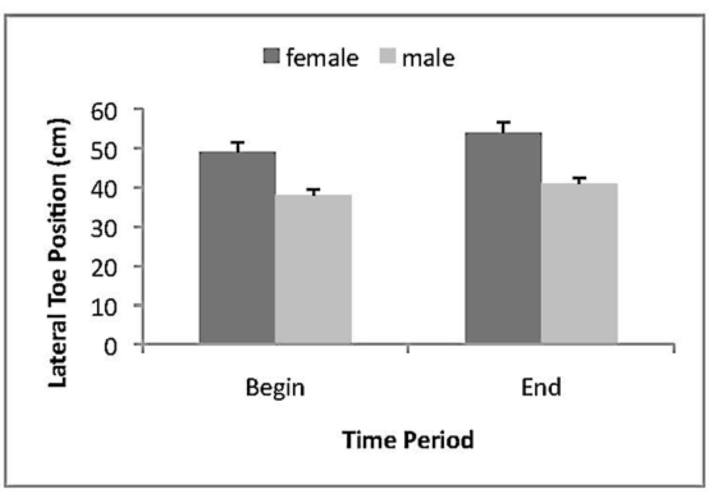

Figure 2 Mean lateral toe position by gender and time period

Summary

Successful navigation through the fire ground necessitates effective avoidance of obstacles and securing adequate footing. In this study, the toe-obstacle clearances significantly decreased as the boot weight and task time period increased. Insufficient toe-obstacle clearances often result in unsuccessful obstacle avoidance at the job site and may lead to loss of balance (Krell and Patla, 2002). Results from this study indicated that boot weight and task time period affected firefighters' gait characteristics in negotiating obstacles. Subjects were more likely to trip over obstacles when wearing heavier boots and after walking for a period of time. Men and women firefighters adopted different kinematic strategies in negotiating obstacles. By swinging the foot outward, female subjects increased the toe height to help maintain toe clearance above the obstacle. Findings from this study may provide scientific evidence for firefighters and manufacturers in boot selection and design for preventing falls on the fire ground.

The findings and conclusions are those of the author and do not necessarily represent the views of NIOSH. Mention of any products does not constitute the endorsement of NIOSH.

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Study on Trip Probability Against Obstacles During Locomotion

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Trip accidents normally occur in workplaces, as well as in normal life. During locomotion, trip accidents happen when the balance of the human body is lost and, in advance, at least one foot is required to contact with the obstacle. Best and Begg [2008] pointed out that minimum toe clearance could be used to evaluate trip probability. Twenty male and fifteen female subjects participated in this experiment. After the marker sets were attached to their feet, the subjects were instructed to walk on a level surface at their freely selected speed. The position of the toe and heel was indirectly measured by a virtual tracking method. With a total of 353 trials, the trajectory of the toe was determined, assuming that they are normally distributed. In addition, the probability that the toe would contact with the obstacle was calculated.

Introduction

Slips and trips are commonly cited as the major causes of falls. However, little research has been performed so far on trips, as compared to slips. During locomotion, trip accidents happen when the balance of the human body is lost and, in advance, at least one foot is required to contact with the obstacle. Researchers have recognized the importance of minimum toe clearance (MTC) because the foot travels with its maximum horizontal speed in the gait cycle around this instant.

Despite similar results about MTC from previous researches [Begg et al. 2007; Karst et al. 1999; Winter 1991]. many countries have set different standards to prevent tripping accidents [BAuA 2008]. According to BAuA's study, the regulations describe the height of an obstacle between 10 mm and 30 mm. This big variance is because there is no evaluation method of an individual's foot contacting obstacles during locomotion.

Best and Begg [2008] have calculated the tripping probability. A single subject was used in this study. The calculation focused on the MTC variability during the gait cycle. MTC is evidently the most important factor influencing the tripping which could be followed by a fall, but it is not the only cause of tripping during locomotion. The objectives of this study were, firstly, to identify the foot trajectory during the gait cycle and, secondly, to calculate the tripping probability.

Method

Participants

Twenty males (age 26.9 ± 4.5 years) and fifteen females (age 24.9 ± 4.7 years) were studied. Through the health and fitness questionnaire, participants were checked as being free of conditions which might impair normal locomotion. The study was approved by the Research Ethics and Sincerity Committee of the Occupational Safety and Health Research Institute (OSHRI).

Table 1. Body dimensions of participants

Variables	Male mean (SD)	Female mean (SD)
Age(years)	26.9 (4.5)	24.9 (4.7)
Body mass(kg)	70.2 (14.3)	50.9 (5.0)
Height(cm)	174.6 (6.8)	158.9 (4.2)
Crotch height(cm)	75.6 (4.0)	68.3 (3.0)

Experimental set up and procedure

Due to the interference during locomotion, it is impossible to attach markers directly to the toe and heel in order to measure the foot clearance with the surface. Their position could be tracked as a virtual point referring to the marker set. Therefore, participants were provided with shoes fit for them individually, and two marker sets were attached to the right shoe in advance.

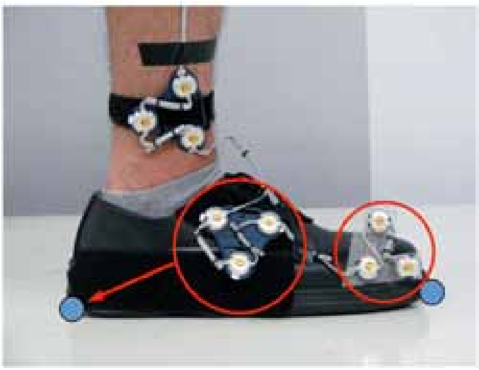

Fig. 1 Virtual points of toe and heel using marker sets

The participants walked on a 10 m long floor at a self-selected speed and foot clearance data was collected using the OPTOTRAK CERTU.S. (NDI, Canada). To cover the whole floor, two OPTOTRAK CERTU.S. systems were used, and the registration to match the coordinates of two devices was performed prior to the measurements whenever they were moved. One marker set was also attached to the floor to define the origin and the axes of the global coordinate. At least 10 trials for each participant were performed, and the data was simultaneously checked.

Data analysis

Data was analyzed using a Visual 3D (C-motion Corp.). Some trials were discarded because the data was incomplete. As a result, there were 196 trials for males and 157 trials for females that were analyzed. Heels trike and toe off were determined on the basis of kinematic data. One swing phase data was extracted from every trial. To eliminate the effect from the individual's physical differences, data was normalized to 100% of the swing phase. To calculate the tripping probability, it was assumed that foot clearance data is normally distributed. After determining the mean and standard deviation values of each point during the swing phase, the cumulative distribution function was acquired from the probability density function as follows.

$$f(h) = \int_0^h P(x)dx = \int_0^h \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)dx$$

Results

Fig. 2 shows the mean values of the foot trajectory for males and females during the swing phase. The MTC is recorded to be 1.58±0.77 cm for young adults (1.81±0.77 cm for males and 1.28±0.65 cm for females). This value is within the range reported by previous research [Begg et al. 2007]. Table 2 shows the mean and standard deviation of foot clearance at major points in the swing phase.

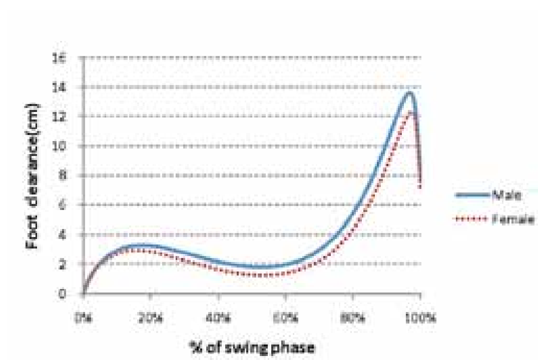

Fig. 2 Foot trajectories during swing phase

Table 2. The mean and SD of each point

% of swing phase	Total		Male		Female	
	mean	SD	mean	SD	mean	SD
9.7	2.8	1.0	2.9	1.1	2.7	0.8
20.2	3.1	1.1	3.3	1.1	2.9	1.1
29.6	2.6	1.1	2.8	1.0	2.3	1.0
39.6	2.0	1.0	2.2	1.0	1.7	0.9
50.0	1.6	0.8	1.8	0.8	1.3	0.7
60.4	1.8	0.7	2.0	0.7	1.4	0.6
70.6	2.8	1.1	3.1	1.2	2.3	0.8
80.2	5.1	1.8	5.5	2.0	4.5	1.3
90.3	9.7	2.5	10.4	2.7	8.8	1.8
97.0	13.1	2.3	13.6	2.5	12.3	1.8
100.0	7.4	1.6	7.8	1.8	7.0	1.2

Fig. 3(a) and 3(b) represent the tripping probability at each point of the swing phase according to the height of the obstacle. At the early stage of the swing phase, there is no significant difference between the males and females in the trip probability against the obstacle, since the foot clearance of the males and females was not very different. However, in the interval where the foot clearance is very different between the males and females, the trip probability is also distinctively different. The thick line in the figure represents the tiptoe trajectory, while the thin lines represent the tripping probability obtained from the standard cumulative distribution function.

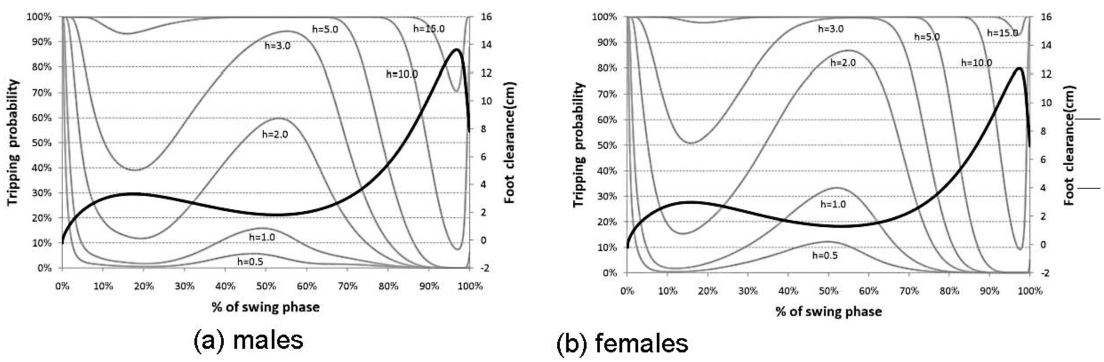

Fig. 3 Tripping probability according to height at each point of swing phase

The tripping probability of one step can be obtained by integrating the cumulative distribution function at each point according to the obstacle height over the entire swing phase interval, and it is shown in Fig. 4 and table 3.

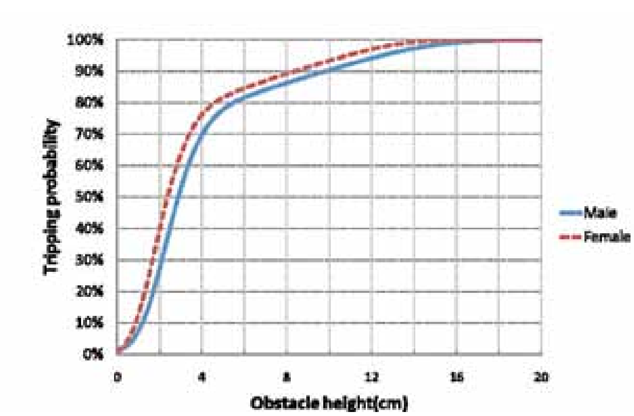

Fig. 4 Tripping probability for one step

Table 3. Tripping probabilities

Obstacle (cm)	Male	Female
0	0.8%	1.1%
0.3	1.8%	2.7%
0.6	3.5%	5.7%
0.9	6.1%	10.4%
1.0	7.3%	12.4%
1.2	10.0%	17.0%
1.5	15.3%	25.1%
1.8	22.0%	33.9%
2.0	26.9%	39.7%
3.0	52.5%	63.3%

Conclusion and Discussion

In a conventional study [Best and Beg 2008], trip probability was calculated based only on the MTC, not on the entire locomotion. The points of MTC are the points of maximum locomotion speed, so trip probability at those points is definitely high if there is an obstacle. However, the assumption that an obstacle be located only at those points is not reasonable, and the calculation of trip probability over the entire locomotion is appropriate. On the other hand, the trip probability in this study is based on the assumption that the participants should not recognize the existence of the obstacle. Since it is not appropriate to assume that foot contact with an obstacle always leads to an accident, further study in this regard should be performed.

As shown in the results, due to the characteristics of human walking, trip cannot be perfectly prevented if an obstacle is not recognized, however low it might be. Thus, limiting obstacle height to reduce trip accidents is a matter of how much the probability is to be accepted. This may be the reason why the regulations as regards to obstacle height vary from country to country. From this point of view, the method suggested in this study can be used in calculating the probability of a foot contacting with an obstacle and the tripping probability under various conditions.

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Fashion Footwear and the Risk of Falling in Young Women

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According to the American Academy of Orthopedic Surgeons, the purpose of shoes is to "protect your feet and prevent injury." Current choices in footwear frequently go beyond this basic function and take on different forms to meet consumers' fashion and comfort desires. Although both men and women have many choices in non-prescription footwear, there is a greater variety in women's shoes. Footwear's influence on gait and the potential for falls in older women (aged 65 years and older) has been previously investigated; however, falls among women are not limited to the elderly. This paper presents a review of previous research relating footwear to gait parameters, with an emphasis on fashion footwear worn by young and middle-aged women (20 to 65 years old).

Introduction

According to the American Academy of Orthopedic Surgeons, the purpose of shoes is to "protect your feet and prevent injury" [AAOS, 2010]. Current choices in non-prescription footwear frequently go beyond this basic function and take on different forms to meet consumers' fashion and comfort desires. Although both men and women have many choices in footwear, there is a greater variety in women's shoes, ranging from thong sandals to stiletto high-heels, and incorporating a wide mix of styles in between (e.g., mules, oxfords, flats, pumps, etc.). Footwear is a choice made by the wearer, and thus is a potentially modifiable factor that may predispose an individual to falling. The effects of footwear on both gait and risk of falling has been investigated, and research has shown that heel height affects gait kinematics and kinetics. However, aside from high heels, research has not specifically addressed a relationship between fashion footwear and gait performance in younger women. Multiple research studies have identified other characteristics of footwear, such as heel collar height and mid sole hardness, as factors affecting balance and fall risk among persons age 65 and over ([Menant et al. 2008b] and these data may provide insight into the effects of wearing different styles of fashion footwear.

Talbot et al. [2005] surveyed 390 men and women (age 20 to 92) who experienced a fall in the previous two years. They found that during ambulation (walking, turning, or standing), women fell more frequently than men in both the younger (25 to 45 years) and middle age (45 to 65 years) age groups, with 45% of falls for young female fallers (N = 31) versus 13% for young male fallers (N = 23). Conversely, 39% of the young males' falls occurred during sporting activities, compared to 10% of the young women's falls. The authors reported more similar percentages during ambulation for middle aged women (N = 90) and men (N = 41), 46% versus 42%. Although the sample sizes were small, the trend indicates young and middle age women are falling more frequently during ambulatory activities than men in the same age groups.

Talbot et al. also asked participants to identify the perceived cause of the fall. They report that, across all age groups, the percentages of men and women attributing the perceived cause of the fall to accident/environment and balance/gait impairment were similar (39.1% versus 35.5%, and 39.1% versus 38.7%, respectively). In their evaluation, footwear was only considered as an "environmental" factor, included with "wet surface/slippery footwear." Thus, it is not possible to determine if specific characteristics of footwear were related to the reported falls. The National Inpatient Sample (NIS) database was sampled for falls occurring on level ground involving both men and women between 1998 to 2007. As shown in Figure 1, the data demonstrates that while hospitalization due to a fall is more likely in the elderly, younger patients are also admitted to the hospital after falls, and women are more frequently hospitalized after a fall than men when older than 20 years of age.

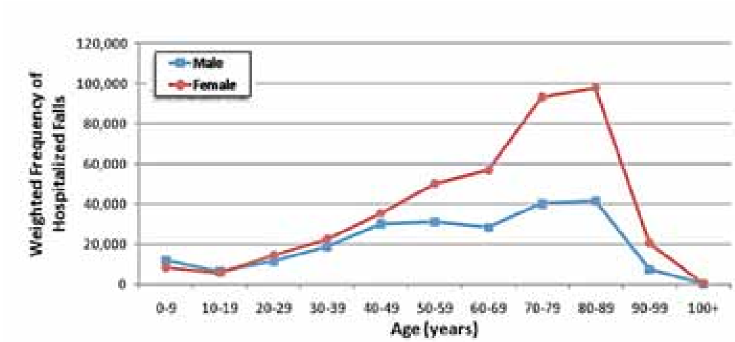

Figure 1: NIS data for male and female falls on level ground from 1998 to 2007.

Since men and women in the age groups between 20 and 65 years should reasonably be expected to move about in similar environments, and age related changes should not have a role, specific characteristics of footwear appears to deserve further consideration. We suggest that characteristics of fashion footwear (e.g.,heel height, heel collar height, and sole stiffness) worn by women in this age group may be a factor in the likelihood of a fall.

In the remainder of this paper, we consider the characteristics of fashion footwear that may be related to an increased risk of falling among women aged 20 to 65. We have limited our review of published research to the effects of specific footwear characteristics of heel height, heel collar height (or lack thereof), and sole stiffness. These characteristics were chosen because they are believed to be relevant to the multiple styles of women's fashion footwear (e.g., high heels, mules/clogs, thong sandals, wedges (strapped or strapless), etc.). As heel height has been identified as a specific risk factor for falling, our initial discussion addresses this footwear characteristic. We then proceed by discussing how information gained from studying footwear characteristics can be generalized to gain insight into the biomechanical implications of women's fashion footwear.

Discussion

Changes in Women's Gait due to High-heeled Shoes

Researchers have shown that wearing high heeled shoes can result in differences in gait kinematics and kinetics in women. Schwartz et al. [1964] demonstrated that women's heel height increased the forces between the floor and the forefoot and that the distributions of forces across the forefoot are altered by heel height. Specifically, they found that forces increased over the first metatarsal head and decreased over the fifth metatarsal head as heel height increased. They postulated that these changes in force distribution were consistent with the increased pronation associated with the instability of wearing high heels with small weight bearing surfaces. Merrifield [1971] investigated gait variables such as stride length, step length, stride width, and foot angle in young women who walked in both flat shoes and in high heels and found significant decreases in stride length and step length when the women wore high heels. Merrifield et al. discussed how high-heeled shoes raised an individual's center of gravity, thereby lessening their stability, which was manifested in a more conservative gait pattern with smaller strides and steps. This finding was supported in an investigation of women ascending and descending stairs in high heeled shoes, which showed that they also adopted a more conservative gait pattern compared to when wearing sneakers [Heller et al. 2008]. Another study quantified joint angles during low heel and high heel gait and found significant differences in knee and hip kinematics during the gait cycle when the subjects were walking in high heeled shoes [Opila-Correia, 1990]. Because the effectiveness of the ankle plantar flexors is reduced during stance in high-heeled shoes, hip flexion is exaggerated to compensate and assist in limb advancement [Esenyel et al., 2003]. Additionally, the required energy for walking has been shown to increase with increased heel height [Ebbeling et al., 1994].

While differences in gait kinematics and kinetics due to high-heeled shoes have been studied extensively in women under 65 years of age, the gait parameters associated with other characteristics of women's fashion footwear have not been investigated as comprehensively in this population. The next section provides a summary of the research that has been conducted on other footwear characteristics and discusses generalizations that can be made to falls among women 65 years and under when wearing these types of shoes.

Effects of heel collar height and sole stiffness to falls

In the absence of a high heel, women's fashion footwear can still have a variety of features that deviate from a standard lace-up or slip-on shoe often worn by men. A literature search did not reveal any studies that directly investigated the biomechanical effects of such features on young females' gait. However, the available literature does provide insights into the potential biomechanical effects of certain characteristics of fashion footwear.

Studies have found that mid sole thickness, mid sole hardness, and outer sole hardness affect balance, with softer, thicker materials leading to a decrease in stability [Robbins et al. 1994; Menant et al. 2008a, 2009a]. These studies involved young and older men and women wearing athletic shoes and oxfords, thus a direct relationship regarding characteristics of women's fashion footwear cannot be made. However, a thong sandal with a soft outer sole might reasonably be expected to impair balance when compared to an athletic shoe. Menant et al. [2009a] found high heel collar shoes yielded a shorter total stopping time on a wet surface and suggested this was due to increased mechanical support around the ankles. This is consistent with the findings of Robbins et al. [1995], who reported that when the ankles of subjects wearing athletic shoes were taped, foot position awareness increased. Exercise decreased foot positional awareness, regardless of if the subject's ankles were taped. Such research may be applicable in a situation where a woman has been wearing a shoe such as a strapless wedge for several hours, and therefore may be at an increased risk of a fall due to the biomechanical effects of the shoe as well as the effects of fatigue.

Not surprisingly, several studies involving post-fall interviews of elderly men and women found that slippers had the highest frequency of being worn at the time of a fall [Sherington and Menz 2003; Hourihan et al. 2008]. Many slipper styles, like thong sandals, lack any type of heel support and have a soft mid sole and sole. Sherrington and Menz [2003] reported that shoes with no fixation were more likely to be associated with a trip than any other type of fall and surmised that these types of shoes tend to promote a shuffling gait.

Menant et al. [2009b] recommended a well-fitted shoe with a firm fastening mechanism, a medium sole hardness, a low square heel, a high collar and no flare for both young and older people. This recommendation is consistent with "theoretically optimal 'safe' shoe" described in Lord et al. [2001], having a high heel collar, thin firm mid sole, bevelled heel, mid sole flare, and textured sole.

Conclusion

Research has demonstrated that women's footwear, high-heeled shoes in particular, alter gait kinetics and kinematics. Furthermore, certain performance metrics have been tested in specific shoe types; for example, Brecht et al. [1995] showed that young women were less able to maintain balance in cowboy boots than in tennis shoes when exposed to an acceleration of the platform on which they were standing. The peer reviewed literature also describes how certain footwear parameters, such as mid sole hardness and collar height, have been implicated in falls within the elderly. However, these specific parameters have not been evaluated for the population of young women and the styles of shoes they wear. In 1995, Continental Airlines lowered their required shoe height (for personnel including flight attendants) to ¼ inch, and a spokesperson reported that fall incidents fell by 80 percent [Sixel 1998]. Such data indicates that a young woman's choice of footwear may influence her risk of falling. However, while the biomechanical consequences of wearing high heeled shoes have been fairly well documented within the literature, the kinematics and kinetics associated with other women's fashion footwear such as thong sandals, mules, clogs, platform shoes, and wedges have not been extensively studied. Further research into which, if any, footwear parameters are associated with an increased risk of falling is warranted to assist young women in choosing their shoes in a way to minimize personal risk.

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Coherence of Gait and Mental Workload

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We propose a spectral analysis to evaluate the coordination of gait and mental task. Our hypothes is that when the mental workloads and the gait control are coherent, the capability to prepare for a perturbation is enhanced. Thirty volunteers walked with harness on instrumented treadmill. Two different levels of computations (1 and 2 digits additions) were introduced to the subjects. A bicycle break was applied, to grab and pull a light weight polyurethane rod attached to each subject's shoe heel, causing unexpected tripping effect. The results show that there is no significant phase spectrum effect, but significant amplitude effect of cross-spectrum. For those subjects who could not recover from the perturbation within one step, the entropy of the cross periodograms are significantly decayed due to the increase mental workload.

Introduction

Slips, trips and falls (STL) constitute the majority of workplace accidents. Falls, fatal in extremely severe cases, can cause various injuries from head concussion, neck whiplash, paralysis, back pain, broken hip, to torn anterior cruciate ligament (ACL). Even if there is no fall in some situations, trying to catch the balance can cause muscle sprains and strains to muscles. To prevent STL, most studies emphasize tribology, cleaning protocol and precautionary measures such as lighting, anti- slip shoe sole design. Few studies address the dual task coordination, the coherency between the gait and the given mental work load. The research gap is partly due to the assumption that human gaits are cyclic and feed-forward. If a walker can perceive, anticipate and prepare for the incoming hazardous stimuli, at least one to two steps ahead, his gait is less likely to be perturbed. When the difference, between the anticipation and environmental stimuli, is so significant that he does not have enough joint moment or time to bring the center of mass inside the base of support, a slip, trip and fall mishap is more likely to happen. Accordingly, many research approaches are proposed, such as psychophysics focusing on the perception of the walking conditions; physiology muscle strength; and biomechanics on toe or heel clearance and reaction time. In either approach, one critical issue is to identify the underlying mechanism for the gait adaptation.

Coherence Tuning Model

Conventionally, coherence or covariability are considered intrinsic within normal human biomechanics and can be depicted as the normal random processes that occur in motor control across multiple repetitions of a task, such as the bipedal gait. However, some studies suggest that many biological behaviors described as stochastic in nature are actually the result of nonlinear dynamics [Glass and Mackey 1988; Amato1992]. Haken et al. [1985] proposed a model to account for the observations on human bimanual coordination that revealed basic features of self-organization which refers to the pattern formation of and pattern change in a non-equilibrium system that is open to the exchange of energy and information with its environment. In Haken *et al* [1985] they found that

1. Only two stable states exist: in-phase motion and antiphase motion.

2. As the frequency increases, the amplitude of motion decreases.

3. As the frequency increases past a critical frequency, antiphase motion abruptly changes to in-phase motion.

4. Beyond this transition, only in-phase motion is possible. That is, for frequencies above the critical frequency, only in-phase motion is stable, while below the critical frequency both in-phase and antiphase motions are stable.

By using the four, consider that there are two tasks: gait and a mental task, and both can be tracked and indexed by harmonics with amplitude r, and phase φ under frequency ω :

$$x_{gait}(t) = r_{gait}(t)\cos\left(\omega t + \phi_{gait}(t)\right) \text{ and } x_{task}(t) = r_{task}(t)\cos\left(\omega t + \phi_{task}(t)\right)$$

For either activity: $\dot{x}(t) = -r(t)\left(\omega + \dot{\phi}(t)\right)\cdot\sin\left(\omega t + \phi(t)\right) + \dot{r}(t)\cdot\cos\left(\omega t + \phi(t)\right).$

For nearly simple harmonic, they require that $-r(t)\dot{\phi}(t)\sin\left(\omega t + \phi(t)\right) + \dot{r}(t)\cos\left(\omega t + \phi(t)\right) = 0$.

Assume that the gait and the mental task can be coupled with following hybrid model of the Van der Pol and Rayleigh differential equations:

$$\begin{cases} \ddot{x}_{gait} - \alpha\dot{x}_{gait} + \beta\dot{x}_{gait}^3 + \gamma x_{gait}^2\dot{x}_{gait} + \omega^2 x_{gait} = -(\dot{x}_{gait} - \dot{x}_{task})\left[a - b(\dot{x}_{gait} - \dot{x}_{task})^2 - c(x_{gait} - x_{task})^2\right] \\ \ddot{x}_{task} - \alpha\dot{x}_{task} + \beta\dot{x}_{task}^3 + \gamma x_{task}^2\dot{x}_{task} + \omega^2 x_{task} = -(\dot{x}_{task} - \dot{x}_{gait})\left[a - b(\dot{x}_{task} - \dot{x}_{gait})^2 - c(x_{task} - x_{gait})^2\right] \end{cases}$$

where the coupling coefficients *a*, *b*, and *c* are assumed to be "small" relative to *a*, *b*, and *g*, yielding a weak coupling (e.g., $\alpha = 0.5;\ \beta = 0.001,\ \gamma = 0.3875\ a = 0.049,\ b = 0,\ c = 0.036$).

To solve the two equations for $\dot{r}_L, \dot{r}_R, \dot{\phi}_L$, and $\dot{\phi}_R$, we need to integrate both over a period 2π/ω, and set equal to 0 and solve for r_{gait}, r_{task}, and $\left(\phi_{gait} - \phi_{task}\right)$:

$$\dot{r}_{gait}(t) \approx \frac{\omega}{2\pi}\int_t^{t+\frac{\omega}{2\pi}} \dot{r}_{gait}(\tau)d\tau = \frac{1}{8}\left[\begin{array}{l} r_{task}\left(4a - \left(c + 3b\omega^2\right)\left(3r_{gait}^2 + r_{task}^2\right)\right)\cos\Delta\phi + \\ r_{gait}^2\left(4\left(\alpha - a\right) + r_{gait}^2\left(c - \gamma + 3\left(b - \beta\right)\omega^2\right) + r_{task}^2\left(c + 3b\omega^2\right)\left(2 + \cos 2\Delta\phi\right)\right) \end{array}\right]$$

$$\dot{r}_{task}(t) \approx \frac{\omega}{2\pi}\int_t^{t+\frac{\omega}{2\pi}} \dot{r}_{task}(\tau)d\tau = \frac{1}{8}\left[\begin{array}{l} r_{gait}\left(4a - \left(c + 3b\omega^2\right)\left(3r_{task}^2 + r_{gait}^2\right)\right)\cos\Delta\phi \\ +r_{task}^2\left(4\left(\alpha - a\right) + r_{task}^2\left(c - \gamma + 3\left(b - \beta\right)\omega^2\right) + r_L^2\left(c + 3b\omega^2\right)\left(2 + \cos 2\Delta\phi\right)\right) \end{array}\right]$$

$$\Delta\dot{\phi}(t) \approx \frac{\omega}{2\pi}\int_t^{t+\frac{\omega}{2\pi}} \left(\dot{\phi}_{gait}(\tau) - \dot{\phi}_{task}(\tau)\right)d\tau$$
$$= \frac{r_{task}^2 + r_{gait}^2}{8r_{gait}r_{task}}\left[\left(-4a + \left(c + 3b\omega^2\right)\left(r_{gait}^2 + r_{task}^2\right)\right)\sin\Delta\phi - r_{gait}r_{task}\left(c + 3b\omega^2\right)\sin 2\Delta\phi\right]$$

By tuning the magnitude *r* and phase difference D*f*, we can reach the optimal coherence:

$$\Delta\phi = \cos^{-1}\left(\frac{-4a - \left(c + 3b\omega^2\right)\left(r_{task}^2 + r_{gait}^2\right)}{2\left(c + 3b\omega^2\right)r_{gait}r_{task}}\right)$$

$$\left|r_{gait}\right| = \left|r_{task}\right| = \frac{2\sqrt{\alpha - a\left(1 - \cos\Delta\phi\right)}}{\sqrt{\gamma + 3\beta\omega^2 - \left(c + 3b\omega^2\right)\left(3 - 4\cos\Delta\phi + \cos 2\Delta\phi\right)}}$$

Experimental Results

Given the model discussed, we propose a new approach to analyze coordination of the kinematic and kinetic variables, where the cross spectral densities, between the ground reaction force and the duration of the mental task, provide the index of coherency. When there are mental workloads, the gaits become more automatic and the cross-periodograms show less entropy. As such, the flexibility to prepare for a perturbation is enhanced. Thirty volunteers without any reported neural, musculoskeletal problems, participated in the study. They walked with harness on instrumented treadmill at an average speed of 2.4±0.3 mph for 10 minutes, and the last 2 minutes (150~240 steps) were collected. Figure 1 shows the vertical ground reaction force profile where the basic gait parameters, including weight acceptance (WA), mid-stance (MS), and push-off (PO) can be identified. Two levels of computations, 1, and 2 digits additions, were introduced to the subjects on a big screen in front of the subjects. The subjects were asked to speak out loud, though the accuracy was not evaluated.

Figure 2 shows the overlapping period between the computation and the sum of the vertical forces of both feet. To match Figures 2 and 1, the MS were identified. Depending on the cognitive proficiency, the computations could be conducted during any period (e.g., WAL-WAR, MSL-MSR), and there is no clear preferences on the initiation time. Figure 3 shows (a) the amplitude (modulus) of the cross-spectrum estimate against frequency; (b) the coherency squared of gait and computation task, and (c) phase spectrum in radians of gait and computation task. The effect due to the difficulty of computational task is significant to both amplitude and phase. When a bicycle break was applied, to grab and pull a light weight polyurethane rod attached to each subject's shoe heel, causing unexpected tripping effect, the results show that there is a significant effect of the amplitude (modulus) of cross-spectrum, but no significant effect on phase spectrum. For those subjects who could not recover the perturbation within one step, the entropy of the cross-periodogram are significantly decayed due to the increase mental workload.

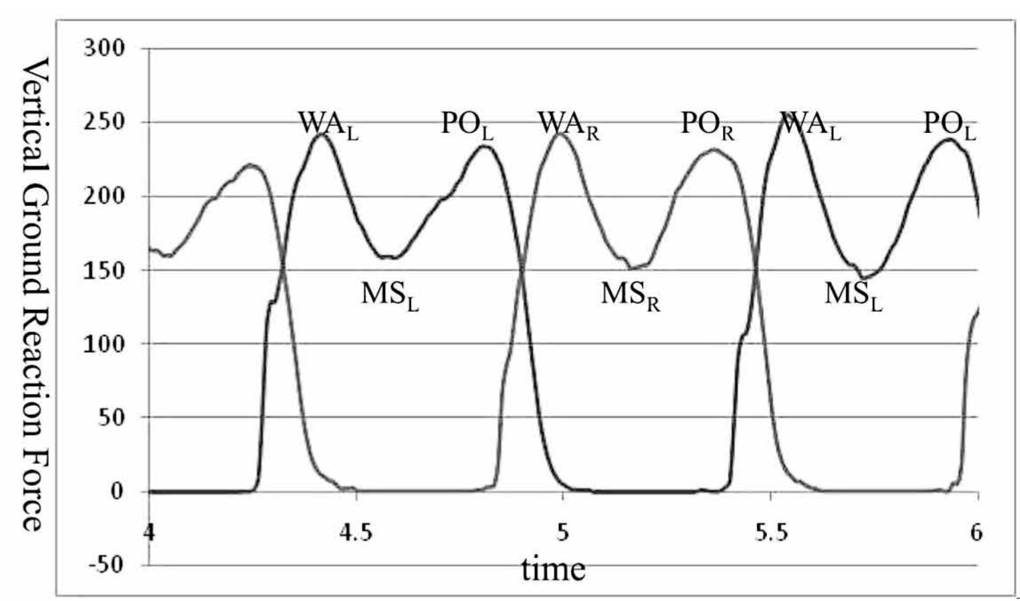

Figure 1. Major parameters of the vertical ground reaction forces for left- and right-foot (WA: WeightAcceptance, MS: Mid-Stance, and PO: Push-off)

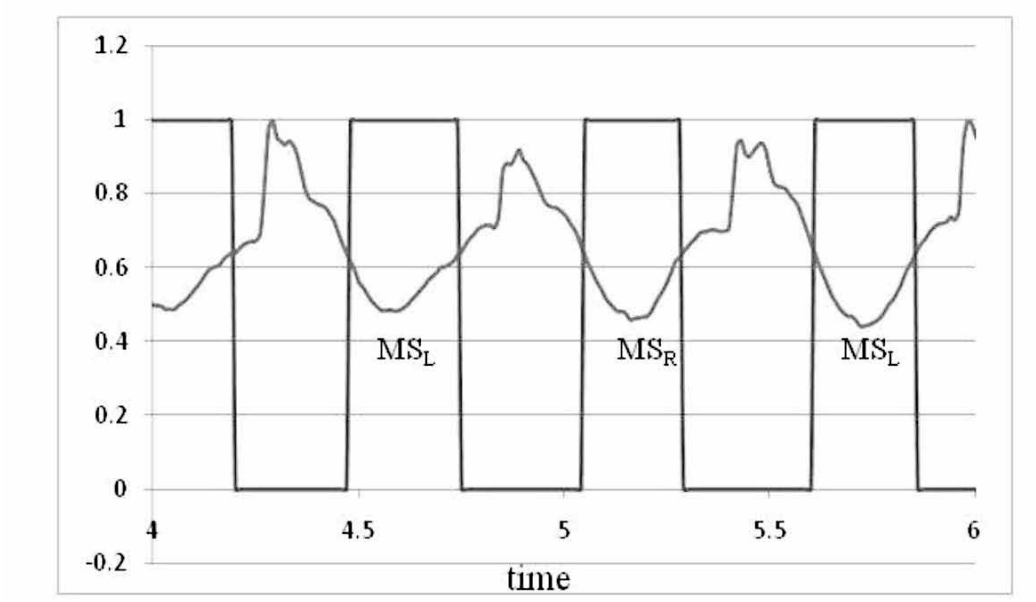

Figure 2. The summation of the left and right ground reaction force during the same period of Figure1, and the rectangle wave represent the period of computations. Both normalize to unitscale (100%).

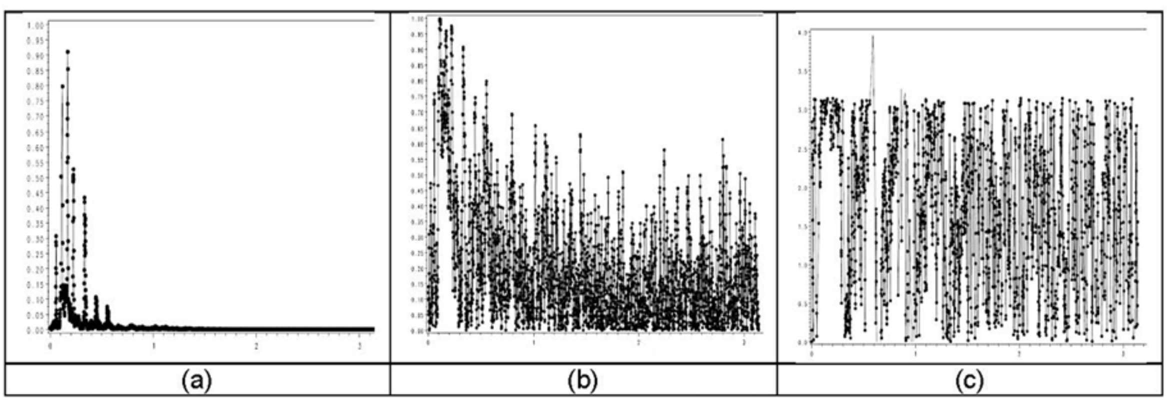

Figure 3. (a) the amplitude of the cross-spectrum estimate against frequency; (b) the coherency squared of gait and computation task; (c) phase spectrum in radians of gait and computation task.

Summary and disclaimer

Conventional gait analysis by using inverse pendulum model emphasizes four objectives: propulsion, stance stability, shock absorption, and energy conservation [Perry 1992]. This study provides a novel tool based on the coordination of gait and a mental task, where the stride-to-stride coherence or covariability analysis may be useful:

1. As already observed, the study attempts to distinguish and couple fast, automatic processes (i.e., gait) from slow, deliberative (i.e., computation) processes. Computation ability was a late arrival in evolutionary terms, preceded by unconscious perception-action by a considerable margin. Bipedal gait control should be the default dominant system, while conscious computation is a uniquely acquired plug-in that may to be synchronized more than we generally assume.

2. Amplitude is more important than phase coherency; however, there is no clear indication that a perfect coherency is needed. In fact, the data suggests the opposite of our hypothesis, that too much coherency may be detrimental to the recoverability from a perturbation.

3. The proposed approach may become a tool for job screening, training, and senile gait evaluation if the nature of coherence can be revealed through more detail analyses.

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Spheroidal Heel Posterior: Implications for Slips and Falls

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The importance of initial heel strike in ambulation and the effect upon friction of heels that are beveled or convex at their posteriors in the sagittal plane has been recognized. This study investigates the effect of curvature also in the coronal plane, that is, spheroidicity. Using a modified PIAST Mark III, tests were conducted with an actual heel and variously shaped test pads at various strike angles. It was found that the COF of spheroidal heel and pad posteriors tested at an angle was 42% of that when tested on their flat, although nothing like the approximately 1.5% found for the posterior tangential contact area compared with the pad flat contact area. However, the 42% is substantial and suggests the importance of testing for spheroidicity, and the merit of the PIAST modifications adopted for this study to enable this.

Introduction

Slip testing of a pedestrian surface after a heel-slip incident indicated that the surface was not slippery; subsequent examination of the shoes revealed that their heels were pronouncedly spheroidal at their posterior as a result of wear. Four questions arose: at initial heel strike, did extreme smallness of contact area, consistent with spheroidally tangential contact with the pedestrian surface, contribute to the slip; does the area change with variation of heel strike angle and radii of spheroidal curvature;does the planar testing of heel material with the testing device, a Brungraber Mark III portable inclinable articulated strut slip tester (PIAST)1, sufficiently account for area of tangential contact of heels at initial strike, and; can the testing device be modified to test for different heel strike angles, including with the use of actual heels without damaging them?

Kim and Smith [2002] refer to increase in size of initial heel strike contact area in the sagittal plane as a result of heel wear. They depict this as planar wear angled to the main heel surface, that is, beveling of the heel flat (although their manipulation of heel strike angles presumably also contributed to curvature in the sagittal plane). Lloyd & Stevenson [1989] reported that at initial heel strike, heels beveled in the sagittal plane provide greater friction than flat heels because of the greater bevel contact area compared with the heel's posterior edge, and postulated that curvature of heel posteriors in their sagittal plane would manifest even greater traction.

The present study is of heel posterior curvature not only in the sagittal plane, but also in the coronal plane, in other words, spheroidicity. This evidently occurs over time as a result of a person's variability of heel strike angle in three planes: – sagittal with respect to the pedestrian surface (horizontal plane);horizontal with respect to the sagittal plane, and; coronal with respect to the horizontal.

If heel-wear is planar, contact area with the pedestrian surface will increase. However, if it is curved, contact area will tend to decrease (subject to the compressibility of the heel material) because contact is at a tangential point.

Marpet and Brungraber [1996] found that reducing the PIAST pad width had a small effect in wet condition on friction, whereas Chang et al [2008] found that reducing the pad size of the PIAST significantly increased friction and that the greatest effect was with a test pad of 6.45 cm^2. The test foot of the English XL articulated strut slip tester has an area of 7.92 cm^2, an area suggested as being indicative of initial heel strike contact area [ANSI/ASSE, 2008]. However, even

[1] Described, for example, by Chang *et al* (2008, 2009); discussed in ANSI/ASSE TR-A1264.3-2007; and standardised in ASTM F1677-05 (for the Mark II PIAST)
[2] Intended as typical initial heel strike contact area (Bowman and Angelopoulos, 2000).

these areas are much greater than areas of contact anticipated for the spheroidal heels. In contrast, the 0.64 cm^2 contact area of the Tortus is much closer to the area imagined for spheroidal contact.

Chang et al [2008] suggested that the reliability of the PIAST could be further increased by a pad size smaller than they tested, but that modification of the test foot mechanism would be required. The modification for the present study enables testing of very small areas of heel and test pad posteriors, at different strike angles.

Method

The PIAST was modified by replacing its platform's short legs with height-adjustable ones, and attaching a small, height-adjustable and angle-adjustable wheeled strut to a leading corner of the test foot holder; the wheel is small, nylon, toroidal and with ball bearings to minimise contribution to coefficient of friction (COF). For each inclined pad, the wheel was located equidistant from the axle of the test foot axle to the axle as the test pad contact point with the test surface.

For each combination of test pad, test surface, angle and condition (dry or wet), nine strikes were conducted. A slip was judged in the way used by Chang et al. [2008]. 1296 tests were performed. For comparison, a preliminary test was conducted with the heel of the slip incident on three dry surfaces. Three angles of inclination were tested: 0°, 15°, and 30° — approximately corresponding with the ranges reported by Perkins [1978], Redfern et al [2001], Cham and Redfern [2002] and Fischer et al; and Kim and Smith (op cit). Selectable angles enables testing for the effect for the same pad of varying spheroidal radii; for the decrement in distance of the pad strike contact point from the anterior of the pad as a result of wear wear (noted by Kim and Smith 2002); and to test for typical variety of actual heel strike angles. The 0° tests were conducted without the wheeled struts on the test clips. Four surfaces were tested: polished ceramic tile, glass, smooth textured ceramic tile, and smooth hardwood timber board, each in dry and water-wet conditions.

Six test pads were used, each cut out of a black rubber "Tempo" heel manufactured by Topy in France. The Shore A hardness of the rubber was 88 at 15 seconds. One pad was square and grooved to avoid sticktion. Three were semi-circular in the horizontal plane at their posterior, and grooved. One of the semi-circular pads was planar, one was curved in its sagittal plane (semi-cylindrical), and one was curved in the sagittal and coronal planes (spheroidal). Two pads were narrow: one of them was rectangular and aligned at the posterior of the test pad clip, and the other was located centrally on the clip, parallel with the sagittal plane and spheroidal at its posterior. Areas of the pad contact surfaces were calculated by scanning and digitizing. The contact areas of the heel flats were identified by lightly moistening them on a flat surface, and posterior contact edges and surfaces were identifiable after testing by well-defined "bruise" marks.

Results

For the actual heel at the three angles and three surfaces (excluding glass) in dry conditions, the COF and contact area (shown parenthesized), were: – 30° and 15°: 0.27, (0.35 cm2); 0°: 0.42, (20.1 cm2). The proportion of posterior to heel-flat contact area was 1.75%. Hence, for an area reduction to 1.75% of the heel-flat area, there was a COF reduction to only 63%.

For the test pads, posterior contact area varied from 0.11 cm^2 to 0.76 cm^2 (mean: 0.35 cm^2), compared with the pads' flat surface area of 10.8 cm^2 to 39.5 cm^2 (mean 25.7 cm^2). The proportion of the posterior to flat surface area was 0.46% - 2.9% (mean 1.3%).

The mean COF in the wet was 0.36 for pads at 0° and 0.21 for pads at 30° and 15°, a reduction to 58.7% ($p<0.005$)[3]. The mean COF in the dry was 1.02 for pads at 0° and 0.43 for pads at 30° and 15°, a reduction to 42.2% ($p<0.00001$)[3]. In other

[3] Two-sample t-test with equal variances

words, for the most slippery condition, a reduction of area to 1.3% (of the heel-flat) corresponded with a COF reduction to only 58.7%, whereas for the least slippery condition, the area reduction corresponded with a COF reduction to 42.1%.

The COF difference between pads at 0° and pads at 30° and 15° for spheroidal pads was significant in the wet $(p=0.05)^3$ and much more so in the dry $(p<0.00001)^3$.

Two-sample t-test with equal variances For non-spheroidal pads the difference was also significant in the wet $(p<0.005)^3$ and the dry$(p<0.00001)^3$.

The COF of pads at 30° was slightly less than for pads at 15°, but not significantly $(p>0.05)^3$, and slightly less for non-spheroidal pads than for spheroidal pads ($p>0.05$). The contact area at 30° and 15° was significantly greater for spheroidal pads than for non-spheroidal pads $(p<0.05)^3$. Standard deviation (SD) of COF results varied much more for dry than for wet tests: in the dry, SD was 17.74 for uninclined and 8.21 for inclined tests; in the wet SD was 35.75 and 20.98 respectively.

Discussion

Results contrast with those of Chang et al. [2009] who reported that COF tended to increase with decreasing (Neolite) pad size. However, there was a substantial decrease between their smallest pad (2.54 cm) compared with their largest pad (7.62 cm) — reductions of 58% for dry and 81% for water wet conditions. They discounted the smallest pad size because of its instability; in contrast, the PIAST modifications for the present study manifested stability of the heel and test pads.

The Results suggest that spheroidicity of the heels of the slip incident contributed to the slip, but not conclusively. It is possible that the interaction of the rubber heel and pads prevents further reduction of COF.

The increased normal pressure resulting from the greatly decreased contact area may cause deformation, compression and interlocking with the test surface as discussed by Kim and Smith [2002] and Smith [2008].

The tilting device wheel might have contributed to the COF results; however, this would mean that the COF of the pad would be to that extent less.

The PIAST foot plate modification is only suitable for testing posterior edges and tangential contact points on curved surfaces, not for beveled pads or heels, because of the difficulty in aligning the tilting strut so that the surface of the bevel is measured and not its leading or trailing edge.

Conclusion

Anticipated very small initial heel strike contact area due to spheroidicity was realized: when tested on the PIAST, the contact area of pads tested at an angle was less than 2% of the contact area of pads tested on their flat. However, this proportion did not correspond with COF results which, for pads tested at an angle, were approximately 50% of COF for pads tested on their flat. The area at inclined contact was slightly greater for 30° than for 15°, but not significantly.

COF of pedestrian surfaces is derived, with the PIAST, from test pads tested on their flat. The Results of this study suggest the value of also testing them at an angle so that posterior geometry, including spheroidicity, can be analyzed. The PIAST modifications (platform height-adjustability and test-foot tiltability) were effective for testing specimens at an angle; however, further testing to validate the testing with and without the test foot modification is required. The test results provide a possible explanation for the slip incident that prompted this study, but not a conclusive one.

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Effects of Limbering Up Exercises to Prevent Falls on Physical Performance and Fall Risks in Elderly Workers

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The purpose of this study was to investigate the effects of limbering up exercises to prevent falls in elderly workers. A total of 77 elderly factory workers with a mean age of 57.2 years old participated in this study. Limbering up exercises with particular emphasis on balance, agility and muscle strength were designed to improve physical performance. The limbering up exercises were performed five times a week before starting work for eight months. Participants underwent physical performance tests, which included static/dynamic balance, agility, mobility, flexibility and muscle strength, to determine physical performance and fall risks at the baseline and after an eight month trial period. Statistically significant improvements were observed in the static balance (single-leg balance with eyes closed), agility (square step test), flexibility (maximum step length) and muscle strength (chair standing) in elderly workers after the end of the eight month trial. However, no significant differences were observed in dynamic balance and mobility between the baseline and the end of the trial. The fall risks (actual fall and near-fall experiences) significantly decreased at the end of the eight month period. These findings provide evidence that limbering up exercises result in significant improvements in physical performance related to risk factors, causing falls in elderly workers. Performing these limbering up exercises to prevent falls could be an effective approach to improve risk factors, causing falls by elderly workers.

Introduction

In Japan, Ministry of Health, Labour and Welfare reported that there were 24,792 fall accidents and 335 falls and downfalls resulting in the death of a worker in 2008. Of these, 21.8% occurred in the manufacturing industry. Slips, trips and falls in workplace can result in serious injuries; fractures, sprained joints, back injuries, contusions and lacerations. These injuries cause a lot of pain and suffering, and sometimes result in death. The risk of falls increases with age. A 10-fold increase in the incidence of falls was reported in older adults (50 years old and over) compared younger individuals [Thomas and Brennan, 2000].

Exercise is generally accepted to be effective for the prevention of falls in older adults. Appropriate exercise decreases the risk of falls by improving balance/postural stability and increasing muscle strength. Moreover, a meta-analytic study has demonstrated that exercise is effective for lowering the risk of falls in older adults. Thus, a well-designed exercise program is effective to improve physical functions and fall risks.

Limbering up exercises (also known as radio taiso) refer to the warming up exercises popular in Japanese, along with the music broadcast on public radio every morning. Limbering up exercises is frequently performed among workers in companies to stretch and refresh their body and mind. It has been suggested that limbering up exercises have positive effects for preventing pain, discomfort or damage to the joints and muscles leading to musculoskeletal disorders before lifting, carrying or undertaking other work activities [Moore, 1998; Hess and Hecker, 2003]. However, limbering up exercises have not been examined as a means of safety measures to prevent falls in workplaces, and there is little information about the effectiveness of limbering up exercise programs designed to prevent falls in the workplace. Therefore, we have to quantify the effects of limbering up exercises to prevent falls in elderly workers.

Method

A total of 77 male factory workers with a median age of 57.2 years (age range, 50–64 yrs) participated in a trial for preventing falls. Subjects completed medical histories, exercise histories, and information on lifestyles by questionnaire and physical examination before participation in the study. The physical characteristics of the participants are shown in Table 1.

Table 1. Characteristic of the participants

Age (years)	57.2±3.2
Height (cm)	165.6±5.5
Weight (kg)	60.6±8.1
BMI (kg/m^2)	22.1±2.7

Data are expressed as means ± SD.

Physical performance tests

1) Static balance (Single-leg balance with eyes opened/closed)

Static balance was measured by recording how long subjects could remain standing on their self-reported dominant leg with their eyes opened and closed. Subjects were instructed to stand on the preferred foot while resting their hands at waist level and then raising the other foot approximately 5 cm off the floor with their eyes opened or closed. The test ends when the subject touches the free foot on the floor, removes the hands from the hips, moves the supporting foot from the original starting position, hooks the free leg behind the support leg, or reached the maximum time of 120 (eyes opened) or 60 (eyes closed) seconds.

2) Dynamic balance (Functional reach)

Subjects performed the functional reach test by standing perpendicular to the wall on which a meter stick was affixed and stood with their feet placed 10 cm apart. The meter stick was adjusted to the level of each subject's acromion process. Subjects were asked to flex their right shoulder to the level of the meter stick. Next, the investigator assessed and adjusted postural alignment in this position to prevent excessive shoulder protraction or retraction and made note of the starting point by evaluating the tip of the subject's middle finger in relation to the meter stick. Subjects were then instructed to reach as far forward as possible without losing their balance and touching the wall. The displacement of the tip of the subject's middle finger between the starting and ending positions was recorded to the nearest 0.1 cm as the magnitude of the subject's functional reach.

3) Mobility (Timed Up and Go)

The Timed Up and Go test was used to measure functional mobility. The time taken to complete rising from a chair, walking 3 m, turning and walking back to the chair and sitting was recorded in seconds. The starting position was standardized so that the subjects commenced the test with their feet flat on the floor and their arm resting on the armrests. No physical assistance was given. Each subject performed this test twice, and the mean score was recorded.

4) Flexibility (Maximum step length)

Maximum step length was determined as the distance between two consecutive footprints, measured from the heel of one footprint to the heel of the next footprint. Step width was determined as the distance between the outermost borders of two consecutive footprints.

5) Agility (Square step test)

Square step test in a standing position was used to measure agility. The subjects were asked to jump from /to a square box in the order of forward, right, backward, and left, as fast as possible, and the time was measured using a stopwatch. Each subject was asked to perform two practices and then the test was repeated twice, the better time of the two tests was taken for the individual data.

6) Muscle strength (Chair standing)

The chair standing measured the time needed to stand 10 times from a standard chair without using the upper extremities. Subjects were asked to rise to a full standing position and then return back to a seated position as fast as possible. Timing begun when the examiner said "Go" and stopped when the subject's buttocks touched the chair on the tenth repetition.

Fall risks

A fall was defined as a sudden and unintentional change in position from an upright posture –with or without loss of consciousness – that caused the person to land on the ground. Participants were asked to report any fall episodes during the previous year (including at home), and monthly near-fall experiences (during working time) were closely monitored at the baseline and eight months later.

Limbering up exercises

The limbering up exercises with extra emphasis on balance, agility, and muscle strength were designed to improve physical performance. The limbering up exercises included toe/heel standing, forward range, side-range, single-leg squatting, and toe touching; targeted balance, agility, and muscle strength [Whipple, 1997]. Toe/heel standing was aimed at facilitating ankle and joint flexibility, forward range was aimed at increasing muscle strength and agility/reaction time in upper extremities, side range was aimed at increased muscle strength and to agility in upper extremities, single-leg squatting was aimed at improving muscle strength, balance and ankle flexibility, toe touching was aimed at improving muscle strength, balance and ankle flexibility. In order to improve agility/reaction time effectively, the tempos were maintained at about 130-140 BPM. The limbering up exercises were performed five times a week before starting work for a period of eight months. Most of the activities were accompanied by music played on a cassette player. Throughout the eight month trial, movements were modified for participants with the aid of an instructor. Participants underwent physical performance tests, including static/dynamic balance, functional reach, agility, mobility, flexibility and muscle strength to determine physical performance and fall episodes at the baseline and after an eight month trial period.

Statistical analysis

The statistical analysis was performed utilizing the SPSS for Windows (Version 17.0 Ins., Chicago, IL). Data is presented as means ± standard deviations. To test changes in outcome measures between baseline and after an eight month trial, a student's paired t-test was performed. Significant difference in fall risks was analyzed using a chi-square test. Statistical significance was preset at the $P<0.05$ level.

Results

The changes in the static/dynamic balance and flexibility are shown in Table 2. The results showed significant increase from 10.0 ± 9.5 to 14.6 ± 14.3 in single-leg balance with eyes closed ($P<0.05$) and from 102.4 ± 15.1 to 106.1 ± 2.5 in step length ($P<0.05$) after 8 months. Table 3 shows the changes in muscle strength and agility that indicated a significant decrease from 15.8 ± 5.6 to 14.6 ± 4.8 in chair

Table 2. Changes in static/dynamic balance and flexibility at the baseline and after an eight month trial

Variables	Baseline (n = 77)	8-month (n = 77)
Static balance: single-leg balance		
Eyes opened (sec)	82.1 ± 43.6	86.4 ± 37.9
Eyes closed (sec)	10.0 ± 9.5	14.6 ± 14.3*
Dynamic balance		
Functional reach test (cm)	34.5 ± 6.7	38.7 ± 6.9
Flexibility		
Maximum step length (cm)	102.4 ± 15.1	106.1 ± 12.5*

Data are expressed as means ± SD, *$P<0.05$.

Table 3. Changes in muscle strength, mobility, and agility at the baseline and after an eight month trial

Baseline Variables	8-month (n = 77)	(n = 77)
Muscle strength		
Chair standing (sec)	15.8 ± 5.6	14.6 ± 4.8*
Mobility		
Timed up and go (sec)	5.9 ± 1.6	5.6 ± 1.1
Agility		
Square Step Test (sec)	5.7 ± 3.2	4.8 ± 1.6*

Data are expressed as means ± SD, *P<0.05.

standing (P<0.05) and from 5.7 ± 3.2 to 4.8 ± 1.6 in square step test (P<0.05). However, no significant differences were seen in the single leg balance with eyes opened, functional reach and timed up and go. Table 4 shows the changes in fall risks(actual fall and near-fall experiences) at baseline and after the 8-month trial. The fall risks were significantly decreased from 13 (16.88%) to 4 (5.19%) in actual fall (p<0.05), and from 36 (46.75%) to 19 (24.68%) in near fall experiences (P<0.001).

Table 4. Changes in fall risks at baseline and after an eight month trial

Variables	Baseline (n = 77) Frequency (%)	8-month (n = 77) Frequency (%)	χ^2	P-value
Actual fall				
Yes	13 (16.88)	4 (5.19)	5.3559	P<0.05
No	64 (83.12)	73 (94.81)		
Near-fall experiences				
Yes	36 (46.75)	19 (24.68)	8.1737	P<0.001
No	41 (53.25)	58 (75.32)		

Summary and Conclusion

The present study revealed limbering up exercises significantly increased the static standing time on single-leg with eyes closed (static balance), step length (flexibility), square step test (agility) and chair standing (muscle strength) in the elderly workers. Performing limbering up exercises also showed significant improvements in fall risks.

These findings provide the evidence that limbering up exercises result in significant improvements in physical performance related to fall risk factors which cause falls in elderly workers. Performing these limbering up exercises to prevent falls could be an effective approach to improve risk factors which cause falls in elderly workers.

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Issues of Wear and Tear on the Shoe Heel Surfaces and Their Effects on Slip Resistance Performances

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The aim of this study was to formulate a clear picture on wear phenomena of shoe heel surfaces during the early stage of dynamic friction measurements and identify the wear effects on slip resistance performance. Novel concepts and theory were suggested to identify underlying wear regimes of the heel surfaces. Dynamic friction tests were conducted using two types of shoes and a floor specimen. Topographic changes and wear developments of each heel surface were quantitatively and qualitatively measured by surface roughness parameters and microscopic observations. All the results clearly identified that variouswear modes such as adhesive, abrasive, ploughing, and fatigue were involved as main wear sources and the resultant effects on slip resistance performances. This study suggests that future research on slips and falls should pay attention to the issues on wear and tear behaviors of the footwear and their impacts on slip resistance performance.

Introduction

Slip resistance properties between the footwear and floor surfaces under different walking conditions have been studied for many years. Recent studies have raised issues on wear behaviors of the footwear with slip resistance measurements [Manning et al., 1998; Kim et al., 2001]. These studies reported that surface topographies of the shoes and floors constantly changed in specific ways during slip resistance tests. As a result, extended tests on the shoe heels led to structural changes and affected the coefficient of friction (COF)measurements. Kim et al. [2001] introduced a concept on shoe surface changes and wear developments with dynamic friction tests. Although those studies showed strong relationships between surface roughness and slip resistance properties, fundamental aspects on wear behavior and associated tribological characteristics of the heel surfaces were infrequently investigated. The present study was, therefore, aimed to develop refined concepts on wear phenomena of the shoe surfaces and suggest a comprehensive wear model. For the validations of the new concepts and the suggested theoretical model, initial and rubbed heel surfaces of two shoes were systematically analyzed by quantitative and qualitative methods during slip resistance tests. New and rubbed heel surface were measured by a number of surface roughness parameters for the quantitative analysis. A series of micrographs were taken by a scanning electron microscope to monitor wear developments and surface changes of the rubbed heel surfaces for the qualitative analysis.

Theory Developments

Basic wear model and assumptions

When a shoe contacts a floor, the two surfaces seem to initially touch only at tiny discrete areas where their highest asperities are in contact. A local pressure at the contact regions would be high enough to cause plastic deformations of the heel asperities even at the lightest load because an elasto-plastic modulus of the heel would be significantly less than that of the floor. If the shoe heel slides on the floor, then the heel surface would be ruptured, deformed and ploughed by wedge-shaped asperities of the floor surface. Based on these assumptions, the following wear model for the shoe was suggested:

1) Adhesive wear would take place when the relative movement between the heel and floor surface induce breakage of the junction inside the heel surface rather than at the interface. This would affect only the upper layers, where the tops of asperities would be broken off.

2) Abrasive wear would be considered as events of displacement of polymeric materials from the heel surface, caused during the relative sliding motion by the ploughing effects of hard protuberances on the floor surface. This would affect both upper and lower layers of the heel surface because polymeric materials could be removed from valley and peak areas.

3) Ploughing could take place when the heel-floor interaction does not include any material removal but results only in material relocation on the heel surface. This would affect both upper and lower layers of the heel surface because polymeric materials would be moved on the surface, forming peaks and leaving valleys.

4) Fatigue wear could occur when the heel surface is exposed to a large number of alternating tensile and compressive stresses, which are typical modes of heel striking and sliding during walking activities. This is most likely to occur in cases when the floor surface has more blunt rather than sharp projections, and as a result the heel surface would undergo mainly cyclic deformations leading to surface failure.

Incorporated wear model

With estimated topographic changes of the heel surface rubbed against the floor, an incorporated wear model was suggested with roughness parameters. The details of surface roughness parameters are found in the literature [ISO 1998; Kim et al. 2001]:

- If R_t (maximum peak-to-valley), R_{tm} (maximum mean peak-to-valley), R_p (maximum peak height), R_{pm}(maximum mean peak height) and AS (average slope angle) decrease, adhesive wear is assumed to be predominant.

- If R_t, R_{tm}, R_p and R_{pm} decrease, abrasive wear is assumed to be predominant while an increase of R_t,R_{tm}, R_p and R_{pm} will indicate ploughing.

- If R_v (maximum depth) and R_{vm} (maximum mean depth) increase, fatigue, ploughing or abrasive wear is expected.

- If R_t, R_{tm}, R_p, R_{pm}, R_v and R_{vm} and AS increase, ploughing is assumed to be predominant.

Experimental Methods

Slip resistance tests

Slip resistance tests were performed on a pendulum-type dynamic friction tester that was designed to simulate the movements of a human foot and the forces applied to the underfoot at the moment of heel strike and initial sliding.

Test arrangements

- Shoes and floor specimens:

Two double density polyurethane shoes with different sole/heel patterns were used for the tests. The two shoes were named as Shoe No. 1 and Shoe No. 2, respectively. For flooring specimens, ceramic plates were used for the slip resistance tests.

- Test conditions and slip resistance measurements:

Test conditions were limited to clean and dry surface environments in order to eliminate any confounding effects of contaminants by agents other than the shoe and flooring specimens. Each shoe was rubbed against a new ceramic plate 50 times.

Characterizations of the shoe wear

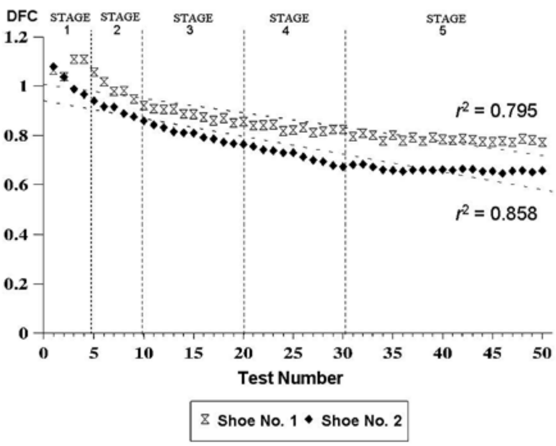
Initial and rubbed heel surfaces were comprehensively analyzed by quantitative and qualitative Methods during the tests. For the quantitative measures, a number of surface roughness parameters were measured by a laser scanning confocal microscope. To validate surface roughness data and identify wear phenomena, the heel surfaces were examined by a stereo scanning electron microscope.

Results

Slip resistance performance Fig. 1 shows test results from the two double density polyurethane shoes interacting with the ceramic floor specimens. The main observations were summarized in the following:

• The dynamic friction coefficient (DFC) values decreased at the end of the tests by over 33 % (1.164 to 0.772) for shoe No. 1 and by 40 % (1.079 to 0.646) for shoe No. 2.

Figure 1. DFC results from the two shoes tested under dry floor surface conditions.



• Regression results showed significant relationship between the DFC values and the number of rubbings

(r0.80 for shoe No. 1 and r0.86 for shoe No. 2, respectively).

• The DFC value for shoe No. 1 showed higher values than for shoe No. 2 during the tests. At stage 1 (5 times of rubbings), shoe No. 1 showed a maximum DFC value (1.164), but this value slowly decreased until stage 4 (30 times of rubbings).

• Correlation coefficients showed negative values during the tests. This result indicated that the heel surfaces were actively engaged in massive structural changes and surface damages were most likely due to adhesion, abrasion, ploughing, and fatigue wear.v

Surface roughness analysis

Fig. 2 shows that all the surface roughness parameters were markedly changed during the tests as compared with their initial values.

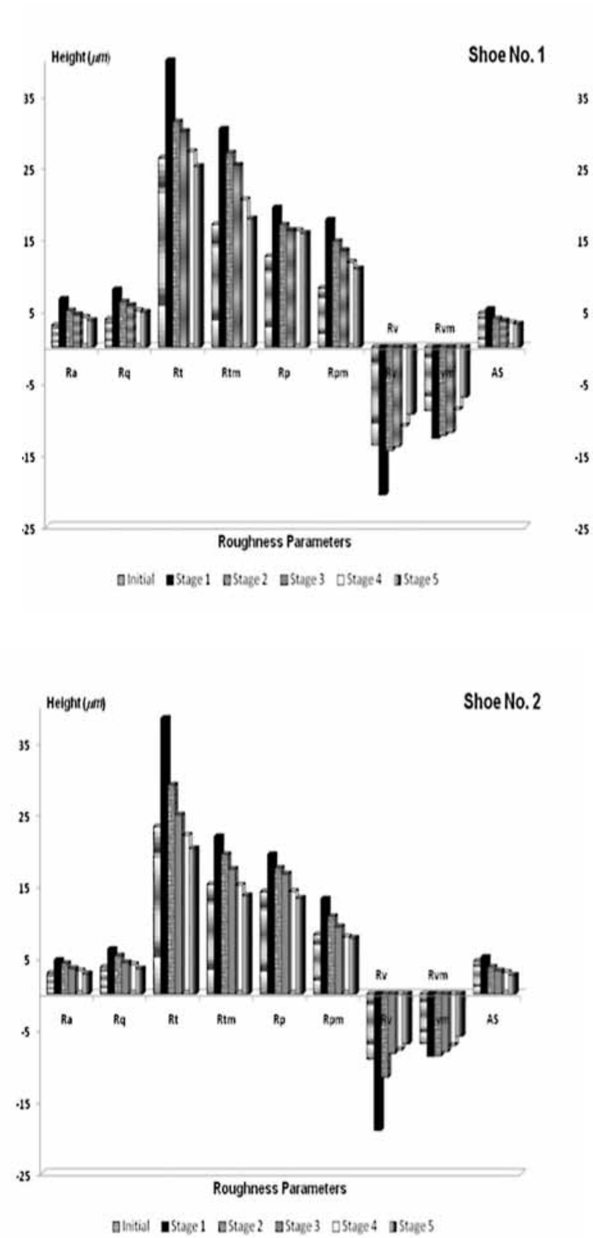


Figure 2. Changes of surface roughness parameters of the shoes during the tests. Microscopic analysis

Microscopic analysis

1) Shoe No. 1The rubbed heel surface of shoe No. 1 showed a number of parallel tearing traces and micro-layered textures as shown in Fig. 3 (i(b)). Width and depth of the tearing traces were gradually increased with rubbings. The edge areas were more severely damaged than the middle areas. This finding suggested that wear proceeded from outside to inside areas on the heel surface so that wear patterns looked curled up and formed thick layers,showing clear evidence of severe abrasion, ploughing, and fatigue.

2) Shoe No. 2

The rubbed heel surface of shoe No. 2 showed totally different features. It was initially covered with a number of small micro-porosities. During the rubbings, the smooth and porous surface was broken open and formed a lot of cavities on its surface layer, creating a new rough surface (Fig. 3 (ii (b)). The heel surface was heavily deformed by the sliding direction. This result showed a strong evidence of abrasive wear. The worn surface was characterized by scratched traces and micro-layered surface textures.

by more rounded asperities were identified as main mechanisms for the shoe wear. Although fatigue wear was not clear, microscopic observations of crack formations and propagations on the heel surfaces provided strong evidences to ascertain this aspect. Whilst the proposed wear concepts and model for the shoes would require further investigations, this study suggests that future research on slips and falls should pay attention to the issues on wear and tear behaviors of the footwear and their impacts on slip resistance performance.

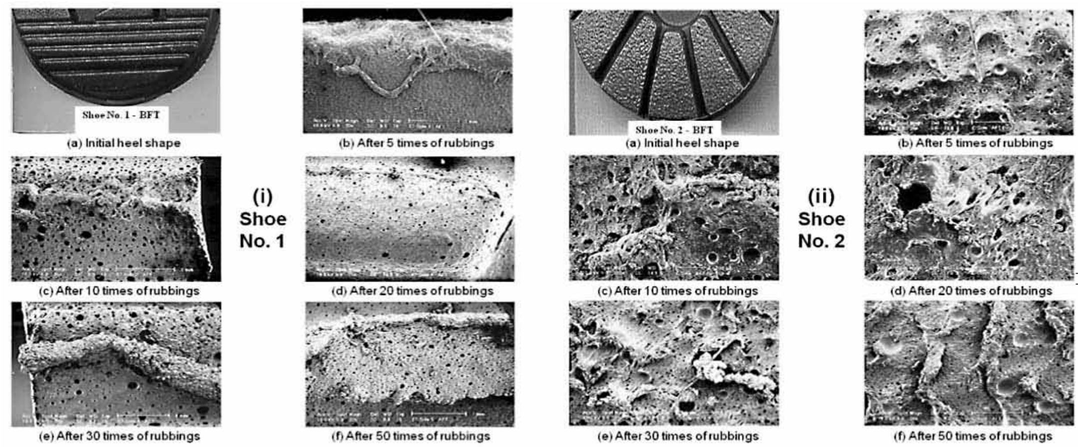


Figure 3. Micrographs of wear tracks of the shoes during the slip resistance tests.

Conclusions

This study was concerned with identifying wear phenomena of the shoe surfaces in an early stage of sliding friction and its effects on slip resistance properties. Novel concepts on wear phenomena of the heel surfaces were proposed in order to gain fundamental insight into the anatomical picture of the tribological characteristics involved. A series of dynamic slip resistance tests were conducted between two polyurethane shoes and ceramic plates under dry conditions. Worn surfaces of the heels were comprehensively analyzed by quantitative and qualitative methods during the tests. The results clearly revealed that plastic deformations and cuttings by relatively sharp asperities and fatigue

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Balance Training Via Multimodal Biofeedback

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We have previously demonstrated that vibrotactile feedback of trunk motion significantly improves balance stability in individuals with vestibular deficits and older adults. Recently we have developed a Mobile Instrument for Motion Instruction and Correction (MIMIC) that enables an expert (i.e. physical therapist) to map his/her movements to a trainee (i.e. patient) in a hands-free fashion. MIMIC comprises an Expert Module (EM) and a Trainee Module (TM). Both the EM and TM are composed of six degree-of-freedom inertial measurement units (IMUs),microcontrollers, and batteries. The TM also has an array of vibrating actuators that provides the user with vibrotactile instructional cues. The expert dons the EM, and his/her relevant body position is computed by an algorithm based on an extended Kalman filter that provides asymptotic state estimation. The captured expert body motion information is transmitted wirelessly to the trainee, and based on the computed difference between the expert and trainee motion, directional instructions are displayed via vibrotactile stimulation to the skin. The trainee is instructed to move in the direction of the vibration sensation until the vibration is eliminated. In a proof-of-concept study, five healthy young subjects were instructed to replicate recorded expert anterior-posterior trunk tilt motion using the aforementioned device with vibrotactile,visual, or combined vibrotactile and visual instructional cues. Preliminary results showed that expert-subject cross-correlation values were maximized and time delays and average position errors were minimized when a 0.5 degree position error threshold and proportional plus half derivative control signal of the angle difference between the expert and subject were used. Subjects had significantly reduced position error when replicating the expert motion with combined vibrotactile and visual instructional cues compared to visual instructional cues alone,and slightly reduced error compared to vibrotactile cues alone.

Introduction

Physical rehabilitation has been shown to improve sensory integration, motor coordination, and strength inpatient populations with balance or vestibular disorders, stroke, or traumatic brain injuries (Crooks et al., 2007;Horak et al., 1992; Mulrow et al., 1994; Ones et al., 2009). During conventional rehabilitation and training,physical therapists communicate proper execution of an exercise to patients through a combination of instruction (verbal, demonstration), feedback (auditory, visual, haptic), and/or physical guidance. Verbal instruction and demonstration are provided prior to and/or during the execution of the rehabilitation exercise and are typically used in combination with augmented extrinsic feedback or knowledge of results (KR). The impact of KR on motor learning varies as a function of the frequency, delay, and precision with which information is provided (Winstein, 1991).

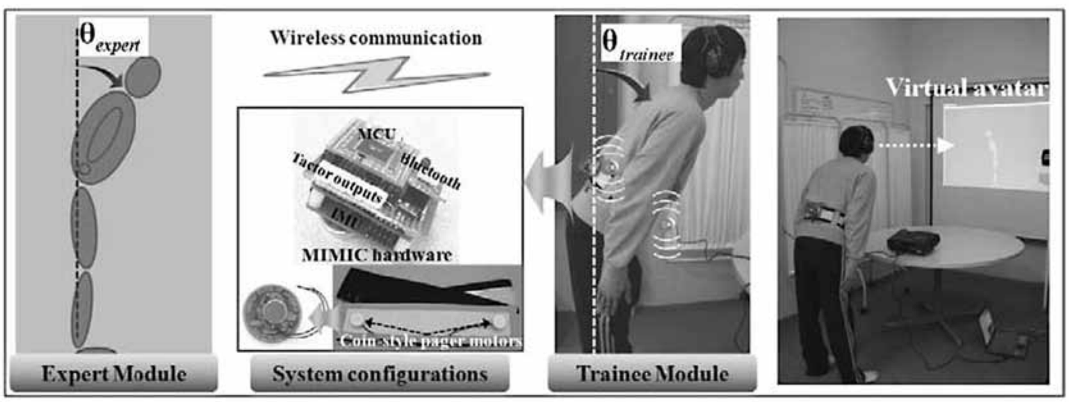
Vibrotactile sensory substitution technologies have been used to display direction and magnitude of trunk tilt information via stimulation of the skin in order to increase postural stability during quiet and perturbed stance in both individuals with vestibular deficits and older adults (Sienko et al., 2008; Ursu et al., 2009; C. Wall, 3rd and Kentala, 2005; C. Wall, III and Weinberg, 2003; C. I. I. I. Wall et al., 2004).

The Mobile Instrument for Motion Instruction and Correction (MIMIC) enables an expert (such as a physical therapist) to map his/her movements to a trainee in hands-free fashion. In a proof-of-concept study, we found that expert-subject cross-correlation values were maximized and time delays and average position errors were minimized when a 0.5 degree position error threshold and proportional plus half derivative control signal were used (Lee and Sienko, 2010). This study builds on our prior work by assessing further benefits derived from the addition of visual feedback to the existing vibrotactile instructional cues.

Method

Figure 1. System configuration The methods described herein are described in additional detail in (Lee and Sienko, 2010). An overall schematic representation of the MIMIC system is given in Figure 1. The wearable IMU-based expert-trainee motion error detection and vibrotactile instructional cuing device is composed of an Expert Module (EM) and a Trainee Module (TM).

Each module includes a six degree-of-freedom inertial measurement unit (IMU), microcontroller unit (MCU), Bluetooth module, data saving module, and battery. The TM additionally has an array of tactors (coin-style eccentric mass pager motors) that provides vibrotactile stimulation to the skin. The expert's body movements are sensed by the EM IMU and processed by an extended Kalman filter (EKF) (Welch and Bishop, 2005) estimation algorithm embedded in the MCU. The estimated expert motion is transmitted wirelessly to the TM via Bluetooth communication, and directional instructions are displayed via vibrotactile stimulation to the skin based on the computed difference between the expert and trainee motion. During trials involving visual feedback, a virtual 3D avatar is used as shown in Figure 1.



Five young (23.4±3.3 years) healthy naïve subjects (3 male, 2 female) participated in the study. University of Michigan Institutional Review Boards approved the experimental protocol, which conformed to the Helsinki Declaration. Informed consent was obtained from each subject prior to the start of the experiment.

Subjects (i.e. trainees) were instrumented with the TM and instructed to 1) stand with their feet parallel approximately 15cm apart (indicated by floor markings) and 2) "move in the direction of the vibration until the vibration stops". Standard foam earplugs and earmuffs were provided to eliminate environmental and tactor noise. Tactors were placed on the trunk midline (navel and spine) at approximately the L4/L5 lumbar level of the spine. Subjects were asked to replicate the previously recorded expert anterior-posterior (A/P) trunk motion by following 1) vibrotactile instructional cues alone, 2) visual instructional cues alone, or 3) combined vibrotactile and visual instructional cues. The expert motion consisted of an anterior 20° trunk bend followed by a 6s static hold at 20° and a posterior trunk bend to return to neutral upright stance. The anterior and posterior 20° trunk bends were performed at a rate of approximately 1.12 deg/s. All trials were performed with eyes open except for vibrotactile alone trials. Note that each subject was asked to bend only at the waist in response to three different instructional cues while they were performing the task. For the vibrotactile instructional cues, 0.5 degree position error threshold and proportional plus half derivative control signal were used (Lee and Sienko,2010). Each subject performed four repetitions of the each instructional modality, totaling twelve trials. The presentation of trial type was randomized and no practice trials were provided. In addition, pre-/post-base line data were collected to assess any potential training effects.

To characterize the subjects' ability to replicate the expert motion, a cross correlation analysis of the expert and subject trunk tilt angle was performed. The output of the cross correlation analysis was normalized between 0 and 1, with 1 indicating perfectly matched motion. Measured time delay was also used to assess motion replication, with a positive delay indicating a time lag between the trainee and expert motion. Average position error between the expert and the subject was also computed. Non-parametric Kruskal–Wallis one-way analysis of variance was performed using PASW (SPSS, Inc.), with each instructional modality (vibrotactile,visual, combined vibrotactile+visual) as an independent variable and cross correlation value (0 to 1), time delay (.), and position error as dependent variables. Significance was defined at the $p<0.05$ level.

Results

Preliminary results showed that subjects maximized cross correlation values and minimized delays and position errors when using a combination of visual and vibrotactile instructional cues. The average cross correlation values for trials involving combined vibrotactile and visual cues (0.98) and vibrotactile cues alone(0.98) were significantly higher than the visual cues alone (0.85) (Figure 2(a)). In addition, subjects had significantly smaller position errors when replicating the expert motion with combined vibrotactile and visual instructional cues (0.27 deg) compared to either vibrotactile (0.34 deg) or visual (2.05 deg) instructional cues alone (Figure 2(b)). The time delay was significantly larger for subjects given a visual cue alone (0.95 s) versus either the vibrotactile cue alone (0.20 s) or combined vibrotactile and visual (0.14 s) instructional cues.

Summary and disclaimer

This paper describes the effects of multimodal instructional cues on subjects' ability to replicate expert motion while using the MIMIC system. We describe a wearable device for real-time motion error detection and vibrotactile instructional cuing that enables experts to wirelessly map their body motion to one or more trainees. The MIMIC has potential applications in both physical therapy settings and the athletic arena; it may also be used by an individual at home to perform balance-rehabilitation exercises either previously recorded in the presence of a physical therapist or distributed via the internet. Additionally, it may be used to simultaneously instruct a classroom of trainees.

The main advantage of this design over other motion replication systems such as described in Lieberman (Lieberman and Breazeal, 2007) or Kapur (Kapur et al., 2009) is that the IMU.S. eliminate the need for any external apparati such as mechanical links, cameras, or magnetic

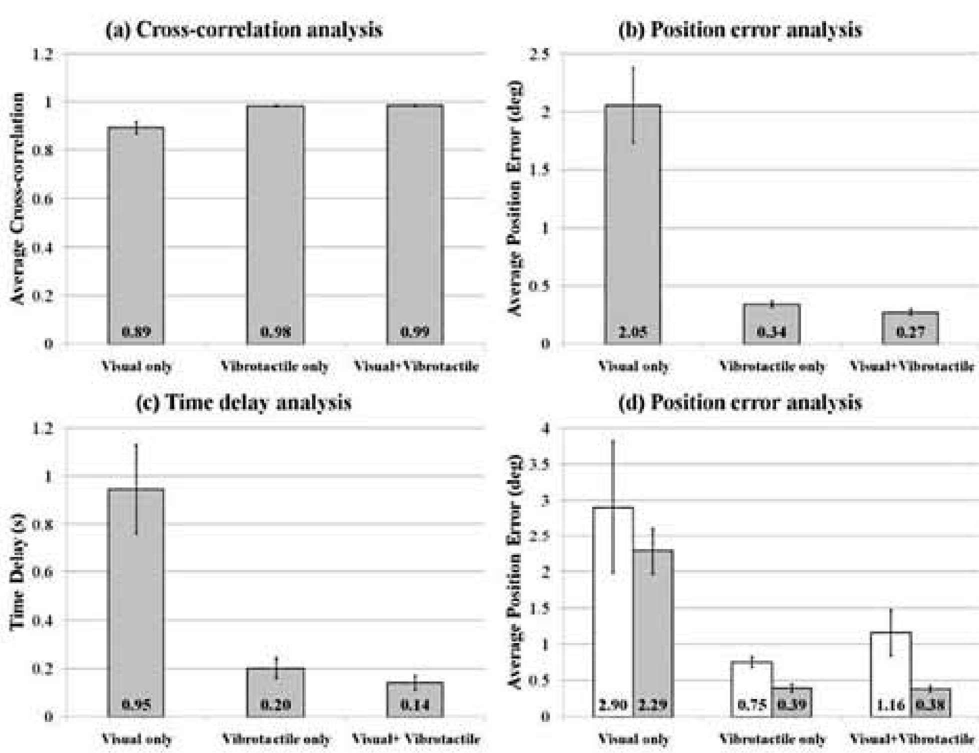


Figure 2. Preliminary results: (a) Expert-trainee cross-correlation; (b) expert-trainee position error; (c) expert trainee time delay; and (d) expert-trainee position error pre/post experiment. Error bars represent standard error of mean.

emitters that are characteristic of mechanical, optical, and electromagnetic tracking systems.

Based on the results of this proof-of-concept study, we demonstrated that subjects could best replicate the relatively simple task of bending at the waist using combined vibrotactile and visual instructional cues based on expert-trainee position error. Their position error in this case was better than that achieved using either vibrotactile or visual feedback conditions alone. In the case of visual instructional cue, the average of position error from all subjects was significantly higher than other instructional cues such as tactile only or combined of visual and tactile. However, combined vibrotactile plus visual instructional cues were not significantly better for replicating the expert motion compared to vibrotactile cues alone. Therefore, it could be argued that a simpler system involving vibrotactile cues alone is sufficient for slow and simple motion replication tasks. It remains to be seen the extent to which motion can be mimicked when multiple body segments receive instructional cues and the motion is faster.

Acknowledgement

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Effect of Excessive Adiposity on Risk of Slipping and Postural Stability

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Obesity in the workplace is a growing concern. Epidemiological evidence indicates the connection between obesity and traumatic workplace injuries, such as fall accidents. However, relevant studies are limited, with mixed findings. Therefore, the objective of the current study was to evaluate the effect of excessive adiposity on postural stability during standing and risk of slip initiation during walking. Twelve young adults (18-30 years old) were involved in a laboratory study. Based on BMI measures, seven participants were categorized into normal-weight group and five into overweight group. Postural stability was quantified using standard Sensory Organization Tests by computerized posturography system. Risk of slip initiation, as quantified by friction demand, was measured by having participants walk on an instrumented treadmill with embedded 3D force plates. The overweight group was found to require significantly higher friction (17.5% more, p = 0.004) than their normal weight counterparts. It was concluded that it is necessary to implement more rigorous environmental control measures for overweight and obese workers in order to prevent slip-induced fall accidents.

Introduction

Obesity in the workplace is a growing concern. Recent statistics indicates that approximately 85% percent hourly manufacturing employees are either overweight or obese [Pollack et al. 2007]. Obesity is associated with a variety of health problems including increased risk of falling. Middle-aged and older obese adults fall almost twice as frequently (27%) as their normal-weight counterparts (15%) each yyear [Fjeldstad et al. 2008]. And once they fall, those who are overweight or obese are 15% to 79% more likely to sustain a fall-related injury requiring medical treatment [Finkelstein et al. 2007]. However, our understanding of the biomechanical mechanism of obesity-related falls has been very limited and largely inconclusive. For example, there has been conflicting evidence regarding the impaired postural stability associated with obesity. Studies [Hue et al. 2007] have indicated that postural instability increased with body weight and Body Mass Index (BMI). Nevertheless, the measures of postural balance were not different between obese and non-obese adults [Fjeldstad et al. 2008]. This may suggest that the increased falling risk associated with obesity may be more related to their impaired ability to maintain their balance during the dynamic process of fall accidents, such as the initiation, detection and recovery paradigm in slip-induced falls [Lockhart et al. 2005].

Therefore, the objective of the current study is to investigate the effect of excessive adiposity on postural stability during standing and risk of slip initiation during walking. It is hypothesized that the risk of slip initiation,instead of postural stability, may differentiate overweight and normal-weight adults.

Method

Twelve healthy young adults were involved in a laboratory study. Their anthropometric information is summarized in Table 1. According to CDC guideline [CDC 2009], seven participants were categorized as normal weight (N, 20 < BMI < 25) while five as overweight (O, 25 < BMI < 30).Informed consent has been approved by the Committee for Protection of Human Subjects at University of Houston and obtained from each participant prior to data collection.

Group	Age (yrs)	Height (m)	Weight (kg)	BMI
N	19	~ 26 1.63 ± 0.11	61.8 ± 8.4	23.1 ± 0.6
O	18	~ 23 1.66 ± 0.12	103.4 ± 64.1 2	8.1 ± 2.7

Table 1 – Summary of participant anthropometric information

Group Age (yrs) Height (m) Weight (kg) BMIN 19 ~ 26 1.63 ± 0.11 61.8 ± 8.4 23.1 ± 0.6O 18 ~ 23 1.66 ± 0.12 103.4 ±64.128.1 ± 2.7.

During the postural stability session, each participant went through the standard Sensory Organization Tests(SOT) using computerized posturography system (NeuroCOM Balance Manager, NeuroCOM Int'l, OR). SOT involves 6 test conditions: (1) eyes open, fixed visual reference, fixed support; (2) eyes open, sway visual reference, fixed support; (3) eyes close, fixed support; (4) eyes open, fixed visual reference, sway support; (5)eyes open, sway visual reference, sway support; (6) eyes close, sway support. During the walking session, each participant was instructed to walk on an instrumented split-belt treadmill (TO-08-B, Bertec Co., OH) at their normal speed for approximately 5 minutes. Three trials of ground reaction force under the dominant foot were obtained from the embedded 3D force-plate at a sampling rate of 1000 Hz. Friction demand (i.e., required coefficient of friction) was calculated as the peak negative ratio between anterior-posterior force and vertical force [Perkins 1978]. One-way between-subject ANOVA was performed in JMP 8 (SAS Institute, USA), with the weight group (N or O) as the independent variable, and the equilibrium scores under 6 test conditions and the friction demand as the dependent variables. A significant level of . = 0.05 was adopted.

Results

As illustrated in Figure 1, there was a significant group effect (p = 0.004) on friction demand. In average, the overweight group was found to require 17.5% higher friction than their normal weight counterparts. In other words, the overweight group was more likely to initiate a slip on a slippery surface.

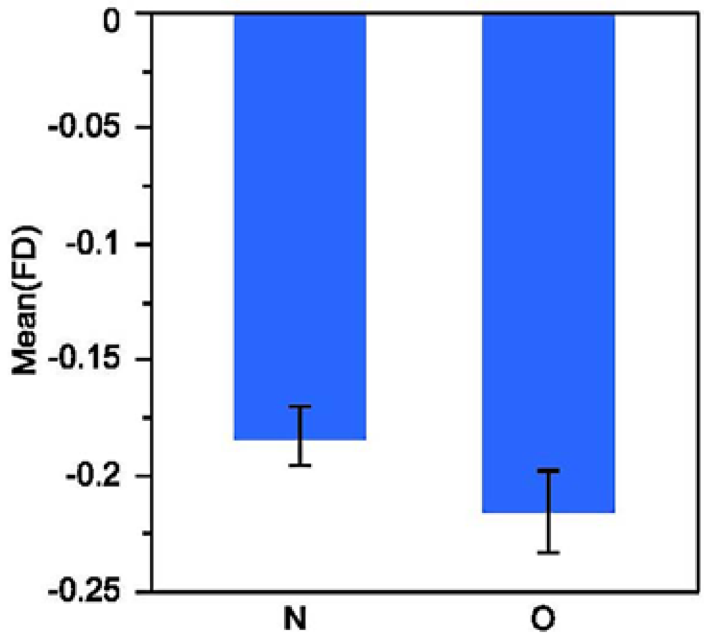

Figure 1 – Friction demand (mean ± 1SD) by group

Contrary to friction demand, no significant group effect was found on the equilibrium scores in any of the 6 test conditions (Figure 2). In other words, there is no evidence showing the overweight group had impaired postural stability during upright posture than their normal weight counterparts.

Discussions and Conclusions

A better understanding of the effect of increased level of body adiposity on individuals' ability to maintain balance under upright posture as well as dynamic conditions (e.g., walking) would afford a greater opportunity to develop new fall prevention strategies and guidelines specifically for obese populations in the workplace. The objective of this study was to investigate the risk of slip initiation between overweight and normal-weight adults.

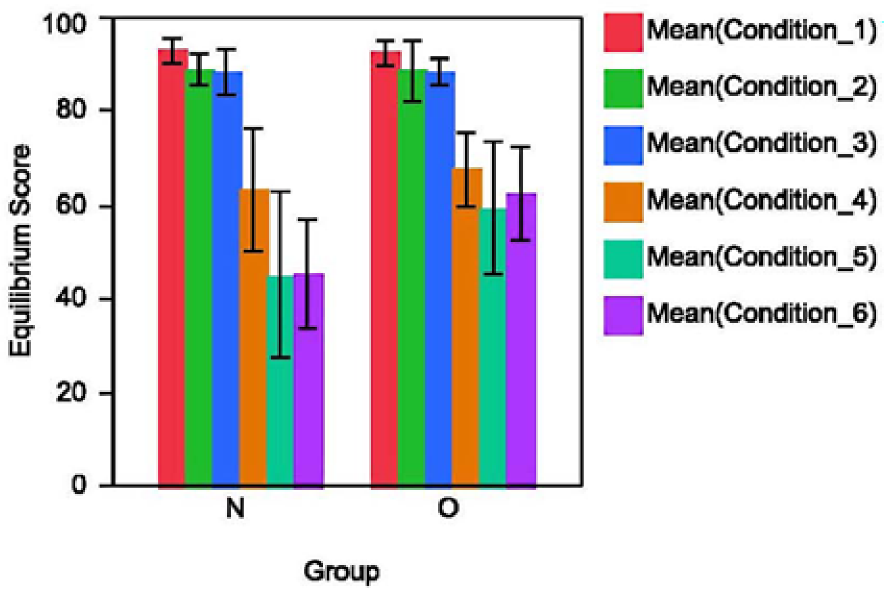

Figure 2 – Postural stability (equilibrium score: mean ± 1SD) by group

As expected, the overweight group requires significantly higher friction during walking, even though there is no evidence showing they have impaired postural stability during upright posture. This finding supported the postulation in the literature that the fall accidents in obese individuals are more related to dynamic measures of stability [Fjeldstad et al. 2008]. Friction demand has been widely studied for general population and it is agreed that maintaining an adequate level of floor coefficient of friction (COF) is important in preventing slip-induced fall accidents [Gronqvist et al. 2001]. Although the scientific community has yet to reach a consensus on the safe level of floor COF [Gronqvist et al. 2001], it can be reasonably concluded that based on the current findings, higher standard on floor COF has to be implemented in places where overweight and obese workers are prevalent. Over the years, researchers have proposed several mechanisms to explain the obesity-related fall accidents. Through computer simulation, it has been demonstrated there is an exponential increase in ankle torque requirements as the body fat increases [Corbeil et al. 2001]. In addition, increased body mass leads to increased moment of inertia about the ankle joint [Corbeil et al. 2001], which may present as a disadvantage in the reactive-recovery phase of a typical slip-induced falls. The current study contributes to the mechanism of obesity-related falls by showing that the biomechanical disadvantage starts as early as the slip initiation phase for the obese individuals.

As a preliminary investigation, the current study is limited in several aspects which need to be addressed in future studies. Besides limited sample size, the current study also lacked the representation of more severe obese status (i.e., BMI > 30). In addition, the BMI measurement only provides a gross categorization of one's weight status. More precise knowledge of one's body fat percentage and distribution will certainly aid our understanding of the influence of excessive adiposity on the biomechanics of falls. Lastly, by inducing slip/trip types of perturbation, future studies are needed to investigate the effect of obesity on the detection phase and the reactive-recovery phase of slip-induced falls. In summary, the current study concluded that the risk of slip initiation during walking, rather than postural stability during upright posture, may better explain the obesity-related fall accidents. In addition, the fact that overweight adults require significantly higher friction during walking makes it necessary to implement more rigorous environmental control for workplaces where overweight and obese workers are prevalent.

Acknowledgement

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Kinetic Learning in Occupational Fall Prevention Training

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Occupational fall accidents remain a significant cause of injuries and fatalities among the American workforce. Identifying effective proactive intervention is key to preventing occupational fall accidents. In this manuscript, fall safety in light of fall prevention training programs will be discussed. This training program is modifiable and allows safety team to target safety strategies that can mitigate recurring fall accidents.

Introduction

Occupation fall accidents continue to pose a significant burden to our industry, both in terms of human suffering and economic losses. The U.S. Bureau of Labor Statistics (BLS, 2007) reported that in 2007, a total of 835 fatal falls were recorded (15% of job-related deaths), and fall accidents accounted for more than 30% of all non-fatal injuries involving days away from work. Furthermore, compare to 2006, falls on same level rose up 21% and fall from nonmoving vehicles rose about 17% in 2007 (BLS, 2007).

As noted by NIOSH (2000), "exposure to fall hazards is a nearly constant aspect of employment." As such,the accident statistics presented above may remain unchanged unless substantial progress is made towards new means of reducing occupational fall occurrences. Such reductions are typically achieved through either fall protection (for fall to a lower level) or fall prevention (Hsiao and Simeonov, 2001). Fall protection refers to interventions aimed at minimizing injury severity after a fall event is initiated. The current OSHA standard for fall protection and other existing standards address this issue, covering fall protection systems, guardrails, and other related approaches. Despite the existence of such standards, such protection systems are not currently used with sufficient frequency or correctness (NIOSH, 2000). Furthermore, fall protection cannot prevent an incident from occurring (Smith and Veazie, 1998). Given this evidence, reliance on fall protection may not bean effective approach towards minimizing occupational fall accidents. Furthermore, although a static coefficient of friction of 0.5 is recommended to prevent a slip on a level surface, currently no standard or law requires that a floor must have a certain level of slip resistance. Additionally, the frictional properties of support/walking surfaces are not well defined and may change significantly with changes in environmental conditions (e.g., heat and moisture) and hamper balance control during dynamic tasks (Chang et al., 2001,and Hsiao & Simeonov, 2001). Given this evidence, reliance only on floor COF recommendation may not bean effective approach towards minimizing occupational fall accidents. Rather, fall prevention remains an important and perhaps even a critical task. As such, there is an important need for identifying effective proactive intervention strategies to prevent occupational falls. Since most occupational falls appear to be initiated by a perturbation (slip/trip) on a walking surface, fall prevention can be facilitated by a better understanding of friction demand/stability characteristics while ambulating on stable/unstable walking surfaces at normal and faster work-paces with and without the load, factors that adversely affect slip/trip/and fall recovery, and interventions that promote safe walking and ambulation (including the non-moving vehicles – i.e., ingress and egress).

Furthermore, since most adults learn better with active engagement of the training activities rather than seating in a classroom (Knowles et al., 2005) "kinetic learning" can facilitate the safety training. Kinetic learning refers to a teaching and learning style in which the learning takes place while performing a similar real-world activity instead of watching movies or slides. In this presentation, recent studies conducted at Virginia Tech Locomotion Research Laboratory regarding the training mechanisms associated with occupational fall accidents are reviewed in terms of epidemiology, tribology, biomechanics and psychophysics. In this manuscript, the mechanisms of kinetic learning in fall safety will be discussed further to identify research gaps and intervention approaches to reduce fall accidents in general population as well as the occupational settings.

Methods

In the context of fall safety and fall reduction efforts, a training program was developed to reduce gaps in knowledge and skills necessary to enhance employees ability to recognize and take appropriate measures (actions) to various fall hazards. Utilizing the Adult Learning Theory (Knowles et al., 2005), Fall prevention training program consisted of two components: the presentation of controlled information such as the nature and location of fall hazards (in-class setting), and practice (i.e., gait training course or Kinetic Learning Module - KLM) that result in better performance (in terms of reducing falls) according to standards which can be evaluated. Fall prevention curriculum included 1) knowledge of falls or common cause of falls, 2) tribology, psychophysics, and biomechanics of falling, 3) end result and consequences of falling, 4) gait modification techniques (i.e., KLM). In-depth knowledge regarding fall accident characteristics such as fall locations, time of the day, and common causes of falls, etc. was first presented to enhance hazard awareness. Afterwards, information and illustration of fall mechanisms were presented to enhance the discrimination of fall-risk-hazards (i.e., psychophysics).

In terms of the gait modification techniques (i.e., KLM), the objective of the program was to improve the training effect which can lead directly to our central set - i.e., slip perturbation training can improve balance and reduce future fall accidents utilizing various principles. Numerous studies have observed an increased ability to recover from a fall upon repeated exposure to a slip-perturbation (Bhatt et al., 2006; Pavol et al., 2002; and Lockhart et al., 2007). These investigators have suggested that adaptations to avoid falling can be modulated via both feed forward and feedback mechanisms (Cham and Redfern 2002; Horak and Nashner 1986). These adjustments to repeated perturbations during stance and gait reflect an individual's adaptability in stability control within the CNS. For example, the CNS can integrate afferent inputs to monitor and update the current state of the whole-body center-of-mass (COM) and compare it to a corresponding internal representation of the stability limits (Pai et al., 2003). A slip is initiated if the current state and the internal representation of the stability limits are miss-matched (Lockhart et al., 2002). As such, adaptive refinement of the internal representation of postural stability (to reduce miss-match) by perturbation training may improve the CNS's ability to prevent balance loss. This is because feed forward control requires prior experience and learning of the environmental constrains (e.g., slippery floor) as well as limitations of the controller (i.e., individual). An improved internal representation derived from repeated slip exposures could then improve slip-initiating characteristics (i.e., feed forward control) and modify post-slip reactive responses (i.e., feedback control) to reduce falls.

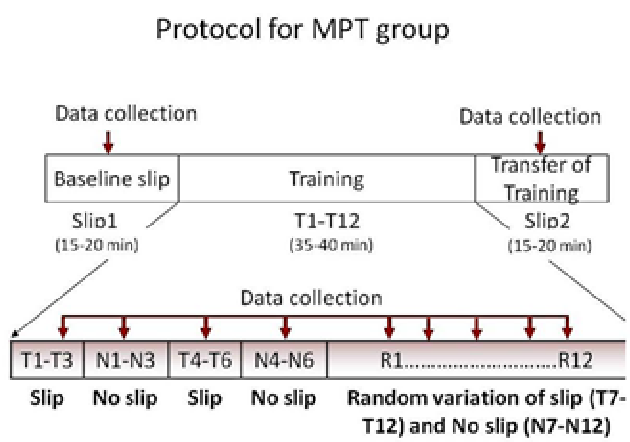
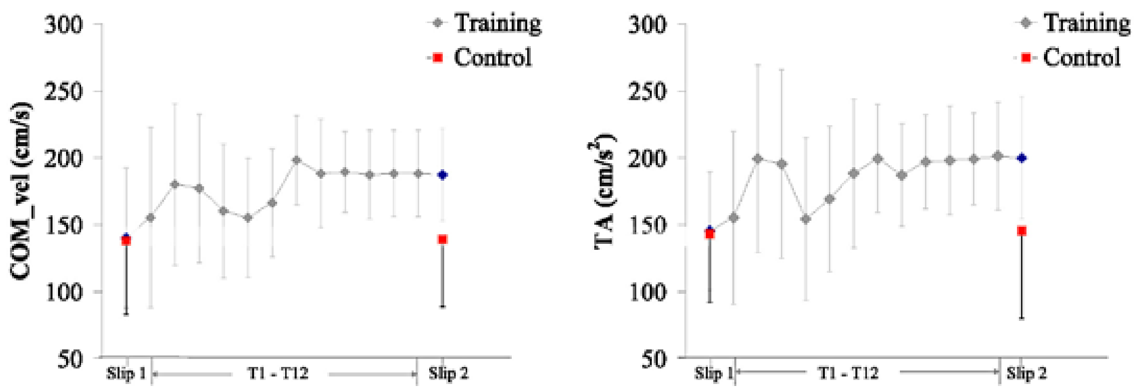


Figure 1. Test protocol for the training group.

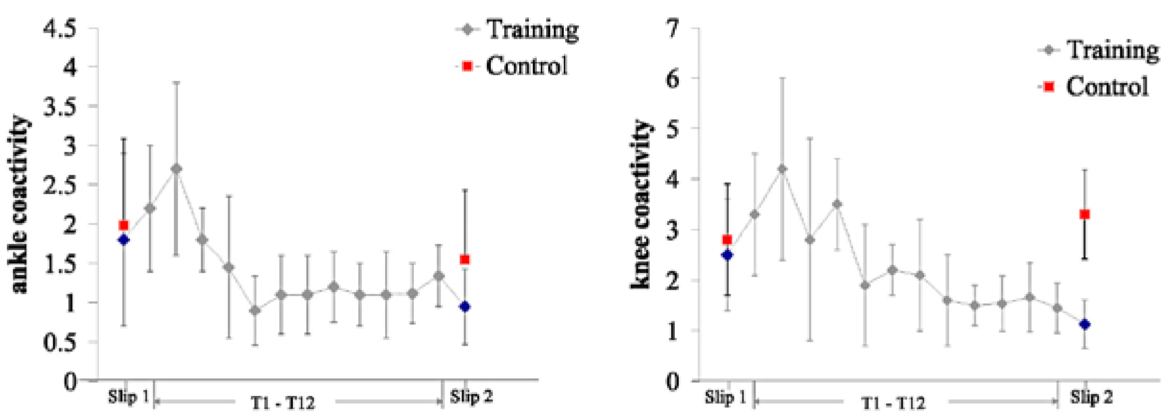
An experiment was carried out to assess the efficacy of simulated slip training in improving balance and reducing falls (Parijat, 2010). Twenty-four participants were recruited and randomly assigned to two groups (kinetic slip training and control). These groups underwent several sessions including the baseline slip trial, twelve simulated slips (utilizing a motorized platform training - MPT) for the training group (non for the control) (Figure 1). Kinematic, kinetic, and EMG data was collected during the sessions.

Results suggested that the training group was able to transfer proactive and reactive control strategies learned. The proactive adjustments include increased whole body center of mass velocity and transitional acceleration after training (Figure 2). These modulations were associated with reduced coactivity of ankle plantar flexors and knee flexors (Figure 3) leading to quicker muscle onset and peak activation, and ultimately leading to quicker slip stop response (Figure 4).



Mean ± 1S.D of center of mass velocity and transitional acceleration of whole body COM (TA) at heel contact from T1- T12 slip training trials (training group), and from SLIP1 and S2 trials(training and control group).

Figure 2. Adjustments/no-adjustments of the whole body COM velocity and transitional acceleration of the whole body COM in two groups (training and control groups). Slower transition of the whole body COM was associated with higher fall risk (Lockhart et al., 2003).



Mean ± 1S.D of peak ankle and knee coactivity from T1- T12 slip training trials (training group), and from SLIP1 and S2 trials (training and control group).

Figure 3. Coactivity of ankle plantar flexors and knee flexors of the training and control groups. Training group's coactivity was reduced after the platform training.

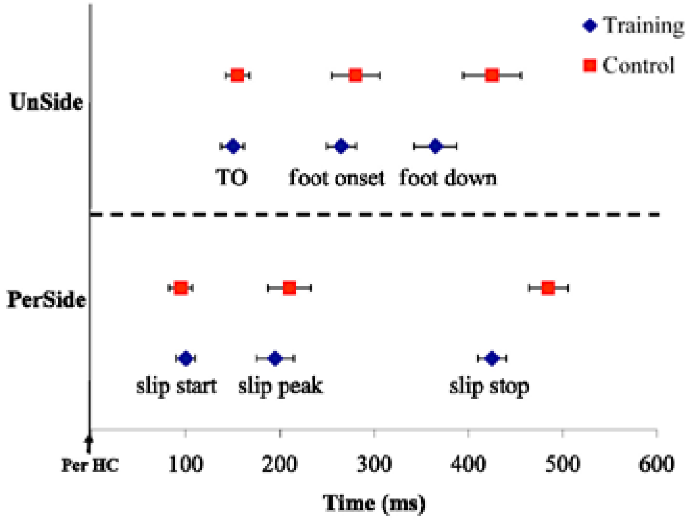


Figure 4. Phases of slip recovery from the heel contact (HC) to slip-stop of trained and control group on perturbed foot (i.e., slipping foot) and unperturbed foot with SD (lateral bars). The differences of import occurred during the foot down and slip stop of the perturbed and unperturbed foot – i.e., with training, subjects were able to use their unperturbed limbs quicker leading to a faster foot-down response ultimately leading to quicker slip stop and reducing falls.

Fall Prevention Training Program

In order to teach gait modification techniques and improve the understanding of slip resistance (e.g., slip resistance shoes, load carriage, work pace, etc.), a fall-arresting rig was composed at their training center (Figure 5) for the UPS, and for the other companies, a portable fall arresting harness system was utilized. Method of ingress and egress was presented utilizing force transducers to illustrate the impact force alterations to lower extremity joints when using and not using the handrails – i.e., three-point-contact method was presented, illustrated and practiced (Figure 6).

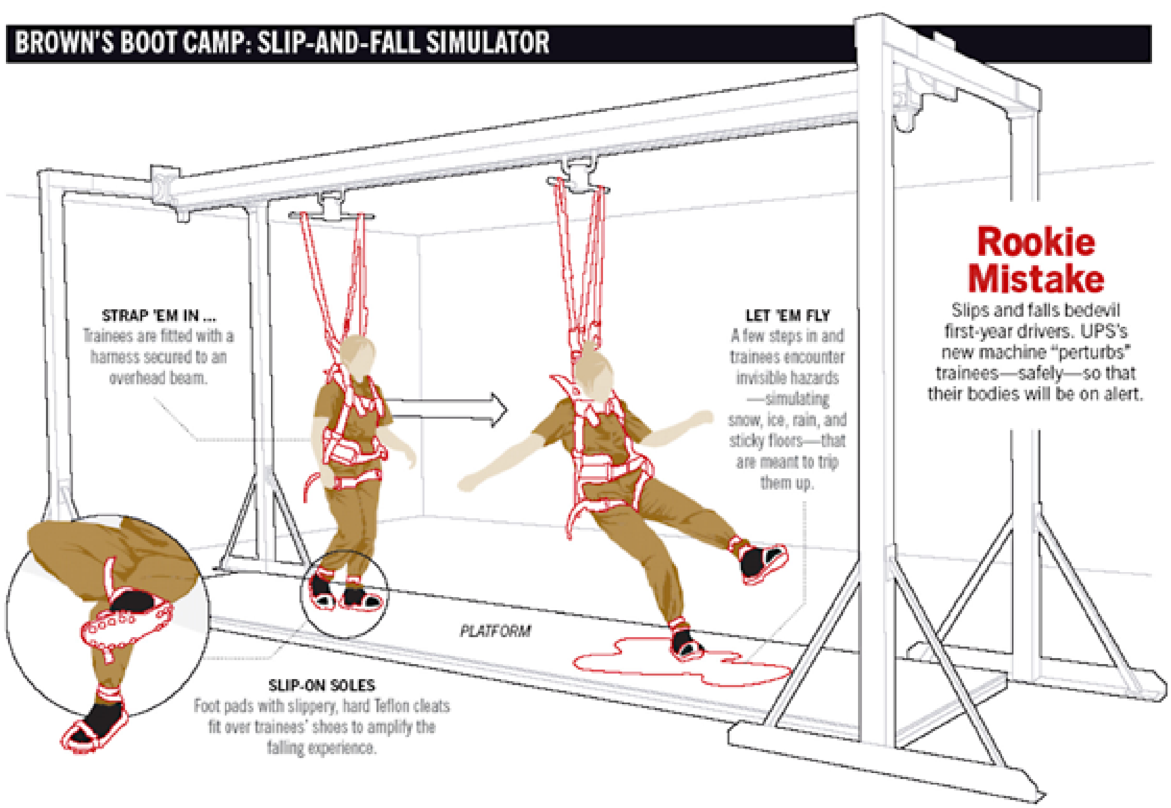


Figure 5. Fall-arresting system at the training center (Fortune, November 12, 2007).

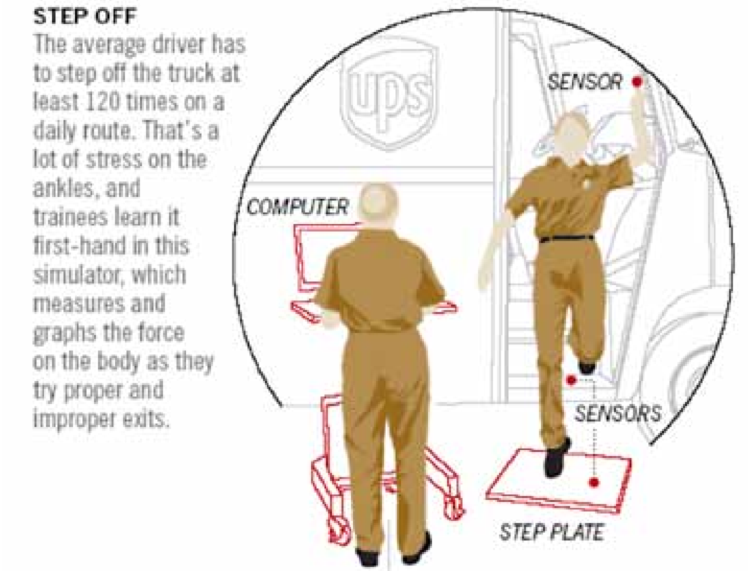


Figure 6. Ingress/egress station at the Training Center (Fortune, November 12, 2007).

Results

The results indicated a beneficial effect of training in reducing slip severity and recovery kinematics. Preliminary results indicated 79.3% greater reduction in injuries for the employees trained with the above system and the whole program compared to those receiving traditional training. Concurrent 61% great reduction in accidents for the training group was observed. Although implicated, parsing the results from the slips and falls module from other safety modules were difficult and only the overall percent reduction in injuries were reported herein.

Discussion

As indicated, fall prevention curriculum consisted of materials relevant to providing a better understanding of the mechanisms associated with occupational falls – i.e., biomechanics, psychophysics, tribology, and epidemiology. Furthermore, active engagement (i.e., kinetic learning) was possible via slip simulators. Although effective in occupational fall prevention, this type of training program should be carefully considered with safety in mind. Additionally, further research is needed to provide dose/response relationship for various occupations.

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Use of Walking Simulations to Assess the Frictional Requirements of Slip Resistant Gait

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Falls account for more than 20% of fatal injuries in workers over the age of 65 years old, and are often initiated by slips. Experimental studies have been useful to identify biomechanical variables that may impact slipping severity, but to determine the causes of failed recovery attempts from experiments alone is a challenging endeavor. Modeling and simulation techniques can complement experimental approaches to identify both the causes of falling and fall recovery strategies. The purpose of this study was to demonstrate the feasibility of using simulations to determine the subject-specific peak required coefficient of friction (RCOF) and to assess a slip simulation utilizing this parameter. This was achieved by using a model that included foot-floor interaction to find the set of moments that best tracked the joint angles and measured ground reaction forces obtained from a dry trial. A slip simulation was then generated by driving the model with moments obtained from the dry condition and by reducing the foot-floor friction coefficient (μ). The peak RCOFs obtained through simulations were almost identical to their experimental counterpart. There was also an agreement between the simulation peak RCOF and the μ value obtained for each subject, under which the resulting body kinematics were substantially different from the dry gait patterns. This correspondence supports the validity of our simulation results.

Introduction

Slip and fall incidents are a serious problem in older workers. Thus, research into the postural control mechanisms of slips and falls is an important step towards the reduction of occupational fall-related injuries and deaths. Research is needed to understand the impact of biomechanical variables, i.e. initial conditions and post-slip responses, on falling risk and how aging affects this relationship. This knowledge cannot be acquired through experiments lone. Whole body simulations of slipping are needed to meet these research needs. The purpose of this study was to demonstrate the feasibility of using forward dynamic simulations to determine subject-specific peak required coefficient of friction (RCOF) values. These simulations were used to determine the coefficient of friction (.) value under which body kinematics will diverge from normal gait. The potential findings of this work could be used to (i) reduce the risk of slips and falls, (ii) may provide insights into the impact of active corrective moments needed to prevent a fall, and (iii) may have important implications in safety-related research, specifically in the design of slip-resistant shoe and flooring environments.

Methods

Normal walking kinematics and bilateral ground reaction forces were collected for two healthy subjects(Subject 1: male, age=25 yr, mass=69 kg, height=170 cm; Subject 2: female, age=22 yr, mass=55 kg, height=160 cm). The subjects walked along an 8.5 m long walkway. Following the normal walking, a glycerol solution was applied onto the force plate without the subject's knowledge to generate an unexpected slip at heel contact of the left foot (leading leg). Written informed consent approved by the Institutional Review Board of the University of Pittsburgh was obtained prior to any testing. A walking model incorporating foot-floor interaction, modeled using an array of damped springs with friction under the foot, was utilized to find, using parameter optimization, the set of moments that best tracked the joint rotations and ground reaction forces obtained from a dry trial [Mahboobin et al. 2010]. The joint moments used in the optimization were the bilateral hip, knee, and ankle moments, and the lumbar extension moment. The optimization was accomplished in two stages and consisted of using non-gradient and gradient-based optimization methods. In the non-gradient optimization, a hybrid of particle swarm [Kennedy and Eberhart,1995] and Nelder-Mead downhill simplex [Press et al. 1988] methods were used. Obtaining a maximum instantaneous error of less than 10°, 25 N, and 100 N were judged to represent acceptable qualitative agreement between the simulated and measured joint rotations, horizontal ground reaction forces, and vertical ground reaction forces, respectively. The solution obtained from the non-gradient method was used in a deterministic, gradient-based optimization as the initial starting guess. The gradient-based optimization was accomplished using the Levenberg-Marquardt method [Marquardt 1963; Press et al. 1988].

Normal gait was simulated from the leading leg heel contact (0 ms) to 190 ms after. Slip was simulated by reducing the frictional forces applied to the leading foot (i.e., by reducing .). The applied joint-moments remained the same as in the dry gait simulation.

Results

The optimization of normal/dry walking resulted in joint moments that reproduced main features of the experimentally collected data (Figure 1). Overall, the root-mean-square (RMS) error between the simulated and

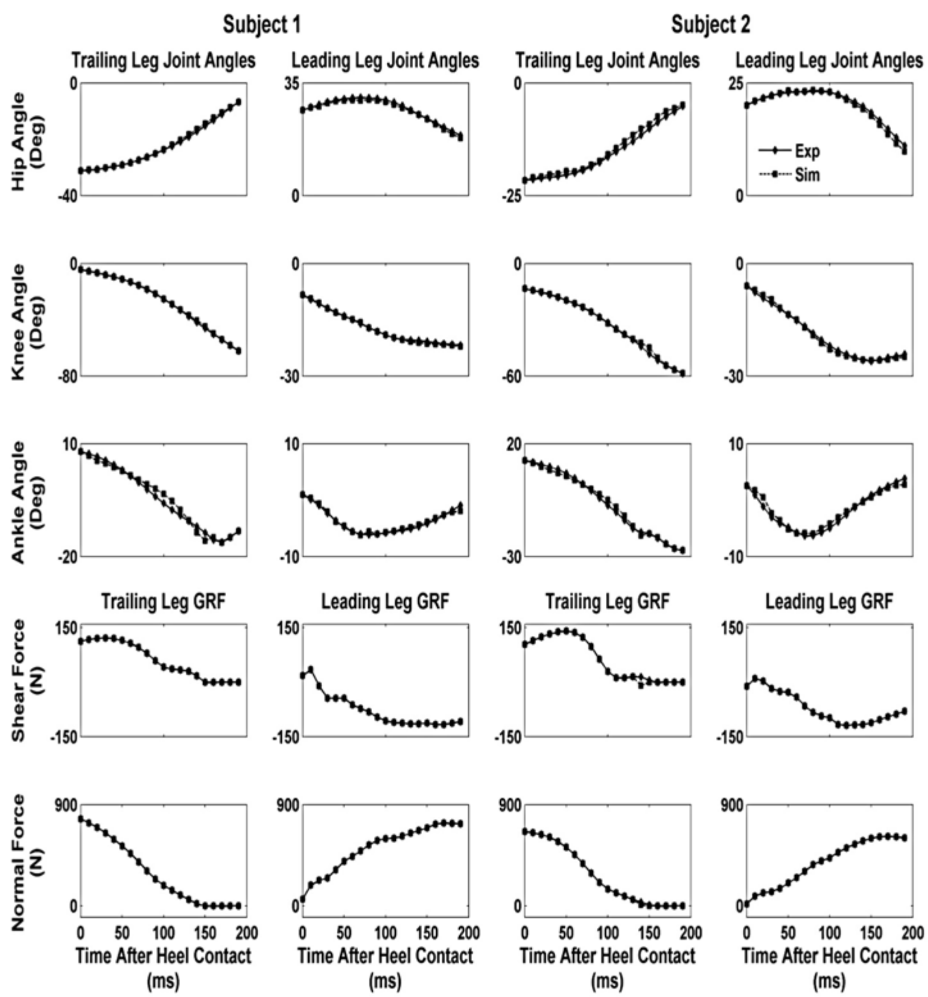

Figure 1. Normal/dry joint angle and ground reaction force comparisons between experimental(diamond) and simulation (square) data, where the top three panels show the trailing and leading leg hip, knee, and ankle joint angles and the bottom two panels show the anterior-posterior(shear) and vertical (normal) ground reaction forces for Subject 1 (left columns) and Subject 2(right columns), respectively.

experimental joint rotations for both subjects was less than 1.2°. The RMS error between the shear and normal ground reaction forces, for both the trailing and leading leg, were less than 0.08 and 0.17 N, for Subject 1, and 5.5 and 5.7 N, for Subject 2, respectively.

The experimental and simulated peak RCOF patterns were almost identical (Figure 2), with RMS errors less than 3.3×10^{-5} and 4.5×10^{-5} for Subject 1 and Subject 2, respectively. Applying the required joint moments needed in normal/dry walking in the slip simulations with values of $\mu \geq$ peak RCOF, resulted in only a minor deviation in gait kinematics from the dry condition. And the slip simulations indicated that walking with normal/dry joint moments in environments characterized by $\mu <$ peak RCOF results in kinematics that will be substantially different from normal/dry gait patterns.

Conclusions

The slip simulation findings imply the need for early and appropriate active corrective responses to prevent a fall, especially in slippery environments with $\mu <$ peak RCOF. This need was evident when comparing the experimental and simulated slips. In addition, the agreement between the simulation peak RCOF and the value identified in our simulations support the validity of our simulation results. A limitation to our approach is the use of a planar model rather than a three-dimensional model. More complex models will be needed to fully understand slipping behavior, as experimentally measured postural recovery responses from slips are not restricted to the sagittal plane.

In summary, we feel that forward dynamic simulations may have a potential for use in occupational falls prevention research and applications.

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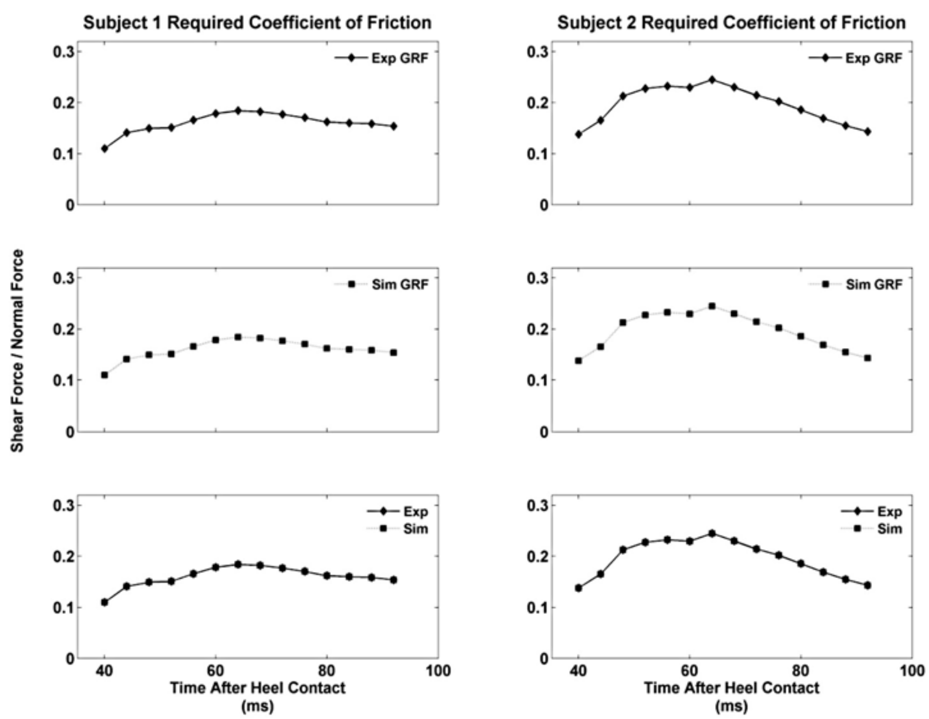

Figure 2. Computed experimental and simulated required coefficient of friction,calculated using the dry ground reaction forces, for Subject 1 (left panel)and Subject 2 (right panel).

A Methodology for the Analysis of Lateral Friction in Curved-Path Walking

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The objective of our work is to develop a methodology so that we can compare the medio-lateral component of Utilized Friction for a pedestrian negotiating a curve with the Friction-Circle model of classical physics. Pedestrians instrumented to capture path and velocity information walk upon predefined straight-ahead and curved paths, walking over an instrumented force plate. The forces measured by the force plate are resolved as per the information from pedestrian-position sensors into the A-P and M-L components, from which the Utilized Friction components are calculated. These Utilized Friction coefficients are compared with the friction that would be implied by the Friction-Circle model: μ = v2/r. The lateral component of Utilized Friction measured by the force plate was less than that predicted by the friction model. We hypothesize that the friction-circle model overestimates the Utilized Lateral Friction because the change in direction is not fully implemented by lateral force against the floor; rather, part of the change in direction is accomplished by joint rotations in the stance limb and trunk. Additionally, for comparison purposes, an instrumented skater shod in in-line skates skated the pre-defined paths.

Introduction

While Gait Parameters, including the anterior-posterior (A-P) and medio-lateral (M-L) components of the Utilized Friction, have been extensively analyzed for straight-ahead walking, the same cannot be said for walking in a curved path. Courtine and Schieppati's [2003 a,b] papers explored many curved-path gait parameters, but did not address Utilized Friction. In walkway-safety practice, in order to account for any increase in Utilized-Friction requirements due to acceleration and deceleration, changing direction, and so forth, a 'safety factor' is conventionally added to the typically-required friction involved in straight-ahead ambulation. For example, while the actual Utilized Friction coefficient in straight-ahead walking is approximately 0.3 [Redfern, et al. 2001], many involved in pedestrian-walkway safety hypothesize 0.5 as the threshold separating slip-resistant from not-slip-resistant conditions [Sacher 1993; Marpet 1996]: a 67%.safety factor. (That 0.5 threshold value has found its way into ASTM International and American National Standards Institute (ANSI) standards: D2047 and A1264.2 respectively). The quantitative characterization of the Utilized-Friction components in walking on a curved path is one of the main building blocks in the assembly of a quantitatively-characterized, rationally-set threshold for separating slip-resistant from not-slip resistant pedestrian ambulation scenarios.

Methodology

Experimental subjects were outfitted with position sensors (Polhemus Liberty Electro-Magnetic Tracking System) attached to the left and right calcanei (backs of the heels) and on the back over S2 (to approximate the center of gravity (COG)). The subject walked along a set of predefined paths drawn onto the walkway over an AMTI OR6-5 instrumented force plate. Three-dimensional spatial coordinates were collected for the position sensors at 120 Hz. The force-plate data were recorded at 1000 Hz.

The data were transformed from walkway coordinates to the pedestrian-body coordinate system:

$$\begin{bmatrix} X_{it} \\ Y_{it} \end{bmatrix} = \begin{bmatrix} \cos(\theta_t) & \sin(\theta_t) \\ -\sin(\theta_t) & \cos(\theta_t) \end{bmatrix} \begin{bmatrix} x_{it} \\ y_{it} \end{bmatrix}$$

where

X_{it} is the transverse component of motion of marker i at time t in the body - coordinate system

Y_{it} is the longitudonal component of motion of marker i at time t in the body - coordinate system

x_{it} is the transverse component of motion of marker i at time t in the walkway - coordinate system

y_{it} is the longitudinal component of motion of marker i at time t in the walkway - coordinate system

θ_t is the instantaneous angle between the body - and walkway - coordinate systems, calculated as

$\theta_t = \tan^{-1}\left(\frac{\breve{y}_t - \breve{y}_{t-1}}{\breve{x}_t - \breve{x}_{t-1}}\right)$, where $(\breve{\ })$ represents smoothed (5 - point moving average) positions.

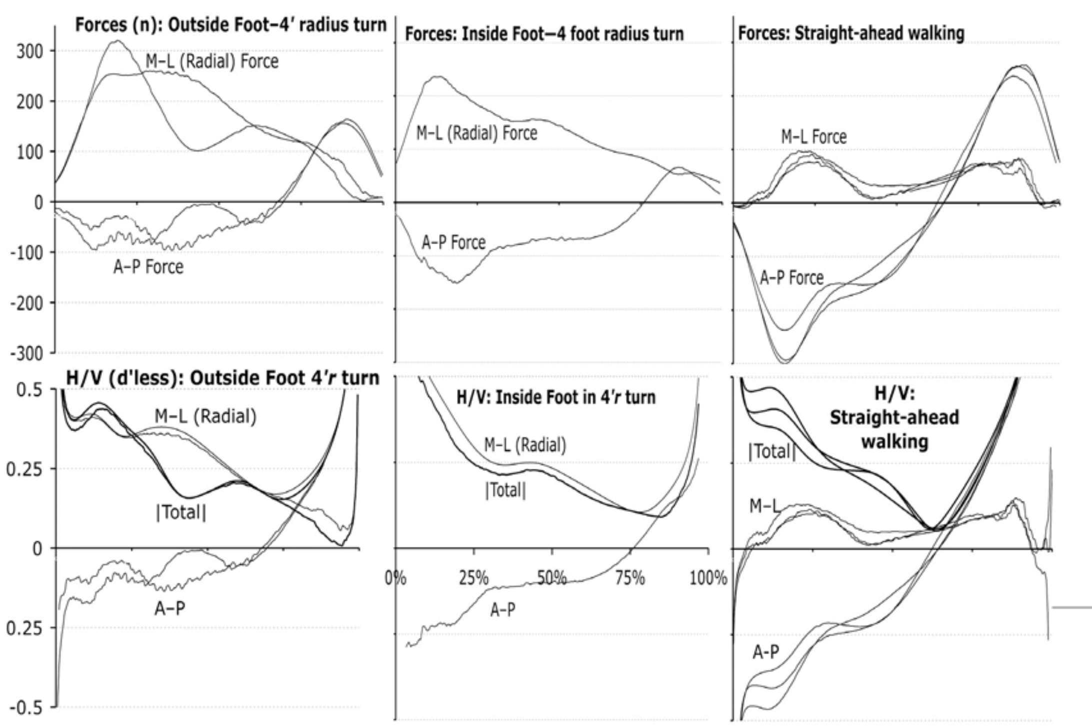
The utilized-friction coefficient ($\mu_{Utilized}$) is typically calculated by the ratio of the RMS in-plane forces divided by the normal force:

$$\mu_{Utilized} = \frac{\sqrt{(F_{xt}^2 + F_{yt}^2)}}{f_{zt}} = \frac{\sqrt{(F_{xt}^2 + F_{yt}^2)}}{F_{zt}}$$

where capital and lower-case letters again denote the respective coordinate systems. In our methodology, we look at the longitudinal (A–P) and transverse (M–L) in-plane body-direction forces separately. Data were recorded for straight-ahead ambulation, along a 3m radius, and along a 1.2 m radius, barefoot, in shoes, and in roller-skates. For each run, the foot striking the plate was determined by examination of the position/force-plate time series. Three trials were conducted under each condition.

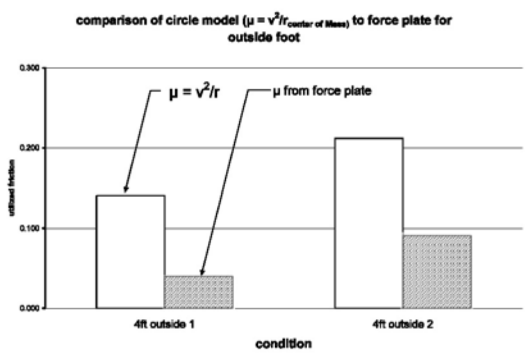
Results

Typical pedestrian-walking results are shown below. The upper triad of graphs share the same ordinate and show the A–P and M–L forces (in Newtons) as a function of %-stance. The lower graph triad, which together share the same ordinate, show the horizontal to vertical force ratio in the A–P, M–L, and the root-mean-square combination of the A–P and M–L forces. This force ratio contains the friction-coefficient information as well as the direction of the force, e.g., looking at the lower-right graph, we can see that the utilized friction starts out in the negative direction, as the foot decelerates, and then becomes positive to power the stride-foot's toe-off.



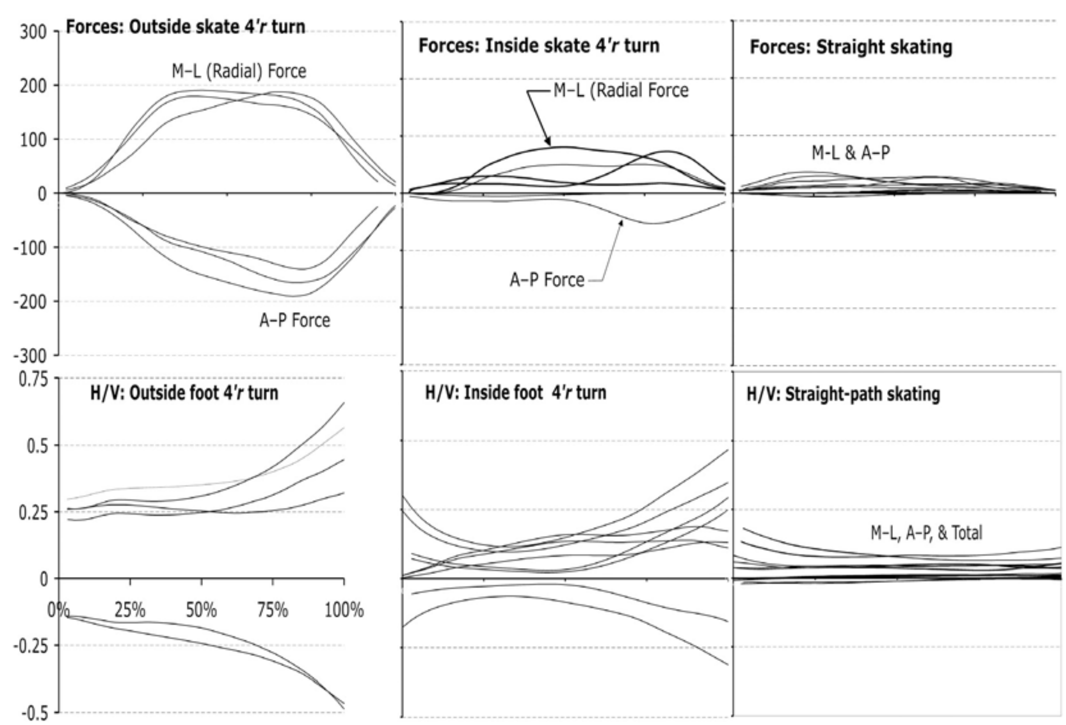
Two things are clear from these graphs: firstly, the radial (medio-lateral) forces in a turn are significantly larger than they are in straight-ahead walking and, secondly, the outside foot exerts significantly more lateral force in a turn than does the inside foot. The asymmetry that we see between the outside and inside force graphs can also be observed by simply looking at the manner in which a pedestrian's feet operate while negotiating a turn. That said, the friction requirements appear to be roughly similar.

A comparison of the Friction Circle model to the measured medio-lateral component of friction for two trials where the outside foot was measured is shown in the graph below:



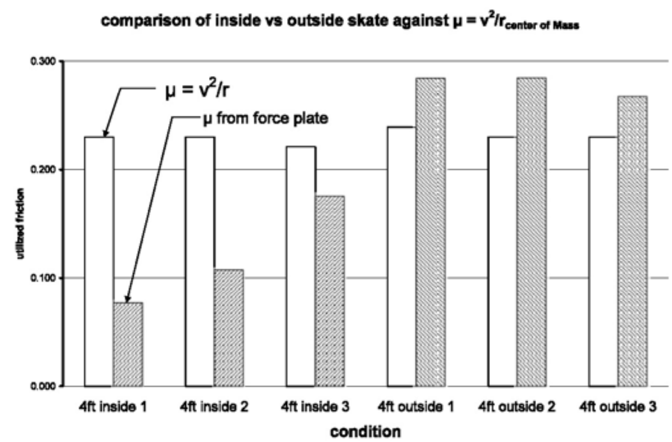
We note that the Friction Circle model over-estimates the utilized friction by a significant amount. We believe that this is due to the fact that the person is not 'static' as they walk across the force plate, but uses motion of the trunk to help accomplish the turn. To investigate this further, additional data were collected for a skater using in-line skates.

A different subject performed the skate trials, skating along similarly marked paths as did the subject who walked. The following graph set is laid out in a manner similar to the pedestrian-graph set:



Some obvious things are worth noting: firstly, the forces and friction required to skate in a straight path are both low indeed. Secondly, except for the forces generated by the outside foot in the turn, there were no easily discernible patterns between the M–L and A–P forces and between the Utilized M–L, A–P, and Total Friction.Thirdly, the magnitude of the forces and utilized friction decreases from the outside foot in a turn to the inside foot in a turn to the straight-path skating.

Once again, a comparison of the Friction Circle model to the measured medio-lateral component of friction was performed, this time for three trials where the outside foot crossed the force plate and for three trials where the inside foot passed over the plate. The following graph shows our results:



It was noted that the utilized COF was different for the inside and outside skates. While the Friction Circle model (the solid white bars) was fairly consistent for all trials, the utilized COF for the inside skate was substantially lower, where the outside skate measured utilized COF was higher than that provided by the Friction Circle model.

Discussion

It is no remarkable insight to notice that the inside and outside feet behaves differently when negotiating a turn. However, the quantification of this difference gives U.S. a better idea of the appropriateness of any selected safety factor for identification of slip-resistant vs. non-slip-resistant conditions. The data here demonstrate that the Friction Circle model is insufficient for estimation of utilized friction. For walking and turning at a self-selected velocity (~1 m/s), the estimates from the Friction Circle model were substantially higher than those measured directly. However, these data were collected on an adult without impairments;those unable to use the arms and trunk for turning may generate greater turning forces with their legs, thus utilizing more friction. Walking at higher velocities would also increase the utilized friction. rom the skating trials, we note the difference in friction utilization under the inside and outside feet. On average, the friction circle model overestimated the utilized friction under the inside skate by over 50%, while the utilized friction under the outside skate was underestimated by approximately 20%. This leads U.S. to suspect that the Friction Circle model is of limited usefulness when evaluating slip-resistance for curved-path walking.

Directions for Future Research

Two subjects cannot be considered as typical of anything. The methodology put forth in this paper needs to be applied to a larger population so that any variation between genders, age, able-bodied versus those with disabilities, etc., can be explored. The marginal change in utilized friction when walking a curved path is only one of a number of factors that should be considered in the setting of any friction thresholds. Acceleration and deceleration, for example, need to be characterized.

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Biofidelity-based Comparison of Barefoot Slip Resistance (Laboratory) Against an In Vivo Tribometer and a Standard Tribometer

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Slip resistance of barefoot pedestrians on water-contaminated walkway surfaces has received little attention compared with shod pedestrians on similar walkways. An *in vivo* tribometer (Step Meter) has been developed that can measure slip resistance of barefoot test subjects on water-contaminated walkway surfaces. Another way to characterize slip resistance is ASTM Standard F 462 which employs a specific portable tribometer (a Slip-Test Mark I Portable Articulate-Strut Tribometer (PAST)), a designated skin surrogate (Silastic 382), and a specified contaminant (a solution of soap in water). In our experiment, two barefoot pedestrians walked over a water-contaminated, marble-surfaced, instrumented force plate, with increasing velocity until each had a noticeable slip. The measured slip resistance from these pedestrians was compared to results obtained using a tribometer measuring the slip resistance of the water-contaminated marble, with the Silastic 382 foot surrogate, as well as with results from the in vivo Step Meter. The pedestrian/force plate and the in vivo Step Meter results were similar, while the tribometer with the Silastic 382 test foot showed poor biofidelity.

Introduction

Pedestrian slip resistance in a variety of environments, with different footwear, has been studied for a number of years [Perkins 1978; Marpet 1996; Hanson et al. 1999; Manning and Jones 2001; Cham and Redfern 2002; Burnfield and Powers 2006; Cooper et al. 2008]. The determination of required and available friction is an important factor in quantifying the probability of a pedestrian slipping for a given walkway surface, velocity, and presence of contaminants. In almost all of these studies, the test subject was wearing footwear. Architects and interior designers have specified smooth marble walking surfaces in interior of bathrooms and swimming-pool decks, where pedestrians can be expected to be barefoot. It is reasonable to assume that these interior walkway surfaces will become contaminated with water, and their slip resistance will be significantly reduced. A review of available literature revealed that there is paucity of information on the available and required friction of barefoot pedestrians. A DIN Standard, using a motorized inclinable ramp has been used to measure the slip resistance of a barefoot pedestrian on a water contaminated walkway surface [DIN 1992]. Medoff et al. [2002] developed an inclinable Step Meter using an in vivo test subject to measure the slip resistance of footwear/walkway combinations, dry and wet. Recently a number of researchers have published studies on the coefficient of friction of a bare foot sliding against marble floor [Sariisik 2009; Ali 2010]. The Sarisiik study used the DIN 51097 Ramp test, with different roughness values of wet marble, while the Ali study was focused on level walking with bare feet on marble with different percentages of detergent in the water-covered marble flooring. Previous research employed a Step Meter that was used with barefoot test subjects, 'stepping' onto a varying angle, water-contaminated walkway surface [Besser et al. 2008]. When the motion of the lower leg was well controlled, it was found that the results were consistent and repeatable. The available friction, as determined by a barefoot pedestrian walking on an instrumented, smooth, water-contaminated walking surface can act as a reference to evaluate the biofidelity of the Step Meter or a tribometer (in our experiments, we used a Slip-Test Mark II Portable Inclinable Articulated Strut Tribometer (PIAST) shod with a Silastic 382 Test Foot and using water as a contaminant).

Objective

To compare the slip resistance of barefoot human test subjects walking on hard, smooth marble, water-contaminated walking surfaces measured using a Step Meter, an instrumented force plate, and a Slip-Test Mark II tribometer (PIAST) with a Silastic 382 foot surrogate.

Method

Smooth marble, commercially-available tile (300 mm by 300 mm by 6 mm thick) was installed over an instrumented force plate (AMTI OR6-5 biomechanical force platform). The marble was contaminated with water over its entire surface. Two test subjects, who had previously been a part of the referenced 2008 Step Meter test test [Besser) et al. 2008] walked, at increasing speeds over this marble surface. For safety, each subject was connected to a BIODEX movable, partial body-weight support system via a harness connected to the top of the device. A person on either side of the BIODEX frame walked in concert with the test subject, matching the subject's speed. The body weight support system was used only as a safety harness, and no body weight was supported (the harness was slack). The test subjects started walking in a straight line approximately twenty feet from the force plate. On successive trials, each walked at ever increasing speeds until they noticeably slipped. Multiple slip trials were collected. The same surface was then evaluated for slip resistance using the Slip-Test Mark II tribometer (PIAST) with a Silastic 382 foot surrogate.

The measured vertical force (Fz) and the shear force (in the horizontal (x-y) plane) were obtained from the force plate data for each subject. The utilized friction was determined by dividing the in-plane force by the normal force.

$$F_f = \frac{\sqrt{F_x^2 + F_y^2}}{F_z}$$

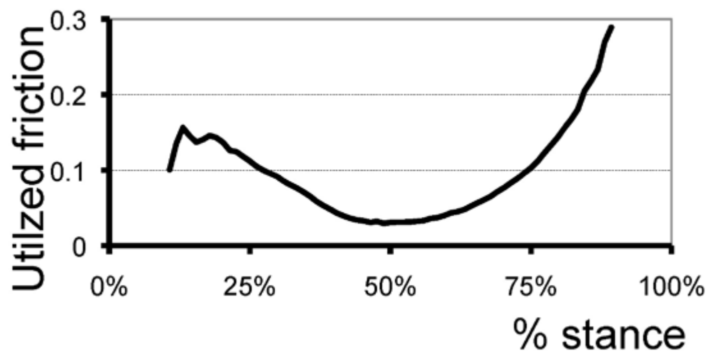
where: F_f = Frictional force (Coefficient of Friction)

$\sqrt{F_x^2 + F_y^2}$ = Sum of in plane shear forces and

F_z = Normal Force

Results

In the following graph, which represents a typical non-slip trial, the Utilized Friction is displayed on the ordinate and percent of stance time on the abscissa. Values for μ are not calculated for the first and last 10% of stance, as these values are inaccurate due to the low Fvertical. The values in the table above were taken from the initial peak in the utilized friction graph (the portion of the graph corresponding to heel slip).

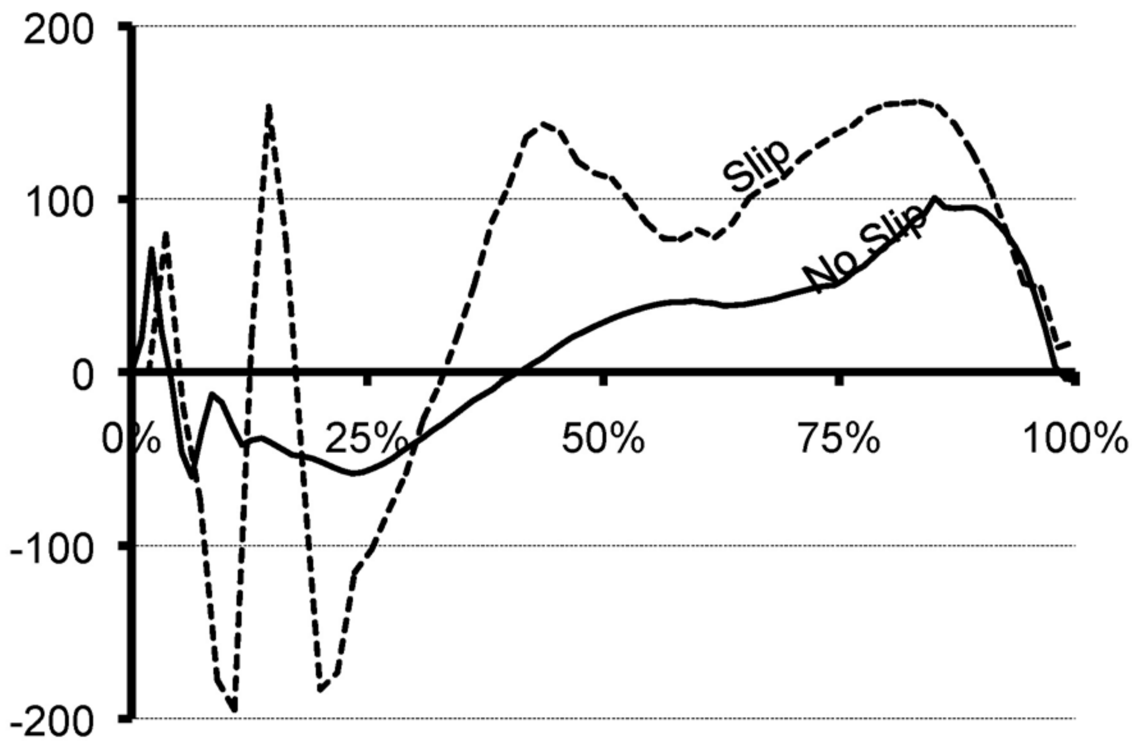


The table below presents the utilized coefficients of friction for the overground walking trials, as calculated from the force plate data.

Table Of Calculated Coefficients of Friction Pedestrians walking on instrumented walkway		
Subject	Trial	C.O.F.
A	1	.176
A	2	.179
A	3	.221
B	1	.220
B	2	.099
B	3	.196

The Slip-Test Mark II, with a Silastic 382 skin surrogate on water-contaminated marble had a slip resistance of essentially zero (hydroplaning).

The ground reaction force (GRF) in the direction of progression (anterior-posterior, or A-P) for one subject for one non-slip (solid line) and one slip (dashed) trial are shown in the figure below. Again, the horizontal axis is normalized to % stance. For the non-slip trial, the A-P GRF after the impulsive first peak has a typically inverted sinusoid appearance, with the downward first portion of the graph representing 'braking', or slowing of the foot, allowing the momentum of the body moving forward to passively carry it over the base of support, followed by a positive 'pushing' force where the ankle generates power to move the body forward toward opposite foot contact. Qualitatively, it was seen that, for a slip, the pedestrian spends less time in 'braking' phase, and when slip occurs, reverses the direction of the force, essentially extending the hip to push back against the ground, trying to actively accelerate the body over the base of support.



A comparison of Anterior-Posterior Ground Reaction Force for a Slip (Dashed Line) and a No-Slip (Solid Line) trial. Horizontal axis is % stance, vertical axis is anterio-posterior force in Newtons.

Discussion

The Step Meter, using barefoot test subjects with their lower leg constrained, on a water-contaminated marble surface, produced an average slip resistance (coefficient of utilized friction) of $m_{Utilized}$ = 0.18 [Besser et al. 2008]. Similarly, the same two subjects achieved an identical average friction level at slip of μ = 0.18 during overground walking on the instrumented walkway. The Slip-Test Mark II tribometer with a Silastic 382 test foot was unable to evaluate the slip resistance of the water-contaminated marble (giving a result of $m_{Utilized}$ = 0.0).

Conclusion

We found that there is good agreement between Step Meter-determined slip resistance for a barefoot-pedestrian on a water-contaminated marble surface and barefoot pedestrians walking on the same water-contaminated marble surface, as determined using an instrumented force plate. Results from a Slip-Test Mark II tribometer with a Silastic 382 test foot results show poor agreement with the other two methods. Further study is required, with a larger population sample, to determine if the observed agreement between the Step Meter results and barefoot pedestrians walking on water contaminated marble surfaces will continue to be produced. However, this study presents preliminary evidence that barefoot pedestrian friction on contaminated walkway surfaces can be evaluated using the Step Meter.

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A Study to Understand Gait Characteristics to Explain Trip-Induced Falls on Crushed Rock Aggregate, Specifically Railroad Ballast

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Same level falls continue to contribute to an alarming number of slip, trip, and fall injuries in the workforce. Railroad safety statistics indicate that ground, ballast (crushed rock aggregate), or floor were principal causes of over one half of all severe injuries to railroad workers. Although railroad workers who work mainly on ballast represent less than 10% of the total population of railroad employees, they experience 28% of reportable injuries and 42% of days absent from work for all railroad employees.

The main objective of this study was to investigate how walking on different ballast types and slopes influences the probability of a trip-induced fall. Ten healthy male railroad employees participated in the study. Gait analysis on two surface orientations (level and sloped) and three surface types (hard smooth surface, Mainline ballast, and Yard ballast) for both left and right limbs were analyzed (n=600 trials). Mainline ballast had a diameter of 2.5–5.5 cm and yard ballast had a diameter of 1.1–2.7 cm.

The current study provides evidence that there is a relationship between walking on crushed rock aggregate and modified gait patterns. Walking on mainline and yard ballasts significantly increased toe clearance requirements compared to walking on a hard, smooth surface. Cadence decreased for yard and mainline ballast. Significant changes in external rotation and increased knee flexion while walking on ballast was observed. Increased requirements for heel and toe clearance may indicate an increased likelihood of a trip induced fall, especially in the presence of fatigue.

Introduction

According to the U.S. Bureau of Labor Statistics Statistics (BLS) [BLS 2009], same level falls contributed to over one million lost work days (LWD) between 2005 and 2008. The source of injury reported by nearly 21% of cases was the floor or ground surface. There is a substantial amount of research focused on the biomechanics of trip-induced falls on level or uphill/downhill walking on smooth surfaces and treadmills, however a significant number of fall related injuries occur on irregular surfaces and slopes that are neither smooth nor level. Ballast, or crushed rock aggregate is commonly used in the transportation, construction, agriculture, and manufacturing industry for walking surfaces. Between 1994- 1998, 25% of all injuries resulting in LWD in the railroad industry were categorized as slip,fall, or stumble related. Two thirds (66%) of these were associated with surface condition or slope [FRA 2010]. For railroad yard workers, walking surface conditions are influenced by many factors including, ballast type or condition, track construction practices, environmental contaminants (rain, vegetation, ice, etc.) and other debris. Almost one third (31%) of all railroad employee injuries occur in the railroad yard [USDOT 1997].

Trips generally occur when the swing foot contacts the ground, or when the stance foot prematurely contacts the ground before initial support [Tinetti et al. 1988]. Minimum foot clearance (MFC), minimum toe clearance (MTC), MTC variability and foot velocity at MFC appear to be important parameters related to a trip-induced fallinduced fall [Begg et al. 2007; Khandoker et al. 2008; Mills et al, 2008]. Variability of frontal plane ankle kinematics during walking on ballast has been reported by others [Andres et al, 2005], however, no data are available about the influence of ballast size and slope (transverse plane) on gait adaptations that may be related to trips. The feasibility of performing gait analysis on ballast, including collection of ground reaction forces, has recently been demonstrated successfully

[Merryweather 2008; Wade and Redfern 2007].

The purpose of this study was to investigate gait adaptations while ambulating over ballast and to determine how ballast size and slope in the transverse plane may influence the probability of a trip-induced fall. Temporal spatial parameters were examined as well as a measure of surface condition roughness and toe/foot clearance during swing.

Methods

Three-dimensional gait data from ten healthy males railroad employees (age (year) = 37.1 ± 8.9; height (cm) = 180 ± 8; mass (kg) = 84 ± 14.1; years with railroad = 8.4 ± 7.7) were analyzed in the Ergonomics and Safety Laboratory of the University of Utah. All participants undertook informed consent procedures approved by the university's Institutional Review Board prior to participation. Custom walkways 76 cm wide and 7.3 m long were designed to contain mainline (2.5-5.5 cm) and yard ballast (1.1 – 2.7 cm), that was supplied by a local railroad yard, and conformed to railroad graduation requirements for ballast (Figure 1). The tracks were constructed on ten adjustable jacks to provide a sloped surface in the transverse plane up to 14° (Figure 1). Three walking surface conditions, yard ballast, mainline ballast, and hard smooth surface (structural plywood sheeting), and two track configurations, level and sloped (7°) were examined in this study. Measurements from multiple locations in a local railroad yard were examined for slope. The mean slope in the yard was approximately 0°. The slope in this study was chosen to compare to work published by Andres et al. [2005]. Each participant was given a new pair of model 2408 Red Wing work boots to standardize footwear. The markers on the foot and ankle were placed on the boots bilaterally over the second metatarsal, heel, and lateral malleolus. A total of ten successful trials were collected for each experimental condition (n=600 total trials). The left limb was always on the downhill side of the slope during all trials.

Kinematic parameters and temporal/spatial parameters including cadence, stride length, step width, stance/swing time were measured using ViconMotus. (ViconPeak, Centennial, CO, USA) with 5 cameras. A measurement of surface roughness for each track was derived using a rolling measurement wheel instrumented with retro-reflective markers. Estimates of toe and heel clearance were obtained by taking the vertical distance between the location of the foot markers and a coordinate system origin located at the location on the track where foot contact occurred.

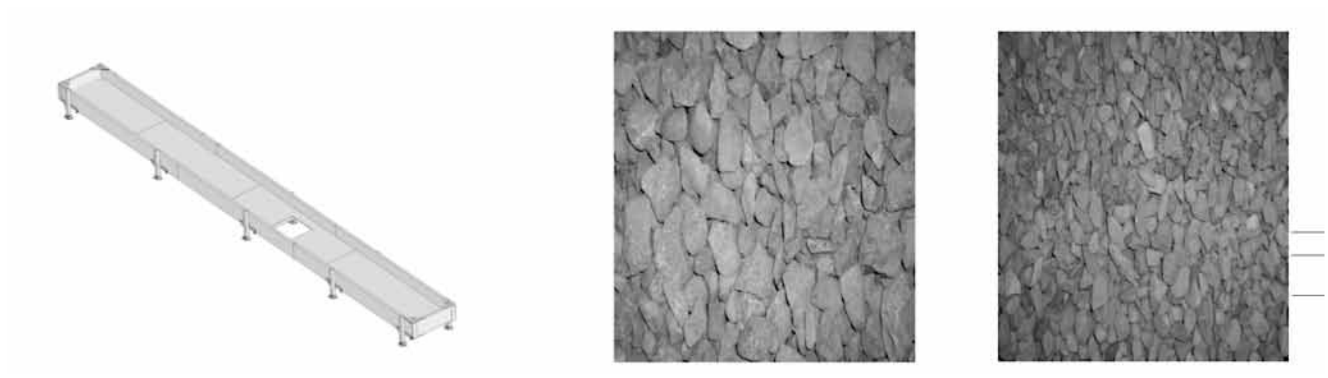

Figure 1. Ballast Track, Mainline Ballast (left) Yard Ballast (right)

Statistical analyses were conducted using a generalized linear model (GLM) in SAS v9.3 (SAS Institute INC., Cary, NC, USA) to evaluate differences ($\alpha<0.05$).

Results

Table 1 presents selected temporal parameters associated with normal gait for males from the literature compared to the current study study [Chao et al. 1983; Giannini et al. 1994; Kadaba 1989; Whittle 1996]. Cadence on the control surface was greater than on both aggregate conditions by surface and slope (p<0.05).

Source	Cadence		Cycle Time		Stride Length		Speed	
Whittle1996	118.5	32.5	1.07	0.25	1.55	0.3	87.6	21.6
Giannini 1994	102	6	--	--	71	8	74.4	15.1
Winter 1990	111	8.7	--	--	1.55	0.1	--	--
Kadaba 1990	112	9	1.08	0.08	1.41	0.14	80.4	13.2
Chao 1983	104	5	--	--	1.56	0.15	76.1	12.5
Current Study								
Control Level	99.2	4	1.2	0.05	1.53	0.12	75.5	7.2
Mainline Level	96.2	4.7	1.24	0.06	1.47	0.1	70.8	4.8
Yard Level	96.9	5.1	1.24	0.07	1.48	0.12	71.4	7.3
Control Slope	99.8	4.3	1.2	0.05	1.52	0.1	75	6.4
Mainline Slope	94.3	5.9	1.27	0.08	1.5	0.11	71.1	7.32
Yard Slope	95	4.8	1.27	0.07	1.52	0.12	71.1	5.7

Mean S.D. *Percentage of total Gait Cycle

Table 1. Temporal Spatial Parameter Comparisons

Lower limb kinematics were significantly altered by surface condition. Walking posture became slightly more crouched with a wider stance and increase in knee external rotation. Mainline ballast had a significantly greater external rotation than yard ballast and mainline ballast (p<0.0001). Slope was not significant (p=0.388). The INT/EXT knee angles were significantly different between uphill and downhill knees (p<0.0001). Knee flexion angle was greatest on yard ballast. Mean toe clearance (Figure 2) for both left and right limbs was significantly different by surface condition (p<0.001). Surface slope had little influence on measured variables.

Discussion

All walking speeds were within normal ranges reported by others, however the mean cadence was generally lower (Table 1). This trend was observed with ballast size, but not slope. The difference in cadence between ballast types was not significant. An increase in external knee rotation was seen on mainline ballast. These gait adaptations may be compensatory mechanisms to improve stability and reduce the likelihood of a trip-induced fall. Peak knee flexion angle during swing also increased with ballast type. Greatest peak flexion angles occurred on yard ballast.

Mainline ballast had the largest variation in surface height fluctuations. These differences were not the same for measures of toe marker height. Observed toe clearance was greatest on yard ballast. Increasing the mean toe clearance height alone is likely to result in higher energy costs leading to fatigue. Yard ballast appears to require more energy during gait, similar results have been found with other compliant surfaces such as sand

[Zamparo et al. 1992]. The variability in toe and heel clearance measures was similar for both ballast types. Both stride-to-stride variability and surface condition variability contribute to measure of MTC and probability of a trip-induced fall [Mills et al. 2008].

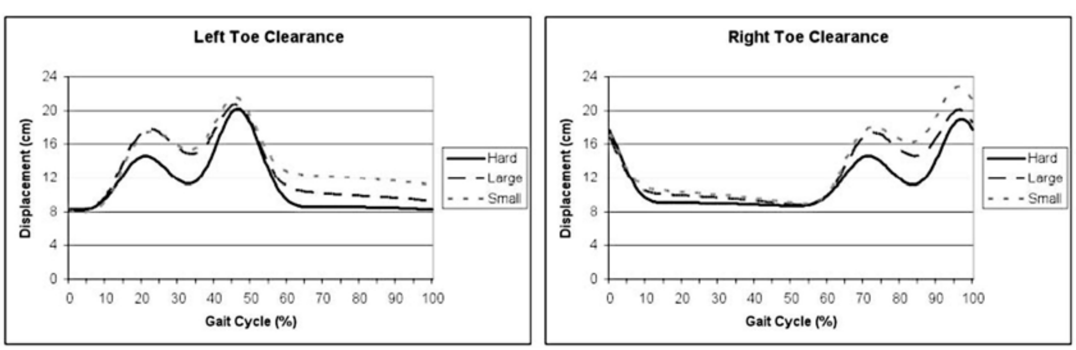

Figure 2. Toe Clearance by Surface

Conclusions

Results suggest that surface slope (7°) in the transverse plane does not have a significant impact on gait parameters and indicators of trip potential. The results show that gait alterations may increase fatigue from walking on yard ballast. This may be a contributing factor related to trip-induced falls. Surface roughness combined with measures of ground clearance is likely related to an increased probability of a trip-induced fall, specifically if the foot during swing prematurely contacts an unexpected surface irregularity. Variability in foot clearance and walking surface roughness should be minimized to avoid potential ground-toe contact while walking. Maintaining walkways and controlling ballast condition are likely important considerations that may reduce variability in walking surfaces. This will likely decrease the probability of a trip-induced fall.

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Effect of Shoe Roughness on Shoe-Floor Lubrication

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Fall accidents represent a significant social and economic burden. The amount of available coefficient of friction (COF) between a shoe and floor surface affects the likelihood of a fall occurring. Surface characteristics (i.e. roughness) of shoe and floor material as well as fluid lubricant contribute to the amount of available COF. Shoe-floor-liquid contaminant dynamic COF has previously been shown to decrease asymptotically with sliding speed. Current testing methods, however, measure COF under a single speed condition. Frictional force between a single shoe and floor material was measured with a pin-on-disk tribometer at three fluid viscosities, three shoe surface roughnesses, and across a range of speeds. The effect of varying shoe material roughness, lubricant viscosity, and velocity on the COF-speed effect was examined. COF was observed to decrease asymptotically with increasing velocity for two of the fluids (1 .9 and 5.5 cP). Three regions of fluid lubrication were observed; boundary lubricated, partially lubricated, and fully lubricated. The boundary lubricated (initial) region resulted in the highest COF. The partially lubricated region conditions resulted in a decreasing COF with increasing velocity. The fully lubricated regime resulted in COF leveling off and increasing velocity having limited influence on COF. To capture the transition from boundary to full lubrication, an exponential regression was fit to COF data. The "safety transition speed," $\upsilon_{O.2}$, which was calculated from the exponential regression model, represents the speed at which the COF goes below 0.2, indicating a higher likelihood of slipping. Increasing fluid viscosity resulted in $\upsilon_{O.2}$ decreasing from 0.544 m•sec^{-1} under 1.9 cP viscosity to 0.117 m•sec^{-1} under 5.5 cP viscosity. At the lowest lubricant viscosity, surfacer roughness appeared to have minimal influence on $\upsilon_{O.2}$, whereas at the medium lubricant viscosity higher surface roughness resulted in higher $\upsilon_{O.2}$ values. Higher UO.2 indicates an increased range of conditions under which there is a low probability of a slip occurring. Roughness was observed to have a more significant effect under increased fluid viscosity lubrication. The new measure evaluated in this study, $\upsilon_{O.2}$, which is based on COF values across many speeds, may be more relevant to slipperiness than the standard COF measure because it takes into consideration the variation in heel velocity during walking.

Introduction

Fall accidents pose a serious social and economic burden. In 2007, Liberty Mutual reported that the total cost due to all fall accident injuries was approximately $13.9 billion [Liberty Mutual Research Institute 2009]. Slip and fall accidents impose a significant risk; of all slip and fall accidents 50% are attributed to improper flooring and 24% are attributed to improper shoe material [National Floor Safety Institute 2010]. During gait, when the available dynamic coefficient of friction (COF) is less than the required COF between shoe and floor material, the likelihood of a slip and fall accident occurring increases [Hanson et al. 1999]. While previous studies have indicated a correlation between COF and risk of slipping, COF is known to be dependent on testing conditions [Beschorner et al. 2006], with results dependent on the device and methodology.

Previous reports have shown that altering the roughness of the lubricated contacting surfaces alters the COF [Chang 1998]. In addition, COF has been demonstrated to decrease asymptotically with increasing speed, consistent with the Stribeck curve [Beschorner et al. 2006]. The effect of roughness on this COF speed curve, however, is not yet understood. The purpose of this study was to examine the effect of roughness on COF under varying fluid viscosities under a range of speeds relevant to walking.

Methods

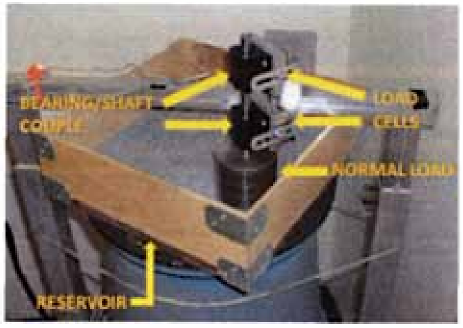


Figure 1. Custom-developed pin-on-disk tribometer

A rate table was converted into a custom-developed pin-on-disk tribometer, Figure 1, and used to measure COF between 12mm-diameter, un-treaded polyurethane (PU) shoe and vinyl (Rq=1.34 μm) floor samples. Shoe material was abraded with 100, 220, and 400 grit sandpaper corresponding to surface roughness (RMS roughness, Rq) of 9.34 μm, 8.2μm, and 7.3 μm, respectively. Roughness values were measured with a profilometer (Taylor Hobson). Trials were collected using three different glycerol-water concentrations, 25%-75%, 50%-50%, and 75%-25%, with corresponding viscosities of 1.9 cP, 5.54 cP, and 41 cP, respectively. Data was collected at 11 speeds ranging from 0.05-1.0m•sec^{-1}, under a 20.9 N normal force. Trials lasted 30 seconds; COF was averaged over approximately 10 seconds.

COF was observed to decrease as velocity increased, following regions of partial and full-film lubrication. The COF curve was fit with an exponential regression, Equation 1. A COF of 0.2 has been suggested as the transition between slips occurring and not occurring (Hanson et al., 1999). A safety transition speed, $\upsilon_{0.2}$, was calculated from the exponential regressions for each trial. An exponential regression was fit to trials lubricated with 1.9cP and 5.54cP viscosity lubricant (n=28); regression fits with an R^2 value less than 0.5 were excluded (n=2). The y-intercept (μ_o), rate of decay (τ), and velocity at which COF drops below 0.2 ($\upsilon_{0.2}$) were calculated from exponential regression equations for each trial.

$$\mu = \mu_0 e^{-\upsilon/\tau} \qquad \text{EQUATION 1}$$

A higher μ indicates an increased level of friction and decreased likelihood of a slip. μ_0 characterizes COF at velocity equal to 0 and is most indicative of boundary lubrication. τ represents the rate of change of COF. An increased τ indicates a decreased rate of decay.

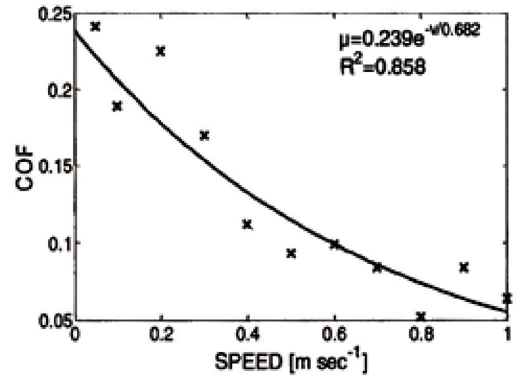


Figure 2 Sample raw COF data with exponential regression fit

Statistical Analysis

ANOVA analyses were performed to determine the effects of roughness and fluid viscosity on the lubrication of the shoe-floor interface. Separate one-way ANOVA analyses were performed using variables μ_0, τ, and $\upsilon_{0.2}$ as the dependent variables and shoe roughness and fluid viscosity as the independent variables. The statistical analysis software, JMP 8 (SAS ®, Cary, NC), was used for all statistical analysis.

Results

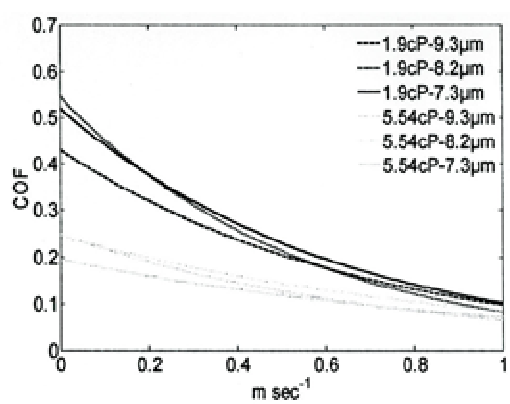
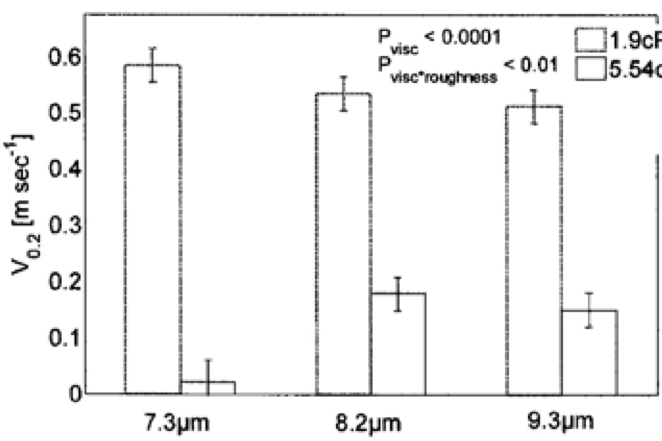


Figure 3 Exponential regression fits under varying conditions

All exponential regression fits followed a similar trend; COF was observed to decrease with increasing speed and fluid viscosity, Figure 3. Roughness was observed to have some limited effect on COF, whereas viscosity had an apparent effect on COF. The speed at which conditions transition from "safe" friction levels to low friction, $\upsilon_{O.2}$, was found to be significantly affected by viscosity (p<O.0001) and roughness-viscosity interaction (p<O.01). Decreasing viscosity increased $\upsilon_{O.2}$ resulting in a greater range of conditions under which friction levels would be considered safe, Figure 4. Post-hoc analysis identified that under 5.54 cP lubrication there was a significant difference in $\upsilon_{O.2}$ of the smoothest shoe sample and the two rougher samples; however there was no significant difference in $\upsilon_{O.2}$ between the rougher samples. Under 1.9 cP lubrication, post-hoc analysis revealed that there was no significant difference in $\upsilon_{O.2}$ across shoe roughness values.



Viscosity significantly affected μ_0 (p<O.0001) and τ ((p<O.0001), Table 1. μ_0 decreased and τ increased with increasing fluid viscosity. Post-hoc analysis revealed that there was a significant difference in τ between viscosities under 7.3 flm and 8.2 flm roughness; however, there was no significant difference in T under 9 . 3~m roughness between viscosities. Roughness significantly affected μ_0 (p<O.005). The roughness-viscosity interaction significantly affected μ_0 (p<O.0005) and v τ (p<O.01).

Data tested under the highest viscosity (41 cP) could not be fit well with an exponential regression. COF ranged from 0.125-0.212 across all roughness with COF falling mostly below 0.2, indicating a less safe condition. $\upsilon_{O.2}$ would be very low under 41 cP lubrication.

Discussion

The available COF under liquid lubrication was found to be affected by viscosity, shoe roughness, and viscosity-roughness interaction. Hanson et al. suggested that the available COF level that represents a transition from a low to increased probability of a slip occurring was 0.2 [Hanson et al. 1999; Redfern and Dipasquale 1997]. $\upsilon_{O.2}$ represents the transitional speed between high and low likelihood of slipping and corresponds to the range of conditions that are considered safe. Higher values of $\upsilon_{O.2}$ indicate a smaller likelihood of slipperiness. This variable may be more appropriate for evaluating the slipperiness of shoe-floor-fluid interactions than COF for an individual testing speed because it accounts for the variability in heel velocities during walking across subjects and throughout slipping.

Lower viscosity fluids were shown to be safe under the greatest range of conditions. Under 1.9 cP viscosity, mean $\upsilon_{O.2}$ was 0.544m·sec^{-1}, dropping to 0.117m·sec^{-1} under 5.54 cP viscosity lubrication. Under the highest lubrication (41cP),

Table 1 Change in μ_0, τ, and $\upsilon_{0.2}$

Viscosity	Rq [μm]	μ_0 [unitless]	τ [m^{-1}·sec]	$\upsilon_{0.2}$ [m·sec^{-1}]
1.9cP	7.3μm	0.521 (0.014)	0.615 (0.048)	0.585 (0.030)
1.9cP	8.2μm	0.547 (0.018)	0.532 (0.062)	0.535 (0.030)
1.9cP	9.3μm	0.430 (0.014)	0.677 (0.048)	0.512 (0.030)
5.54cP	7.3μm	0.206 (0.014)	0.888 (0.048)	0.022 (0.039)
5.54cP	8.2μm	0.246 (0.014)	0.938 (0.048)	0.179 (0.030)
5.54cP	9.3μm	0.248 (0.014)	0.750 (0.048)	0.151 (0.030)

$\upsilon_{O.2}$ would most likely have been very low since most of COF data was below 0.2. For the higher viscosity fluid that achieved partial lubrication, 5.54 cP, the smoothest samples resulted in the lowest $\upsilon_{O.2}$ measurements, which may indicate that roughness is critical in the presence of a moderately viscous fluid.

μ_0 decreased with increasing fluid viscosity, suggesting that boundary lubrication plays a role in decreasing COF with increasing fluid viscosity, with minimal hydrodynamic pressure effects. At higher viscosity lubrication, full-film lubrication is achieved at lower speeds and higher T values were observed, indicating a lower rate of decay due to less of the decreasing mixed-lubrication region and already low COF values.

A limitation of this study is that data was collected using a pin-on-disk tribometer which lacks "biofidelity." It would be beneficial to repeat this analysis with a more relevant slipmeter. Data collection was not randomized so the effects of wear are unclear.

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The Contribution of Environmental Factors to Elderly In-Patient Falls in Acute Facilities

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In-patient falls have been the biggest single category of reported hospital patient safety incidents since the 1950s. This may be due to a combination of patient-related (intrinsic) and environmental factors. Interventions have mostly followed a series of sequential steps: assessment; communication; monitoring; patient modification; and environment modification. This study explored the contribution of environmental factors in 26 reported unwitnessed patient falls using staff interviews and location mapping. It was found that the location of the fall seemed to be associated with the position of the bed rail and that very few of the patients were wearing shoes or socks at the time of the fall. In the U.S., hospitals may not be reimbursed for falls if they are categorized as 'never events' (events that should never occur).

Introduction

In-patient falls have consistently been the biggest single category of reported hospital patient safety incidents since the 1950s [Parrish and Weil 1958]. They are a significant cause of morbidity and mortality and have a high prevalence after admission to hospital [Salgado et al. 2004]. The incident rate for falls is approximately three times higher in hospitals and nursing homes than in community-dwelling older people [AGS 2001]. It has been suggested that this may be due to a combination of extrinsic risk factors [relating to the environment; Hignett and Masud 2006] for example, unfamiliar environment and wheeled furniture, combined with intrinsic risk factors (relating to the patient) such as confusion, acute illness and balance affecting medication.

Many attempts have been made to reduce the number of incidents and fall-related injuries but there has been very little evidence of sustained success in either the incident and injury rates over the last 60 years [Healey et al. 2008; AGS 2001]. Although only a small percentage of patient falls result in death and serious injury they represent a serious financial, governance and resource burden in terms of on-going healthcare costs and litigation [Boushon et al. 2008]. Interventions have predominantly followed a series of sequential steps: assessment, communication, monitoring (observation), modifying the patient (e.g. medication review, continence management and impact protectors), and modifying the environment [Hignett, in press]. This paper investigates the role of environmental factors in acute facilities.

Method

The study investigated 26 reported incidents for unwitnessed patient falls from March to September 2009 in 4 Care of the Elderly wards (n=112) in a large acute UK hospital (1,150 beds). The nurse reporting the incident was interviewed with a structured proforma (figure 1) to add factual information, for example the exact location of the fall, whether the bed rails were raised (3/4 length rails) and the type of footwear worn by the patient at the time of the fall.

The study was granted Ethical Approval from Nottingham Research Ethics Committee 1 (08/H0403/149) and Research Governance by Royal Derby Hospital (DHRD/2008/071).

• Where was the patient found?
• Was the patient injured?
• Were their bed rails up or down?
• Were they using any mobility aids (e.g. stick, frame, wheelchair)?
• Should the patient have been mobilizing independently?
• Was the patient carrying anything?
• Were there any trip hazards (prompt: footwear, type of flooring, liquid on floor)
• What was the lighting level?
• Vision correction – Did the patient use glasses, where they wearing them?
• Was the patient attached to anything e.g. catheter, drip
• How long do you think the patient was on the floor for?

Figure 1. Interview proforma

Results

The data were analyzed descriptively (figure 2), and plotted on location maps for falls (figures 3 and 4).

18 patients fell from the bed (figures 3 and 4), with 5 falling from an adjacent chair or commode (3 fell in the bay or bathroom). 18 patients were found on the floor by the bed, 4 were found by their chair, 3 in the middle of the bay and 1 in the bathroom (figure 5). 10 of the 18 patients falling from bed had raised bedrails; for 7 bed rails were either not applicable as they were not in bed or there was no information. Most patients had bare feet (n=17) at the time of the fall, with 8 wearing shoes, socks or slippers. 14 falls occurred under 'good lighting' (day light or artificial lights), with 12 falls in poorly lit conditions (light from corridor only) usually at night (after 22.30).

The data were plotted on location maps (figures 3 and 4). In the 10 cases the falls occurred from the bed when the bedrails were raised (figure 3), with the patient found on the floor at the lower end of the bed, having 'wriggled to the bottom' of the foot end of the bed.

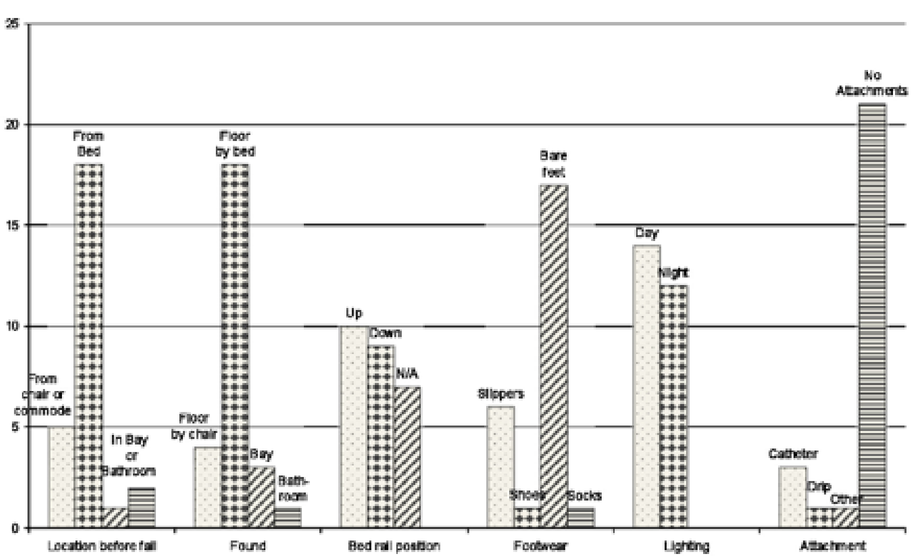

Figure 2. Results from pilot case study

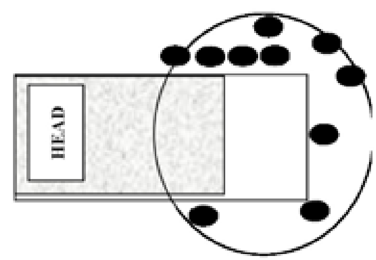

Figure 3. Location map of falls from the bed with raised bed rails

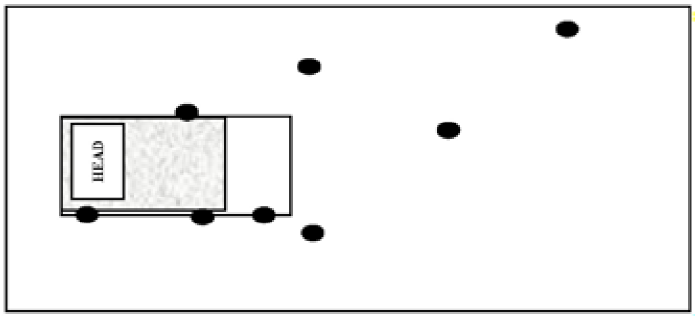

Figure 4. Location map of falls from the bed with no bed rails

In the 8 cases the falls occurred from the bed when the bedrails were not raised (figure 4). The location of the falls is less clustered than figure 3 (with raised bedrails). In 5 cases where the patient fell from a chair or a commode they were found on the floor by the head of the bed (n=4) or at the end of the bed (n=1).Three other patients were found in the middle of the bay and in the bathroom.

Discussion

There have been several interventions to facilitate the route from bed-to-bathroom. These include bringing the toilet to the bed by placing the commode adjacent to the bed, locating the patient in a bed near to toilet in multi-bed bays, and removing obstacles from the bed-toilet pathway (Krauss et al., 2008). It has been suggested that wheeled furniture (e.g. tables, lockers) may contribute to the environmental hazards by moving unexpectedly (Tinker, 1979) but no trials were found to test this hypothesis with fixed base furniture.

The use of bed rails has been discussed since the 1960s, with Fagin and Vita [1965] commenting that 'to many conscious patients, side rails are frightening and imply dangerous illness. To others, side rails are irritating and humiliating because they emphasize the confining aspects of hospitalization.' Bed rails have been used extensively as an intervention to manage falls [Capezuti et al. 2007; Healey et al. 2004], but there is no evidence that they prevent falls or injury [Capezuti et al. 2007]. No published literature was found about the design of hospital flooring for bare feet. Lighting has been discussed as both a barrier (floor reflections and glare) and a facilitating issue (e.g. night lighting)(Chaâbane, 2007). Källstrand-Ericson and Hildingh [2009] suggest that the hospital environment should be adapted to account for the decline in contrast sensitivity with age by using strong, contrasting colours and adequate lighting during night hours.

Conclusion

It has been suggested that changes in hospital design may affect the risk of falls [Gulwadi and Calkins 2008] but research studies have failed to systematically evaluate environmental design interventions. The lack of high quality research on physical environment interventions might be, as Oliver et al. [2007]suggest due to the 'inherent logistic difficulties in performing or interpreting studies in care homes or hospitals associated with population, setting, design, and outcome measurement'. In the U.S. falls resulting in patient death or serious disability while being cared for in a healthcare facility are included in the 28 'never event' categories by the National Quality Forum [2007]. This is likely to raise the priority for finding effective interventions as it is an emerging belief that hospitals may not be reimbursed for events that should never occur, this would include falls. Making environmental changes can be very expensive. If the research evidence is not available to show that different layouts, flooring, lighting and technology can reduce both the incidents and injuries associated with elderly in-patient falls at the time of construction then retro-fitting is unlikely to happen.

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Slipping in U.S. Limited Service Restaurants

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This study examines the experience of limited-service restaurant workers with slipping. A total of 475 workers from 36 limited-service restaurants in six U.S. states participated in a 12-week prospective cohort study on slipping in the workplace. At baseline, participants completed a survey which gathered information about their demographics. During the subsequent 12 weeks, participants reported their slip experience weekly. The average rate of slipping during the 12 weeks of the prospective study was 34.5 slips per full-time employee per year. The mean of the individual rate of slipping varied more than 100 times among the restaurants. The highest numbers of slips were reported in the sink and fryer areas. Liquid and grease were reported as floor contaminants in over 70% of the slips. The highest frequency of slips was reported in sink and fryer areas.

Introduction

Food-service and drinking establishments are among the largest employers in the United States, representing about 6.4% of the total U.S. workforce. Since they comprise a large proportion of the total workforce,restaurants contribute significantly to the overall occupational injury burden [BLS, 2008].Slips, trips, and falls are the major cause of injury among restaurant workers in the United States. Leamon and Murphy, in a study published in 1995, reported that the incidence rate of same-level falls over a 2-year period was 4.1 per 100 full-time-equivalent restaurant employees [Leamon and Murphy 1995].A number of studies have found that the majority of same-level falls result from slipping. Courtney et al [2001] examined national-level injury data from the United States, the United Kingdom, and Sweden, and reported that slipping caused 40% to 50% of same-level falls. In a study of Workers' Compensation claims,Verma et al [2008] reported similar results in women workers over 45 years of age. Field studies, depending on the type of work environment examined, have reported that from 60% to 85% of fall injuries can be attributed to slipping [Manning et al. 1988; Kemmlert and Lundholm 1998; Haslam and Bentley 1999]. A few studies have reported on circumstances of slips, trips and falls at work [Bentley and Haslam 2001; Kemmlert and Lundholm 2001; Leclercq et al. 2007]. However, despite the high proportion of occupational injuries to restaurant workers that are caused by slips and falls, studies reporting on the circumstances surrounding slips and falls in restaurant workers are rare. The present study aims to examine the experience of slipping in restaurant workers. It reports on when (time of day), where (area of kitchen), and why (floor contaminates) slips are occurring in limited-service restaurants.

Methods

The study was conducted in 36 limited-service (also known as "fast-food", North American Industry Classification System Code 722211) restaurants located in the states of Connecticut, Massachusetts, New York, Pennsylvania, Tennessee, and Wisconsin in the U.S. These restaurants belonged to three major chains and, in general, had similar main menu items: hamburgers and french-fried potatoes. A total of 475 workers were recruited from these restaurants. The study was approved by the Institutional Review Board of Liberty Mutual Research Institute for Safety and the Office of Human Research Administration at the Harvard School of Public Health.

Enrollment Procedure

Members of the study team met on site with each restaurant manager to explain the research study, administer a baseline manager survey, and set up an appointment to enroll and survey the restaurant's employees. On the scheduled date, participants were enrolled and surveys were conducted in the restaurant. Participants were given written surveys to fill out on their own. The survey instrument was designed for the study and was made available in three languages: English, Spanish, and Portuguese. Slipping A slip was defined as a "loss of traction of the foot." A study team member carefully explained the definition of a slip to the study participants before they completed any slipping questions on the survey by explaining that,"A slip is simply a loss of traction of your foot - you can slip without falling."After completing the baseline survey, participants were asked to report their slip experience every week for the following 12 weeks. Participants were given a choice of reporting their weekly experience by telephone using an interactive voice response system, by an internet-based survey, or by filling out written survey forms. They were not required to keep a daily log but were asked to remember the incidents until the subsequent reporting day. Information about the circumstances of up to four slips was collected from participants who reported at least one slip in the previous week. They reported the time, area and the type of contamination for each slip. Statistical Analysis Statistics are presented to describe the slipping experience of limited-service restaurant workers. Mean,median, standard deviation, and range are reported for continuous variables; proportions are reported for categorical variables. Overall rates and the average of the individual rates of slipping are also reported. Results Table 1 presents demographic information about the participants. The mean age of the participants was 31years (range = 15 -78), and 24% were 19 years old or younger. More than two thirds of the participants were female (66.1%). The primary language of 88% of the participants was English, 9% was Spanish, and 3% was Portuguese.

Table 1. Demographic Characteristics of Participants (n = 475)

Age (years)		
Mean (Std Dev.)	30.8	(13.3)
Median (range)	27	(15 - 78)
Female Gender (n, %)	314	(66.1)
Ethnicity (n, %)		
White, not Hispanic	263	(55.4)
Black, not Hispanic	93	(19.6)
Hispanic/Latino	85	(17.9)
Other	34	(7.2)
Primary Language (n,%)		
English	420	(88.4)
Spanish	41	(8.6)
Portuguese	14	(2.9)
Education (n,%)		
Never attended school	4	(0.8)
Grades 1-11	155	(32.6)
High School Grad./GED	186	(39.2)
Some College or above	128	(26.9)
Refused/missing	2	(0.4)

At least one week of follow-up data was provided by 422 participants (88.8%). The mean of individual slipping rate was 0.69 slips per 40 work hours (median = 0.14, range = 0.00–22.22) or 34.5 slips per full-time employee per year. The mean individual rate of slipping varied among the restaurants from 0.02 to 2.49 slips per 40 work hours.

Slips were most frequently reported near the sink (25.7%), followed by the fryer area (21.6%) (Figure 1).

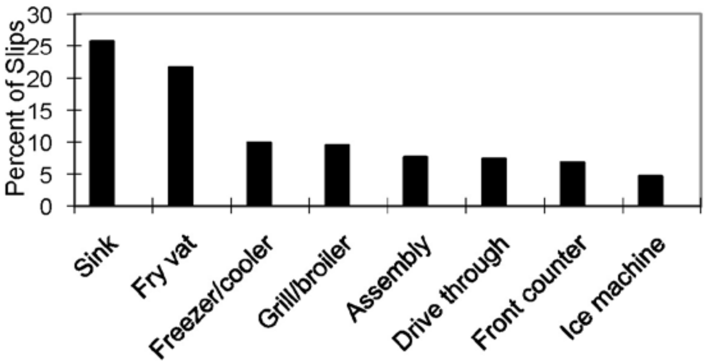

Figure 1. Slips reported by areas in kitchen

The greatest number of slips occurred from 11:00 am to 4:00 p.m. in restaurants from chains A and B (43.8% and 43.4%, respectively) (Table 2). Liquids (which may have included water from a freshly mopped floor), followed by grease, were reported as the floor contaminant present in the majority of slips in the restaurants from chains A, B and C.

Table 2 Time of Slip and Type of Contamination by Chain

	Chain A (n,%)	Chain B (n,%)	Chain C (n,%)	Total (n,%)
Time of Slip				
6:00 am to 11:00 am	61 (31.9)	77 (19.0)	65 (12.9)	203 (18.5)
11:00 am to 4:00 pm	81 (42.4)	175 (43.2)	178 (35.4)	434 (39.5)
4:00 pm to 9:00 pm	34 (17.8)	104 (25.7)	180 (35.8)	318 (28.9)
9:00 pm to 6:00 am	9 (4.7)	47 (11.6)	58 (11.5)	114 (10.4)
Contaminants				
Liquid	60 (31.4)	188 (46.4)	197 (39.2)	445 (40.5)
Grease	58 (30.4)	125 (30.9)	147 (29.2)	330 (30.0)
Food	14 (7.3)	11 (2.7)	25 (4.5)	50 (4.5)
Other	22 (11.5)	30 (7.41)	33 (6.6)	85 (7.7)
No Contaminants	26 (13.6)	39 (9.6)	73 (14.5)	138 (12.6)

Discussion

This study found a high incidence of slipping among restaurant workers. This result is similar to the findings of Courtney et al. [2006]. These findings indicate that slipping incidence remains high in limited-service restaurants. Average rates of slipping in the participating restaurants varied from 0.02 slips per 40 work hours to 2.49 per 40 work hours, a rate ratio of more than 100 between the restaurants with the highest and the lowest rates of slipping. Such a high variation suggests that methods to control slipping hazards may reduce the incidence of slipping and thus the resulting injuries.

In general, the sink and fryer areas were the most slippery. Measures to control slipping hazards in these two areas could lead to a significant reduction in the slipping incidences. Liquid and grease were the top two floor contaminants in restaurants from all the three chains, responsible for about 70% of the reported slips. Following an effective floor cleaning protocol and using safe work practices may reduce the floor contaminants in the restaurants. A high proportion of slips were reported during lunchtime (11 am to 4 p.m.) in restaurants from all the three chains. Lunchtime was generally the busiest time for the restaurants participating in the study. It is unclear, however, whether higher customer demands led to higher floor contamination and rushing and thus higher frequency of slipping, or if more participants were working during lunchtime to meet customer demands, contributing to higher person-time at risk.

Conclusions

The incidence of slipping is high in limited-service restaurants in the United States, and it varies widely among restaurants. A high proportion of slips occurred in the sink and fryer areas. Liquids and grease were reported as the floor contaminant present in the majority of slips and a high proportion of slips occurred during lunchtime.

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A Commentary on Fall-from-Elevation Research

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Falls from elevation are a leading cause of work-related fatal incidents. A total of 609 fatal occupational falls from elevation were recorded in the United States in 2008, as reported by the Census of Fatal Occupational Injuries [BLS 2010a]. Most of the incidents occurred in the construction and service sectors; about 21% of the incidents involved falls from roofs, 20% from ladders, and 15% from non-moving vehicles. In addition, there were an estimated 67,510 nonfatal fall-from-elevation injuries in private industry in 2008 [BLS 2010b]. Of the incidents, the highest frequency of falls occurred in the construction specialty trade (11,110), followed by the administrative and support services (4,290) and the truck transportation group (3,790).

The National Institute for Occupational Safety and Health (NIOSH) has made fall-from-elevation research a priority, and over a period that now extends over several decades, has devoted dedicated laboratories, specialized expertise, cutting-edge equipment and focused resource allocation to the advancement of knowledge related to the causes and amelioration of fall-related occupational injury. A research program and various individual projects have been developed, with oversight, expert opinion and approval from stakeholders and peers. Projects in diverse areas of fall causation, risk exposure and technology-based hazard have competed for funding, been successfully conducted, and have had findings and recommendations widely disseminated. NIOSH strives to advance knowledge and international leadership in this area through the seamless development of a research program that calls for, and utilizes, the best in American and international research and engineering efforts, sincere solicitation of input from affected populations, thought-leaders, academics and peers, and international collaboration to address the diverse and various causes of injury from this source.

Any successful research program must allow for the simple fact that tools and methods of performing work change over time. NIOSH is focused on historical exposures and established risks for fall-related injury, but is additionally focused on emerging technology and work methods, because emerging technology allows for the simultaneous development of safe-by-design structural intervention and prevention methods, and because emerging technology and work methods rapidly become established technology and methods, in the quickly changing work environment of the modern world.

Because NIOSH effectiveness is maximized through targeted research on leading and emerging causes of injury, NIOSH has carefully assessed and determined research priorities, in order to maximize program relevance and impact.

NIOSH priorities have been collaborative and carefully established through consultation with experts, oversight groups, and peers; these priorities have been clearly and widely disseminated in NIOSH source documents and on its website. NIOSH efforts will be focused on reducing fall incidents in the construction, services, transportation, wholesale and retail trade, and in the public safety industries. Factors contributing to fall incidents addressed by NIOSH include personal parameters, task-related elements, and environmental issues.

Studies of the factors and their interactions provide a scientific basis for bettering fall-prevention strategies.

The collection of 23 fall-from-elevation manuscripts that follow address fall risk and prevention in various industries, and were selected for presentation in accord with the above-mentioned NIOSH priority goals. They were presented in the **Fall from Elevation** section of the **2010 International Conference on Fall Prevention and Protection** held in Morgantown, West Virginia, USA, May 19-20, 2010. The authors came from academia, military, government agencies, private industries, and consultant firms, and from five different countries. The presentations were organized into four categories: Human Performance, Structure Performance, Ladders and Stairs, and Hazard Recognition. Subject matter related to human performance included postural control at elevation and fall-control technologies during construction work, truck egress safety, and factors affecting human hand and arm capacities in hanging onto an object in recovering from a fall. The structure performance papers dealt with the use of scaffolds, aerial lifts, roof-railing systems, wood joists, and skylights, with a focus on protecting or resisting human falls. The ladder and stair papers covered human-system interactions; recommendations were made to increase the stability of stepladders and extension ladders, to prevent falls on the stair, to ascend and descend fixed ladders safely, and to properly label non-self-supporting ladders. Additional papers reported risk factors and hazard recognition associated with residential construction workers, ironworkers, and commercial building workers in different countries.

These papers not only remind us the challenges we are facing but also the opportunities for us to collaborate in addressing global concerns on human suffering and the burden to the community due to workplace falls from elevation. NIOSH wishes to extend its sincere thanks to all authors for sharing their knowledge and experience with conference attendees and the global safety research community as a whole.

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Background for a Test Method to Determine the Impact Resistance of a Skylight to a Falling Human

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Currently, the U.S. has no national standard for the impact resistance of a skylight to a falling human. In this paper we consider the biomechanics of different types of falls to assist those developing such a standard. We identify the worst-case fall scenario as a backward fall such that one buttock impacts the skylight. In the case of a male the initial buttock contact area will have a diameter of 14 cm (5.5"), largely representing the projected area of the ischial tuberosity. A 2004 95th percentile U.S. male falling backward so the buttock strikes the skylight in the roof-plane, without any negative muscle work being done, can be modeled as a 121 kgf (267 lbf) test weight dropped from a height of 0.92 m (36"). Even if punctured, a skylight must still prevent a 'fall through.' So a cylindrical sand-filled canvas test weight, formed with a truncated cone at its lower end having major and minor diameters of 0.47 m (18") and 0.14 m(5.5"), would test for skylight 'penetration' and 'fall through' resistance in the same drop test.

Introduction

About 25% of all falls through a roof occur through a preexisting skylight [Suruda et al. 1995]. In 2008 22 workers between the ages of 25 and 64 years died in the U.S. by falling through a skylight; 40 workers lost a median of 81 work days, the highest value for any single type of exposure, and 120 workers lost at least a day from work [BLS 2009]. The U.K. requires skylights to pass a dynamic test of skylight resistance to human impact [ACR 2005] which includes resisting a 45 kgf, 30 cm-diameter, sand bag dropped from 1.2 m (i.e, kinetic energy of 529 J). In the U.S. there is, as yet, no national standard for how strong a skylight should be to support a worker who inadvertently steps or falls on it. Most falls from the upright are caused by a trip while attempting to step forward, sideways or backwards. A major determinant of the dynamic load applied to the skylight is how the human tries to arrest the fall. This, in turn, determines the mass and velocity of the presenting human body part that first strikes the skylight. In the case of a forward fall humans typically attempt to arrest (or "break") the fall by landing on one or both hands, one or both knees, or on hand(s) and knee(s)simultaneously [DeGoede and Ashton-Miller 2002; Lo and Ashton-Miller 2008b] when a rapid step [Thelen et al. 1997] does not suffice. In the case of a sideways fall, if a step does not suffice, subjects tend to try to break the fall with one hand and then a hip [van den Kroonenberg et al. 1996], Lo and Ashton-Miller 2008a]. In the case of a backward fall they tend to land on one or both hands, one or both buttocks, or hand(s) and buttock(s) simultaneously [Robinovitch et al. 2004]. Fatal backward falls through a skylight have been documented [NIOSH 2004] (see http://www.dllr.state.md.us/labor/fatalfact1.htm).

Some skylights or light-transmitting roof panels have a safety screen installed above or below them; whether or not this is the case, for the sake of brevity we shall refer to the unit as 'skylight' in what follows. The dynamic loading applied by a falling human to a skylight generally has two phases: an initial dynamic impulsive phase with an initial large impulsive force, followed by a lower quasistatic phase representing body weight at rest on the skylight [DeGoede and Ashton-Miller 2002]. It is our position that, even if the presenting body part punctures the skylight, then the skylight must prevent a 'fall through' by the rest of the body. The goal of this paper is to identify the 'worst case' load applied by a human falling onto a skylight and to suggest a reasonable test method.

Approach

Because a fall through a skylight is a high threat scenario, subjects may exhibit a startle reaction and then brace themselves for impact by precontracting the muscles in and beyond the presenting body part [DeGoede and Ashton-Miller 2002]. In the case of the pelvis being the presenting body part, it is assumed that the neck, back, abdominal and hip muscles are all fully co-contracted, effectively stiffening the structures and thereby increasing the effective mass of the presenting body part to include the sum of the mass of those body parts. The worst-case scenario is if every muscle is maximally tensed, thereby increasing the effective mass of the presenting part striking the skylight to that of the entire body.

It seems reasonable to design the skylight to prevent a 'fall through'. The U.K. 'Red Book' [ACR 2005] standard reviews some of the mechanical factors that determine the human impact force on a skylight, including a backward fall into a sitting position and landing on two buttocks. Hence potential energy (PE) at the start of a fall is converted into kinetic energy (KE) at impact and thence to strain energy in the skylight. As we shall see, the KE associated with a backward fall exceeds that for other falls because of the large mass of the presenting body part (the pelvis and torso being 45.6% of body weight [BW]) and the considerable height through which it falls to the roof plane (approximately half-body height). At the start of a fall from standing height no other presenting body part, such as a foot, knee, hand, or elbow has as much PE, because either their mass or their initial height, or both, are significantly less c.f., the adult arm: 3.9% BW; a leg 23.3 % BW; and the head, neck, torso, abdomen, and pelvis: 45.6% BW [AAMRL 1988]. Even with an active fall arrest response, their KE at impact is unlikely to exceed that of the upper body and thighs. Maitra [2001] cited two principles in developing the Red Book standard: (1) "a safe margin against failure under human impact, "and (2) that the test should "not be so onerous as to reclassify materials known to be non-fragile." In considering a backward fall with a landing on both buttocks, we argue that the probability of landing symmetrically on both buttocks is considerably smaller than landing with more load on one buttock than the other. This is because a backward trip is initiated by one foot acting asymmetrically about the body axis of symmetry. We note three weaknesses in the Red Book standard. First, Maitra [2001] arrived at a factor of safety of 2.0, but it is unclear how this was used to select the final specifications for the test bag and drop height. Similarly, he states (Item '17') that the final values for the 45 kgf, 30 cm-diameter test bag to be dropped from 1.2 m were "determined by trial and error," but omits description of those tests, the results and how exactly they led to the final specification of the Red Book drop weight and height. Finally we could find no anthropometric justification for the final choice of a 30 cm-diameter test bag.

A rational argument can be made to design a skylight to resist a backward fall by a 95th percentile male, thereby protecting most males and essentially all females: the average male would then have a factor of safety of about 1.5 for static loading. The NHANES III data set (U.S. 1988-1994) shows that the weight of the 95th percentile male (W_{95}) is 267 lbf (121.4 kgf). Portable ladders, for example, are covered by the ANSIA14.1 and A14.2 code specifications. Each rung of a Type IA portable ladder, a ladder designed for consumer or light commercial use, must withstand a static load of 300 lbf without failure. This standard exceeds the weight of the 95th percentile male by 300/267, yielding a static factor of safety of 1.12 for the 95th percentile male]. While a 95th percentile male crash test dummy could be used to drop test a skylight, such dummies cost over $30,000. A sand bag is a more economical option. But what form, drop height and diameter should be used to represent the initial height of a 95th percentile male falling backward from the standing posture? The NHANES III data show that the height of the 95th percentile male (H_{95}) is 74.5" (189.2 cm). From U.S. Civilian data (1988-94), the maximum distance the center of mass of a standing 95th percentile male could fall to the horizontal plane of a roof is 0.918 m (36.1") (this height being equivalent to the "height" of the ischial tuberosities above the roof plane on which the worker stands, as calculated from 0.485 * H_{95} [Chaffin and Andersson 1991]). Hence the Potential Energy (PE) of the 95th percentile male during upright stance is:

$$PE_{95} = W_{95}*g*h = 121.4 \times 9.8 \times 0.92 = 1{,}090.0 \text{ J}$$

From the Robinovitch et al. [2004] paper on backward falls we learn that, for falls onto a soft mattress, not all the potential energy (PE) lost in a backward fall is converted to kinetic energy (KE) by the time of impact. This is because the active leg and trunk extensor muscles dissipate energy as they lengthen, doing negative work in trying to resist the fall. An estimate of the energy lost can be found from the right-most column of his Table 1. On average, when the initial PE is 441 J, the KE just before impact averages 307 J. Thus:

$$\text{Loss in KE is (PE-KE)} = 134 \text{ J}$$

Therefore ratio, R, of Loss in KE divided by original KE is:

$$R = 134/441 = 0.3$$

Hence for the 95th percentile male, the KE_{95} at impact will be

$$KE_{95} \text{ at impact} = 1{,}090 - 0.3*1{,}090 = 762.9 \text{ J}$$

Now we can calculate the height a weighted bag weighing the same as the 95th percentile male would have to be dropped in order to have the same value of KE_{95} as the 95th percentile male would have if he displayed the same behavior as Robinovitch's subjects and dissipated the same ratio, R, of his initial PE as they did during the backward fall. If the weighted bag has a weight W_b, then the height, h_S, it should be dropped from may be calculated from:

$$KE_{95} \text{ at impact} = W_b * 9.8 * h_s$$

Therefore, h_s is given by:

$$h_s = KE_{95} / W_b * 9.8$$

Therefore, if W_b = 121.4 kgf, and if we assume the worker has a normal backward fall arrest strategy to resist the fall, then

$$h_s = 762.9 / 121.4 * 9.8 = 0.64 \text{ m} = 64 \text{ cm} = 25.3''$$

If, on the other hand, W_b = 121.4 kgf, and the 95th percentile worker makes no attempt to resist the backward fall (i.e., the worst-case scenario), then

$$h_s = 1{,}090 / 121.4 * 9.8 = 0.92 \text{ m} = 92 \text{ cm} = 36.1''$$

We conclude that a 121.4 kgf (267 lbf) test weight dropped through a height of 0.92 cm simulates the worst case loading scenario a 95th percentile male could impart to the skylight. A safety factor could be added to protect the 95th percentile male. For a curb-mounted skylight, the specified drop height should be reduced by the curb height.

A human falling backward with fully flexed hips can present a surprisingly small impact area to a skylight. The hips can be flexed through a maximum of 110 degrees [Elson and Aspinall 2008]. In this position the torso and head would approach the thighs and knees. The bilateral buttocks contact area measured in healthy subjects sitting on a hard level surface was 316 cm^2 (48.98 in 2)[Gutierrez et al. 2004]. Therefore a "one buttock"impact area would be half this value: an area of diameter 14.2 cm (5.6"). The material representing the buttock should have realistic thickness and compressive stiffness (i.e, ~2.5 cm-thick and 35 kN/m [Linder-Ganz et al. 2007]). With the thighs flexed upward against the torso, the minimum transverse plane cross sectional area (CSA) of the body would be the CSA of the torso plus the two thighs. Using a NASA anthropometry source for a 40 year-old 95th percentile male chest and thigh circumferences, one can calculate the smallest equivalent diameter as being 0.465 m (18.3”). So, 0.47 m (18”) would be the maximum diameter of the drop test bag required to check for skylight ‘fall through’ resistance.

Conclusions

1. The U.K. Red Book standard test was found to lack certain foundational data.

2. The worst-case fall loading scenario for a skylight is a backward fall onto one buttock.

3. A skylight, equipped with a safety grill if applicable, must be able to resist both the static weight and a ‘fall through’ by a 95th percentile male falling as in (2).

4. To replicate (2 & 3), one would drop a 121 kgf (267 lbf) sandbag bag from 0.92 m (36”) to yield a kinetic energy of 1,090 J (see above). The striking end of the bag should have an initial diameter of 0.14 m (5.5”) to model the padded ischial tuberosity. The bag should strike the skylight, normal to its surface, at its weakest point.

5. To test for skylight penetration resistance and ‘fall through’ resistance in one test the lower end of the drop bag in (4) could be a truncated cone with a maximum diameter of 0.47 m (18”) and apical angle of 70° to represent the torso and fully flexed thighs.

6. If the skylight is curb mounted, the drop height should be reduced by this curb height.

7. The 95th percentile weight value should reflect the increasing obesity of the U.S. male.

8. A quick-release mechanism must initiate the bag drop to standardize the KE delivered.

9. A design solution is needed to preclude the deleterious effects of ultraviolet weathering from reducing skylight resistance to human impact over the life span of the product.

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Gait Parameters and Trunk Movement While Walking on Flexible Wooden Boards of a Simulated Scaffold

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Working on wooden scaffold boards is highly associated with falling incidents in the Chinese construction workplace. This study investigated the effects of scaffold board width and thickness, as well as experience and walking phase, on workers' gait and trunk movements while walking on a simulated scaffold. Two levels of width and three levels of thickness of wooden boards were tested. Body sway and several gait parameters were measured and analyzed. Step length and walking speed were both significantly affected by the interaction between experience and walking phase. The main effects of width and thickness were also significant on the walking speed. A greater walking speed was observed for the wider board and thickest board. Trunk movement(variability of body sway) was affected by the experimental factors in a similar way. Sway variability increased after acclimation to the board condition as compared to the initial pass.

Introduction

Construction workplace safety is one of the most serious occupational safety problems in China. Although various efforts have been made by the government and private industry to address the problem, construction related accidents are still causing both significant financial losses and serious societal burdens. Among these accidents, falls from heights is one of the leading concerns due to severe consequences. Fang et al, [2003] reported that falling from elevations accounted for 43% of the fatalities in the Chinese construction industry. By 2005, according to the news report of the "Safety of Construction" conference held by the Ministry of Construction of P.R. China, the number of construction workers in China had reached 40 million. Among these construction workers were many temporary workers who were farmers with little or no previous work experience in construction. At many of the construction sites in China, especially in the remote areas of the country, flexible wooden boards of various widths and thicknesses are installed on scaffolds and widely used for tasks at heights during both indoor and outdoor construction. Walking on these flexible wooden boards can be particularly difficult and dangerous for construction workers. A previous study by Huang and Hinze [2003] reported that the misjudgment of hazardous situations is a human error resulting in many falls. Unfamiliarity or over confidence regarding the tasks and environments could expose workers to a greater risk due to misjudgment of dangers.

Researchers have investigated gait parameters to understand how individuals respond to different environmental conditions and/or how they can reduce slip and fall potential during walking. For example, Cham and Redfern [2002] reported that the perception of floor slipperiness affects gait strategy, with the reduction of stride length being a common adaptation. Most studies have focused only on ground walking with rigid floor surfaces; balance control while walking on flexible wooden boards was not examined. It is not known whether workers perform differently when walking on these surfaces. In this study, we investigated how Chinese construction workers with different work experiences on scaffolds adjusted their gait and trunk movement while walking on wooden boards of various thickness and width.

Method

A simulated scaffold (Figure 1) was constructed in the laboratory utilizing a total of six flexible wooden boards, including two widths and three thicknesses. The selection of these boards was based on examining a wide range of wooden boards that are typically used on construction sites. Boards with widths of 166 mm and 207 mm were chosen to represent narrow and wide boards. The three levels of thickness utilized were 40, 50 and 62 mm to represent thin, medium and thick boards. Forty healthy male Chinese farmers were recruited to participate in this study. Among them, twenty had more than one year of construction experience using a scaffold and were categorized as experienced workers. The other twenty participants had less than a year of scaffolding experience and were considered as novice workers. An institutional review board approved the experiment protocol. All participants were informed about the details of the experimental protocols and 2 voluntarily signed an informed consent form before the experiment proceeded.

The experiment followed three phases. In Phase 0, participants were asked to stand on one end of the raised wooden scaffold and provide a subjective rating about the difficulty of the task if asked to walk on the board. Each participant rated all the boards, which were presented to them in random order. In Phase I, the wooden boards were put onto the simulated scaffold again in random order. The participants walked across each wooden board from one end to the other. During this single pass, the trunk movements and several gait parameters of each participant were collected by the motion tracking system with the sensors attached to the following positions: L5/S1 joint, C6/C7 joint, and near toe tip and heel on both left and right shoes. At the end of each trial, ratings of perceived difficulty were collected. For Phase II, participants were asked to walk on each selected wooden board ten times, with the six test boards presented in random order. Participants' trunk movements and gait parameters were collected. Subjective ratings were also collected at the end of the last pass. Analyses of variance were used to investigate if participants adjusted their gait and/or trunk movement when walking on various wooden boards. Also investigated was whether there were different walking strategies used between phases for both experienced and novice workers.

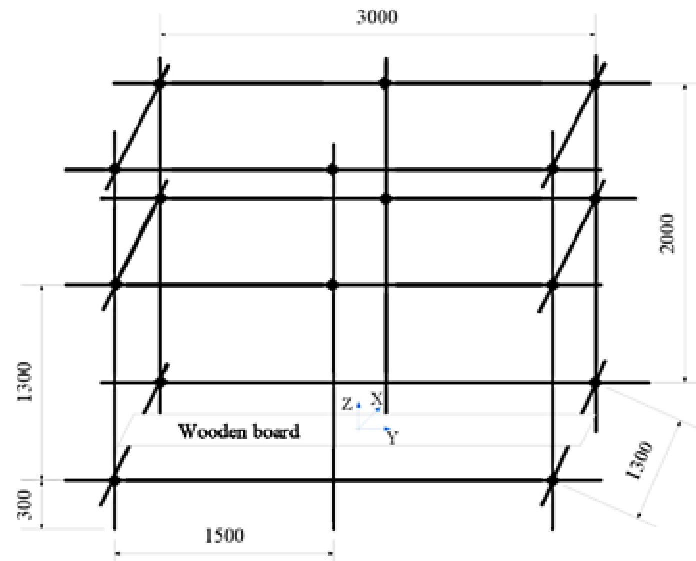

Figure 1. Illustration of the simulated scaffold (unit: mm)

Results and discussion

The kinematic data collected from Phases I and II were calculated and analyzed. Several preliminary results are reported here. The dependent variables were walking speed, step length, stride width, and variability of body sway at L5/S1 and C6/C7 positions. These variables were calculated when participants walked at or near the middle of the board. The results indicated that the step length and walking speed were both significantly affected by the interaction between experience and phase ($p < 0.05$). Experienced workers showed a longer step length than the novice workers when walking on the wooden boards for the first time (Phase I). After acclimation (Phase II), the average step length of the experienced workers was slightly reduced but still longer than the novice workers. The novice workers did not show significant changes in step length between phases. For both phases, the experienced workers showed a higher average walking speed than the novice workers. No significant change was found for the experienced workers across phases. However, a significant increase in the walking speed for novice workers was observed in Phase II. The main effects of width and thickness were significant on the walking speed. A lower walking speed was found when walking on the narrow board in comparison to the wide board. There were interactions between experience and board width on the stride width (Figure 2). Stride width was not different for the narrow board but, while walking on the wide board, experienced workers increased their stride width while it remained the same for the novice workers.

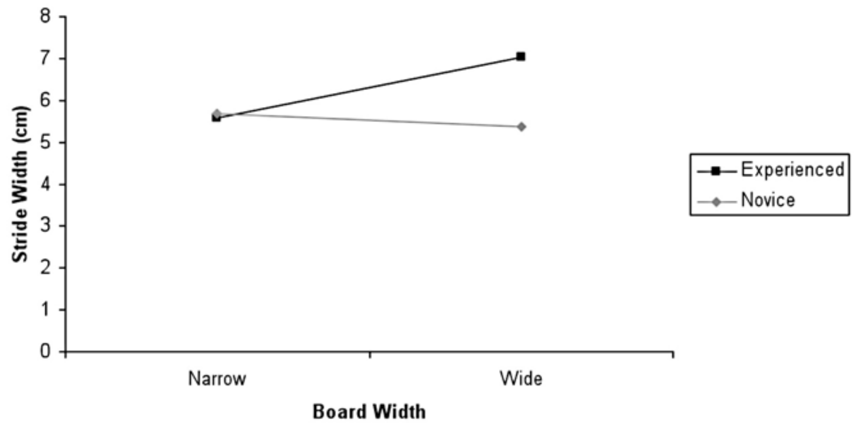

Figure 2. Significant interaction between experience and board width on stride width. Data are averaged across all other factors

Trunk movements were compared through examining the variability of body sway. Most of the factors had a significant influence on the values of variability of the sway at the L5/S1 and C6/C7 locations. No significant interactions were found. The values of variability of sway for both L5/S1 and C6/C7 locations were larger for experienced workers compared to the novice workers. Figure 3 illustrates the results grouped by experience and averaged across all other factors. In addition, for all participants, the value of sway variability increased after acclimation to the board condition (Phase II) as compared to the initial pass (Phase I). Body sway was also affected by the thickness of the board, with increases in both measures corresponding to the thickest board. However, no differences were found between the two thinner boards. The sway at the L5/S1 location increased for the wider board conditions, although no significant changes were detected in the C6/C7 sway.

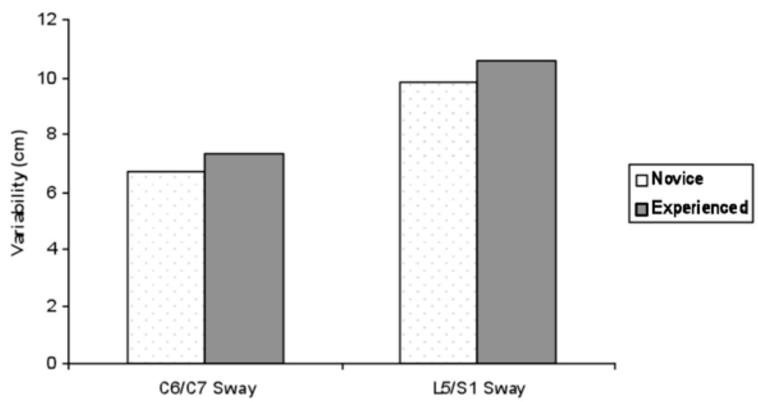

Figure 3. Variability of body sway grouped by experience T

The overall results indicate that both the experienced and novice workers adjusted their gait when walking on various widths and thicknesses of wooden boards to accommodate different board conditions. To maintain a safe walking strategy when walking on the narrower and thinner wooden boards, the workers tended to adopt a lower walking speed. However, different gait adjustments when walking on the flexible wooden boards were observed between the experienced and novice workers. The greater walking speed and longer stride length,on average, for the experienced workers in both phases imply that the experienced workers appeared to have a greater confidence when walking on the wooden boards than the novice workers. One possible explanation is that this may be partially due to their familiarity with and/or capability in this type of work. In contrast, the novice workers showed a more cautious walking strategy when they first walked on unfamiliar wooden boards before they felt comfortable increasing their step length and walking speed after several passes. Similar results are also seen in the body sway results shown in Figure 3. Experienced workers seem to be more relaxed during walking, resulting in a larger variability in values for both body sway variables. The other interesting finding is that the experienced workers took a larger stride width when on a wider wooden board, as shown in Figure 2. By increasing their stride width, the experienced workers have a wider base of support when walking on the scaffold, which might provide a larger safe margin area to better maintain their balance on the wooden boards.

Conclusion

At many construction sites in China, working on wooden scaffold boards is still common. These wooden boards often come in different widths and thicknesses and thus result in variable flexibility among the boards. This could potentially expose the workers, especially those who are hired from farms with little or no previous experience working on scaffolds, to a greater risk if they are not familiar with the wooden boards laid on the scaffold. It is important for the workers to understand the characteristic of the wooden scaffolding boards ahead of time so the appropriate gait and posture adjustments can be made while walking on them. Also, a cautious approach should be taken when walking on unfamiliar board conditions to minimize potential risks due to misjudgment of the walking conditions.

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Work-Related Fall Prevention: Results of a Systematic Review of the Literature

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Background: Falls are a leading cause of injury hospitalizations for active duty U.S. Army personnel. From 2006-2008, slip, trip, and fall-related injuries accounted for 16.1 to 18.4% of all unintentional injury hospitalizations. Slip, trip, and fall-related injuries are also a leading cause of Army non-battle injury-related air medical evacuations from current deployments. To provide for informed prevention planning and decision-making, a systematic review of the scientific literature was conducted to identify existing analytic epidemiology (risk factor) and intervention studies related to fall prevention among working-age adults.

Methods

Ten literature databases representing medical, public health, engineering, psychology, social science, and U.S. government reports were searched. Identified articles were independently reviewed by three scientists, evaluated using pre-defined criteria, and assigned quality scores (highest possible score=10 points). Results: Over 2,200 articles were captured in the initial search. Review of titles and abstracts identified 525 articles, published from 1980-2007, that met inclusion criteria. Seven were intervention and 21 were analytic epidemiology studies. The mean quality score of intervention studies was 6.4 (range: 4.5-8.0); the mean quality score of analytic epidemiology studies was 8.3 (range: 6.0-9.3). Most commonly studied risk factors were age, medical issues/medication, occupational factors, and weight. Interventions included establishment of fall protection standards and educational campaigns. Conclusions: Systematic reviews provide information essential for evidence-based decision-making. The scarcity of analytic epidemiology and intervention studies on work-related fall prevention suggests that further exploration of risk factors and additional intervention trials and/or program evaluations are greatly needed to adequately address this leading cause of injury.

Background

Falls are a leading cause of injury hospitalizations for active duty U.S. Army personnel. From 2006-2008, slip,trip, and fall-related injuries accounted for 16.1 to 18.4% of all unintentional injury hospitalizations [AFHSC 2008; AFHSC 2009; Jones et al. 2010]. Slip, trip, and fall-related injuries were also the leading cause of U.S. Army non-battle injuries in Iraq and Afghanistan, 2001-2006, accounting for 24% and 25% of all air-evacuated non-battle injuries from Iraq and Afghanistan, respectively [Hauret et al., 2010]. To inform military prevention planners and decision-makers, a systematic review of the scientific literature was conducted to characterize the status of knowledge on work-related fall prevention. The primary purpose was to identify and review the quality of existing analytic epidemiology (risk factor) and intervention studies related to fall prevention among working-age adults. A secondary purpose was to identify gaps in knowledge and identify areas of focus for future research.

Methods

Lists of databases recommended for systematic reviews of injury topics were reviewed [Beahler et al. 2000; Bunn et al., 2001]. Selected databases and search engines covered a range of disciplines, including medicine, psychological and social sciences, occupational health, and unpublished government documents. The following 9 data bases were used: National Library of Medicine's PubMed, MEDLINE through OVID®, Excerpta Medica (EMBASE®), Cumulative Index to Nursing and Allied Health Literature (CINAHL®),PsycINFO®, Engineering Index (Ei) Compendex®, Defense Technical Information Center (DTIC), National Technical Information Service (NTIS), and NIOSHTIC. Searches were limited to articles written in English and published from 1980-2007 (MEDLINE, PubMed, EMBASE) or 1980-2008 (CINAHL, NIOSHTIC, NTIS, DTIC, EI Compendex, Psyc INFO). Articles were also limited to studies of adult populations, excluding the elderly. Articles meeting the search parameters were saved to an electronic reference library. Titles of all articles were screened to exclude articles that were unrelated or irrelevant to the primary prevention of slips, trips, and falls. When titles did not offer sufficient information to determine content, abstracts and/or full text were reviewed. Remaining articles were classified by study type, and analytic epidemiology and intervention studies underwent further review. The quality of analytic epidemiology and intervention studies was evaluated by three scientists using previously-established criteria and scoring for expedited public health reviews [Bullock et al. 2010]. Criteria assessed the clarity of the research question, study design, and analytic methods and reporting. Scores for each criterion were summed and corrected to a 10-point scale (1=lowest quality, 10=highest quality).

Results

A total of 2,228 articles were identified in the searches of the 9 literature databases. Following initial screening, 522 articles remained. Three additional articles were identified through reviews of reference lists of selected articles, resulting in a total of 525 articles related to the primary prevention of slips, trips, and falls(Table 1). Analytic epidemiology and intervention studies were further evaluated for quality. The mean quality score for the 21 analytic epidemiology studies identified in the search was 8.3 out of 10.0 points (range: 6.0-9.3) [Heineman et al. 1989; Hunting et al. 1991; Malmivaara et al. 1993; Neutel et al. 1996; Nordstrom et al.1996; McNamee 1997; Kemmlert and Lundholm 1998; Klein et al. 1998; McCarty et al. 2002; Stenbacka et al. 2002; Dunning et al. 2003; Gauchard et al. 2003; Lipscomb et al. 2003a,b; Sprince et al. 2003; Vouriot et al. 2004; Cherry et al. 2005; Talbot et al. 2005; Gauchard et al. 2006; Paulson et al. 2006; Finkelstein et al. 2007; Kool et al. 2008]. The mean quality score for the 7 intervention studies identified in the search was 6.4 pointsout of 10.0 (range: 4.5-8.0) [Lingard and Rowlinson 1997; Nelson et al. 1997; Saarela 1998; Becker et al. 2001; Derr et al. 2001; Lipscomb et al. 2003a,b; Grahn Kronhed et al. 2005].

Table 1: Distribution of Search Results by Study Type

Article Type	Total References (%)
Case Series/Case Reports	194 (37%)
Descriptive Epidemiology	34 (6%)
Analytical Epidemiology	21 (4%)
Intervention Studies	7 (1%)
Reviews of Injury Research	19 (4%)
Other Research (lab, biomechanical)	119 (23%)
Research on a Different Topic	41 (8%)
Non-Research Article (e.g., editorial)	49 (9%)
Other/Unable to Determine	41 (8%)
Total References Categorized	525 (100%)

Among the analytic epidemiology studies, the risk factors most often studied were age (13 studies), medical conditions and/or medication use (10 studies), occupational factors (8 studies), and weight or body mass index(BMI) (6 studies). Modifiable risk factors with the strongest measures of association included consumption of alcohol within 6 hours of a fall (odds ratio of a fall resulting in hospitalization or death =12.9, 95% confidence interval(CI): 5.2, 31.8) [Kool et al, 2008] and use of benzodiazapines as a sedative (unadjusted rate ratio of hospitalized falls among persons 20-59 years of age within 4 weeks of first prescription =10.8, 95%CI: 5.4,23.8) [Neutel et al, 1996]. Risk factors for which 3 or more studies reported statistically significant higher risks of a fall among working-age adults included older age [Malmivaara et al, 1993; Kemmlert et al. 1998; McCarty et al. 2002; Stenbacka et al. 2002; Dunning et al. 2003; Gauchard et al. 2003; Lipscomb et al. 2003a,b; Sprince et al. 2003; Cherry et al. 2005; Finkelstein et al. 2007), alcohol use [Malmivaara et al. 1993; Stenbacka et al. 2002; Kool et al. 2008], and a high body weight or body mass index [Heineman et al. 1989; Gauchard et al. 2003; Cherry et al. 2005; Finkelstein et al. 2007].

Discussion

Research related to slips, trips, and falls has historically focused on the elderly and children. Since the early 2000's, however, national data has consistently shown falls to be a leading cause of emergency department visits across all age groups. In addition, there has been a growing body of evidence of the importance of work-related falls. As would be expected for an emerging area of research, over half of the 525 articles identified in this review of the literature on work-related falls were case series/case reports (37%), laboratory(23%), or descriptive epidemiologic (6%) studies. Such hypothesis-generating studies provide a basis for and can be used to guide prevention and research planning.

The next step in the scientific/public health process requires analytic epidemiology studies, which incorporate use of comparison groups and multivariate techniques, to provide more definitive evidence of key risk factors for fall injuries upon which intervention studies can build. This review identified 21 such studies. While they were limited in number, their scientific quality was high (mean quality score=8.3 out of 10 points). These studies provide necessary information of risk factors, such as age, alcohol use, and body mass index, upon which interventions could be designed. To enhance the ability to summarize results across studies,standardization of risk factor definitions, groupings, referent groups, and injury outcomes in future studies are needed. Risk factors such as use of psycho-pharmaceutical drugs and lower visual acuity have suggested associations with fall risk, but require further study.

The review also identified 7 intervention studies, 3 of which studied the effects of changes in government standards related to occupational fall prevention, 3 assessed the effectiveness of fall prevention education campaigns, and 1 evaluated the effects of a fall prevention organizational intervention. On average, the scientific quality of the studies was unremarkable (mean quality score=6.4 points out of 10.0). Government enforcement of fall prevention standards was the only intervention with evidence of effectiveness. In summary, in the area of work-related fall prevention, additional analytic epidemiology studies are needed. A wide range of risk factors have been studied, but few with enough consistency to draw strong conclusions. In addition, since few quality intervention studies on work-related falls have been done, more intervention trials are also needed. Updates of this review will be necessary, as this emerging field continues to expand.

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Effects of Lateral Reaching on the Stability of Stepladders

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Stepladders are one of the most prevalent types of ladders used in industry with a large portion of falls from ladders occurring while the individual was working on the ladder. Guidelines are provided that recommend the center of mass (i.e. belly button) remain within the rails of the ladder; however, many falls occur because of lateral movement during task performance. Five participants performed ten lateral reaches of various distances while standing on stepladders of four common heights (6′, 8′, 10′, and 12′). Vertical ground reaction forces were collected by four force plates placed one underneath each foot of the ladder. The proportional forces from the contra-lateral feet of the ladder were examined to identify precursors to lateral movement and resulting falls. The predicted force applied by each of the contra lateral rails of the stepladder was 11.5 %, on average, of the total vertical force created by the system during lateral reaches equal to the rail of the ladder. Reductions in vertical forces may be precursors to lateral movement and increased vulnerability to falls.

Introduction

Ladders are widely used throughout many industries with falls from ladders occurring at a high frequency, particularly within the construction industry. In 2005, falls from ladders accounted for approximately 24% of all injuries due to falls in the construction industry [CPWR 2007]. In addition, falls from elevations result in injuries that are generally severe [Cohen and Lin 1991], with falls from ladders being the third leading cause of deaths from falls and second leading cause of severe injury [CPWR 2007]. The high frequency of falls from ladders, and the severity of the injuries involved, creates a critical safety issue. Research has indicated that straight ladders an stepladders are the most commonly used types of ladders [Axelsson and Carter 1995]. Stepladders have a large base of support and are traditionally formed in an "A" shape, with upper treads narrower than lower treads [Yang and Ashton-Miller 2005]. Most studies find that the majority of falls from ladders occur while the individual is working on the ladder, rather than during ascent or descent [Cohen and Lin 1991; Axelsson and Carter 1995]. Although guidelines recommend that the center of mass (COM) remain within the rails of the ladder ("belly button" rule), previous research indicates that lateral tipping is the most common cause of stepladder accidents [Björnstig and Johnsson 1992] suggesting that lateral reaching tasks are prominent in causes of ladder injuries.

Yang and Ashton-Miller [2005] considered lateral weight transfers while individuals were standing on small stools/stepladders. Stability, based on a mathematical model, depended on the height of the individual, the foot position on the tread related to the rail, lateral ground inclination angle, lateral COM displacement, and lateral COM velocity. Further research has identified the risk of reaching while at an elevation, but not within the context of ladder usage. For example, Kozak et al. [2003] evaluated the effect of age on maximum forward reach distances for healthy women who were asked, while standing on a simulated chair, to reach forward towards a target at shoulder height. The purpose of the current study was to analyze and describe the development of instability of a stepladder as a function of the location of the center of mass (within/outside the rails) during lateral reaching by an individual standing on a stepladder and to use this information to empirically support or amend the "belly button" rule.

Experimental Methods

Five participants performed lateral reaching on Type 1A stepladders of four common heights (6′, 8′, 10′ and 12′). The mean (SD) age and height of the participants were 37.0 (3.2) years and 1.71 (0.03) m, respectively. During the experimental session participants wore uniform low-rise trail shoes and a full body harness that was attached to a fall protection system.

All trials were performed at the maximum safe working height for each ladder (i.e. second rung from the top) as indicated by the manufacturer. For each ladder height participants maintained a relaxed vertical position for 30 seconds to obtain baseline information. Ten lateral reaches were then performed towards the right side of the ladder. Participants situated their feet against the ladder rails, which aligned the feet with the shoulders. During the reaches the participants were instructed to keep their right arm extended to their right at approximately shoulder height, left arm relaxed at the side of the body and to lead with their shoulders (Figure 1). To minimize any confounding influences of order, the presentation of the ladder heights was randomized.

Figure 1. Experimental setup

The ten lateral reaches were intended to place the center of mass (i.e. belly button) within and outside of the rail of the stepladder. Location of the belly button relative to the center of the ladder (reach distance) and the position of the ladder rail was obtained using a passive motion analysis system. Vertical ground reaction forces were collected using Kistler force plates (one placed under each foot of the ladder: Figure 1). Vertical forces under each foot of the ladder were normalized using the total force created by the individual and the ladder. Linear regression was used to calculate predicted vertical force values corresponding to a lateral reach equal to the distance of the ladder rail (i.e. the belly button aligned with the ladder rail).

Results

During the baseline trials the vertical forces produced by the system (ladder and individual) were divided almost equally among the four feet of the ladders regardless of the height of the ladder (Table 1).

Height	FP1	FP2	FP3	FP4
6 ft.	27.2 (2.4)	33.0 (4.5)	23.8 (3.5)	16.1 (4.0)
8 ft.	28.7 (8.9)	27.5 (10.1)	23.1 (9.8)	20.8 (10.7)
10 ft.	25.5 (1.9)	28.6 (2.5)	25.3 (3.1)	20.6 (1.4)
12 ft.	27.2 (2.3)	24.1 (2.6)	22.4 (1.8)	26.4 (1.4)

Table 1. Mean (SD) percentage of force applied to each forceplate during baselines

Reach distances were based on the location of the belly button relative to the middle of the top of the ladder. Figure 2 illustrates the vertical forces obtained from each forceplate and the corresponding reach distance for a typical trial. A linear trend line has been superimposed on the graphs, representing the linear regression equation used to determine the vertical force associated with a reach distance equal to the location of the ladder rail. The predicted force for the two contra lateral force plates was determined for each participant and ladder height and are presented as a percentage of the total weight of system. The mean values appear in Table 2.

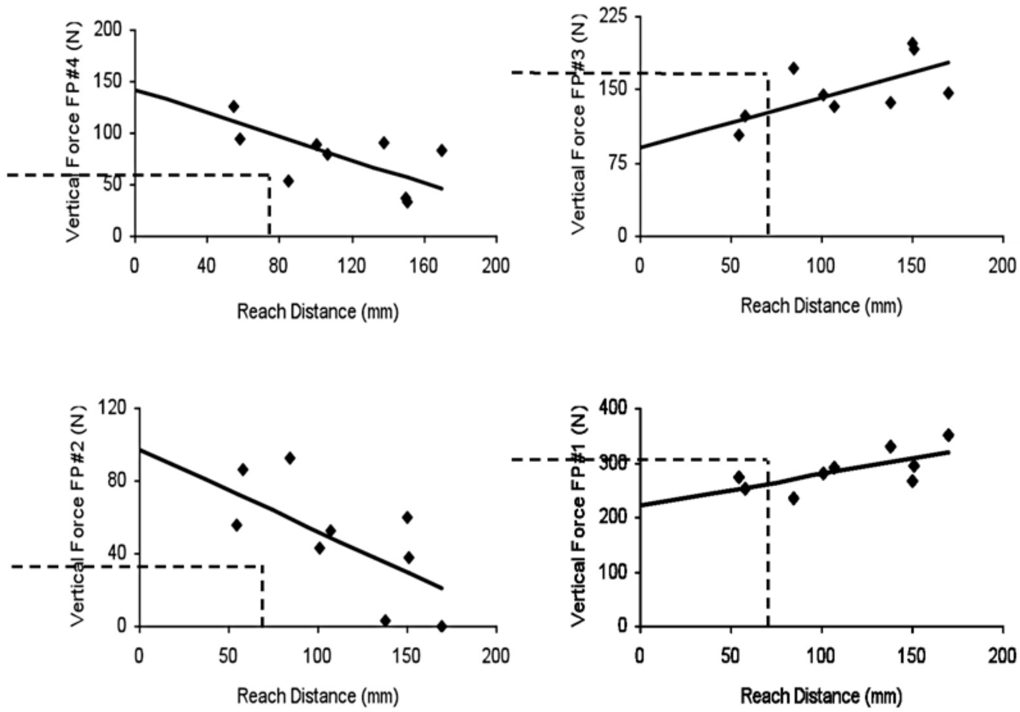

Figure 2. Reach distances and vertical forces for a typical trial. Dashed line indicates forces associated with lateral reaches equal to the rail of the ladder. Linear trend line is superimposed over the data

The predicted vertical forces associated with a lateral reach equal to the rail of the ladder were substantially lower than the baseline trials. On average, there was still some force applied to each of the force plates, indicating that the ladder foot had not raised off the ground; however, there were individual trials that resulted in a zero vertical force for at least one of the ladder feet. Maintaining the belly button within the ladder rails generally allows each ladder rail to remain in contact with the ground; however, the decline in vertical forces indicates a reduction in the safety margin for the system making it more vulnerable to external factors that may initiate a fall.

Height	FP2	FP4
6′	8.8 (4.6)	4.8 (4.2)
8′	9.1 (11.4)	8.0 (8.6)
10′	12.3 (4.2)	10.1 (0.9)
12′	15.6 (5.2)	18.2 (5.2)

Table 2. Mean (SD) percentage of predicted force applied to each contra lateral forceplate during lateral reaches

Discussion

While standing on a stepladder, tasks located outside the bounds of the ladder rails may tempt workers to perform lateral reaches without first descending and moving the ladder to the proper location. The "belly button" rule is a commonly used guideline that recommends maintaining the location of the center of mass, represented by the belly button, between the rails of the ladder. However, a search of the current literature failed to produce any empirical evidence to support this guideline.

The stability of an individual working on a stepladder may be affected by many factors. Working height has been determined to be one of the most influential factors [Yang and Ashton-Miller 2005]. In the current study, the vertical forces associated with the contra lateral rails increased with ladder/working height. This finding does not necessarily indicate that taller stepladders are more stable or less prone to tipping over. Another factor that may compromise stability is the hand force required to perform a task or control a hand tool, which may create a lateral impulsive pushing/pulling force. Further research and analyses will investigate the effect of the moment created by the lateral forces combined with the ladder/working height and use the force profile generated at the bottom of the ladder rails to try and identify situations that could create instability on a stepladder that may be a precursor to lateral movement and falls.

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Imbalance Caused by Transitioning to a Standing Posture

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Standing after maintaining awkward postures may result in instability and could elicit a fall. The objective of this study was to assess the magnitude of imbalance after a perturbation caused by a transition in posture. Forty-five male participants completed three replications of conditions created by four static postures and three durations within posture for a total of 36 conditions. Participants transitioned to quiet standing at a self-selected velocity. Whole body motion was captured and postural sway recorded using two force plates. Balance measures based on the center of mass and center of pressure were calculated for the period following transition to standing. All balance measures were significantly affected by static posture but not by duration within posture. Bending over at the waist generally caused the smallest changes in post-transition balance measures, whereas kneeling postures resulted in the largest. Findings may lead to recommendations for redesign of tasks to reduce the use of certain working postures, particularly in high-risk environments such as construction.

Introduction

Falls from elevations are a serious concern in many industries, but particularly in the construction sector. From 1992 through 2005, falls to a lower level caused the most work-related deaths within the construction industry [CPWR 2007], indicating the severity of such incidents. Falls to a lower level also occur at a high frequency with 60% of nonfatal falls within the construction industry being attributed to falls from elevations as compared with 31% for all industries [CPWR 2007].

Loss of balance is believed to be a contributing cause of falls from elevations within the construction industry [Hsiao and Simeonov 2001]; however, the primary antecedent factors for loss of balance are still unknown. Physical perturbations or volitional movements are one means of disturbing balance. The movement patterns required to perform postural transitions provide a challenge to the stable state of the human postural control system. A variety of postural transitions are performed by construction workers, which vary depending upon the specialty trade and the task being performed [DiDomenico and McGorry 2010].

Extensive literature has examined the transitions from sit-to-stand and sit-to-walk and the effect on balance control and postural stability [Etnyre and Thomas 2007]. However, most of the literature has focused on the elderly and individuals with Parkinson's disease [Inkster and Eng 2004]. Minimal research has examined postural transitions performed in the execution of occupational tasks. Bhattacharya et al. {2003] examined the effects of two transitions ("bend upper trunk to touch knees" and "reach forward to pick up weight") on postural stability under varying environmental conditions. DiDomenico and McGorry [2010] surveyed construction workers to identify postures that result in low levels of perceived postural stability upon standing. The most common non-erect postures (e.g. bent at waist, squatting, and kneeling) were reported to cause the most instability.

Sustaining balance control is integral to reducing the number of fatalities and injuries related to falls from elevation [Bagchee et al. 1998]. Perturbations and movements may disturb balance and create a period of vulnerability for a worker. This project examined postures commonly used in the construction industry and quantified the ability of individuals to maintain balance control upon standing after maintaining static working postures.

Method

Participants

Forty-five male volunteers, between 18 and 65 years of age, were recruited from the local community. Mean (SD) age, height and body mass of the participants were 40.5 (14.8) years, 1.77 (0.07) m and 83.6 (14.1) kg, respectively. All participants reported being in good health and having no recent history of musculoskeletal and neurological abnormalities. During the experimental session participants wore uniform low-rise trail shoes.

Experimental design and independent variables

A 4 x 3 x 3, full factorial, repeated measures design was implemented with two independent variables: static posture and duration within posture. Participants maintained one of four static postures (Figure 1). The duration within posture prior to standing was 30 s, 60 s, and 120 s. Participants completed three replications of the 12 conditions for a total of 36 experimental trials. To minimize any confounding influences of order, the presentation of the conditions was randomized after being blocked by replication.

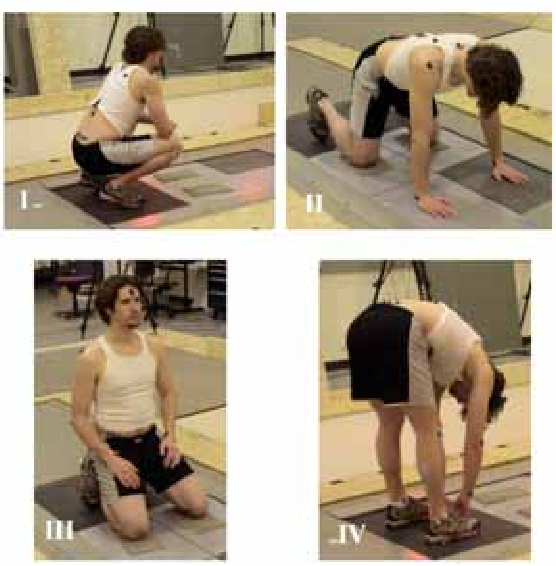

Figure 1. Static postures maintained during the experimental conditions. Squatting (I), Forward kneel (II), Reclined kneel (III), Bent at waist (IV)

Experimental procedures

One of four static postures was maintained for a given duration. When alerted by an auditory signal, participants transitioned to standing at a self-selected velocity. Participants were instructed to look straight ahead at a target and remain as still as possible. Data was collected for a total of 20 seconds, which included the time to transition (<5s). At the conclusion of each trial, a rest period of one minute was provided to minimize fatigue.

Dependent variables

Whole body motion data was collected at 100Hz and low-pass filtered using a fourth order Butterworth filter, 8Hz cutoff. Whole body center of mass (COM) position data were calculated as the weighted sum of 13 segments. Center of pressure (COP) position data from two force plates was sampled at 1000Hz prior to low-pass filtering (zero lag fourth-order Butterworth, 5Hz cutoff). Balance measures for the period following transition included maximum COP velocity (antero-posterior (AP) and medio-lateral (ML)), maximum COM-COP inclination angle (AP and ML), and minimum distance of the COP to the boundary of the base of support (minCOP). Repeated measures analyses of variance using mixed models were performed to determine the effect of static posture and duration within posture while controlling for the age of participants (α=0.05).

Results

Duration within posture did not significantly affect the balance control measures (p=0.203-0.879). Furthermore, there was no significant effect of the interaction between duration within posture and static posture (p=0.280-0.741). All balance control measures were significantly affected by static posture, with bent at waist and squatting being more constrained than the kneeling postures. Maximum COP velocity AP (Figure 2) and maximum inclination angle AP (Figure 3) were not significantly different between bent at waist and squatting or the two kneeling postures, whereas, the maximum

COP velocity ML (Figure 2) and minCOP (Figure 4) were significantly different for each static posture. Maximum inclination angle ML was not significantly different between the kneeling postures (Figure 3).

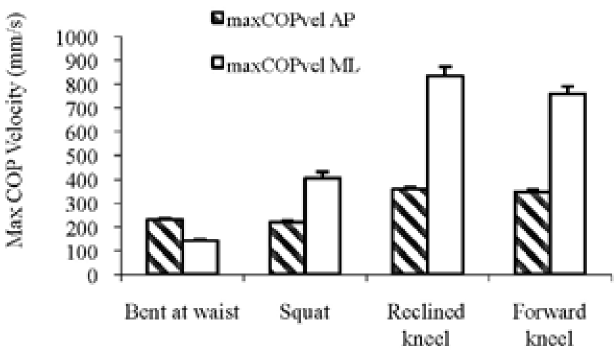

Figure 2. Maximum COP velocity in the AP and ML directions (max COP vel AP and ML) for the four static postures

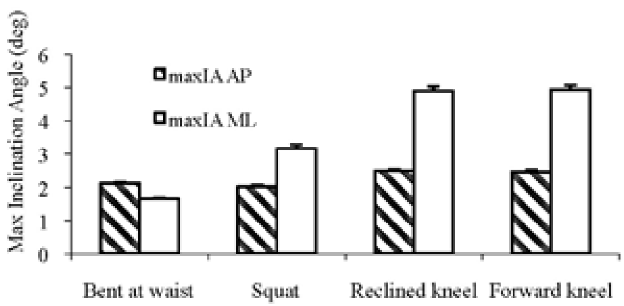

Figure 3. Maximum inclination angle in the AP and ML directions (maxIA AP and ML) for the four static postures

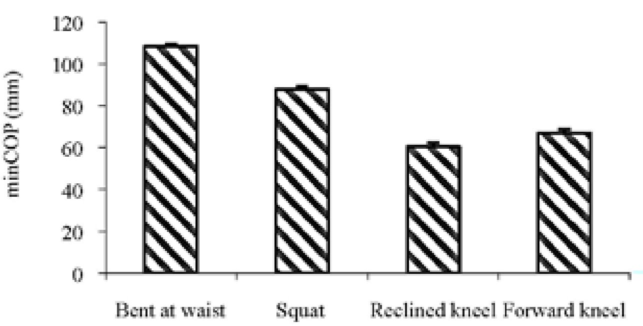

Figure 4. Minimum distance of the COP to the boundary of the base of support (minCOP) for the four static postures

Discussion

Maintaining balance and postural stability is critical for successful task performance, particularly when working at elevations. A variety of factors may influence an individual's ability to maintain balance during task performance, so it is important to discern instances that create a substantial risk of falling [Bagchee et al. 1998]. Volitional movements are one type of perturbation that may affect afferent information that is required to retain balance control and increase an individual's vulnerability to losing balance.

Significant changes in balance control measures were identified following the transitions to standing after maintaining static postures. The time in the posture prior to standing did not significantly affect any of the balance control measures, suggesting that the vestibular system had ample time to accommodate to the new position for all durations prior to the transition and the musculature was not significantly encumbered. These results may not generalize for longer durations within static postures as fatigue and muscular discomfort may affect post-transition balance control measures.

The magnitudes of the balance control measures were dependent upon the static posture, with those requiring greater integration of sensory systems placing the largest burden on balance control. Therefore, the working posture chosen to complete a task may affect balance and postural stability upon standing and transitioning to another task. Results from the current study signify that individuals are more stable when rising from a bent at waist or squatting position than kneeling. It is recommended that tasks, particularly those in high-risk environments such as construction, be examined and possibly redesigned to reduce the use of certain working postures or provide additional measures of fall protection.

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Risks of Accident in Construction Sites in India and How to Prevent Accidents Caused by Falling from Height

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In India, the construction sector remains a relatively high risk segment. News paper reports and self reported incidents show that construction workers experience a higher number of accidents or near miss incidents mainly due to falling from height. Work related conditions that are more prevalent in construction workers include falling from height, slips, trips and falls on stairways and ladders, breakage of handrail and stair rail system and scaffold, fall due to energized electrical equipment at height. Other common related injuries are - violence and aggression, Break-down of lifting machinery, manual handling injuries, back injury due to unsafe lifting of article ,injury caused by falling object, etc. The Government wants to establish the safety in construction sites in India and has introduced Building and other Construction Workers welfare(BOCW) Act (Regulation and Employment and Conditions of services), 1996 by which the risk of accidents can be minimized by enforcing the provisions of the safety standards in construction site.

Introduction

Occupational injuries represent a major problem in construction industry. Severe consequences also do occur as aftereffect including Social and economic losses. Findings of the International Labor Organization reveal that the accident rate in construction is four to five times higher than that of the manufacturing sector on the global scale. [CIDC 2006]. Falls continue to be the biggest cause of fatal injury in Britain's workplaces, with 58 worker deaths in 2007/08(p) resulting from a fall from height The construction industry accounted for 59% of all fatalities to workers as a result of falling from height. On top of this, over 3,235 major injuries such as broken bones or fractured skulls are reported to HSE in 2007/08 year due to falling from height. Out of this the construction industry accounted for 33% (1,198) of all major injuries to workers resulting from a fall from height (www.hse.gov.uk).

The goal of the current study was to conduct a review of literature, news and articles in leading newspapers and self investigation report for information on risks of accidents in construction sites of India. The overall finding of this review provides information on 'Key factors of risk in construction sites of India' and 'mechanism to prevent or reduce accidents caused by falling from height'.

Brief Overview of Literature

Construction labour form 7.5% of the world labour force and contributes to 16.4% of total global occupational accidents [Kulkarni 2007]. Construction has the largest of the fatal injuries of the main industry group. The HSE report of UK indicate that the rate of fatal injuries in construction over the past decade in has shown a general downward trend. The rate in 2008/09 being less then half of the rate in 2000/2001. The rate has decreased by 34% in 3 years (www.hse.gov.uk). This downward trend is due to effective implementation of safety standards in construction sites. (www.hse.Gov.uk).

In India construction is the largest economic activity after agriculture. Health and safety is the most neglected sector and accidental and occupational disease statistics related to construction industry is not available (www.southacia.oneworld.net). The collapse of 240 meter under construction chimney in Bhopal on the 23rd of Sept. 2009 took the lives of 45 Indian workers. The report of 6 killed and 13 injured in Metro Bridge collapse on 12 July 2009 in construction site of Delhi Metro Corporation (DMRC) is the worst accident in its history. Another report of a wall collapse on 17th May, 2008 at a building site in the suburbs of

New Delhi killing at least 17 Indians construction worker leaving more than 20 others injured, (web:abc.net.au/news).

Risks of accidents in construction sites in India

Indian Construction industry employs a work force of nearly 40 million. This workforce comprise 55% unskilled labor, 27% skilled labor and rest are the technical and support stuff [Kulkarni 2007]. The work force in construction is most vulnerable because employment is 'permanently temporary'; the employer and employee relationship is very fragile and short lived. The work has inherent risk to life and limb due to lack of safety, health and welfare facilities, coupled with uncertain working hours. A large number of workers are exposed to the risks of workplace accidents and occupational health problems. The occurrence of fatal accidents in this sector is four to five times that of the manufacturing sector.

Compared to other countries, there is little authentic data in respect of the accident rates, causes or preventive measures taken by the Indian construction industry. No agency till date has been assigned the responsibility to compile such records, and no voluntary efforts have been made in this regard. However, as per one survey reported by Construction Industry Developing Council of India at an all India level, 165 per 1,000 workers get injured during construction activities (www.cidc.in). Construction workers are exposed to a wide variety of health hazard at work. The exposure differs from job to job. The risks of accidents in construction industries in India are Physical, Chemical, Ergonomical, Biological and Psycho-Social.

Common construction activities that lead to accidents are collapsing scaffolds, power tool accident, fall from ladder, safety harness breakage, fall from roof, etc. Work conditions, age, safety training, experience and weather have all been designated as responsible factors of risk in construction sites in India. Nature of workplaces being varied, determinants of occupational injury causation have also been different. The analysis of following case studies for different work conditions in different locations under different weather conditions in India give an idea about risks of accidents in construction sites due to falling from height.

Case study for analysis of accident: falling from height (Case-I)

Establishment	Delhi Metro Rail Corporation
Date of Incident	22nd July, 2009
Accident Type	Collapse of Under Construction Metro Viaduct
Work Location	Zamrudpur, South Delhi, India
Demography	Fatal Injury - 06, Sex - Male, Age - 25-35
Job Description	Construction worker working at height.

Description of Incident: On July,12, 2009 while work lifting of RCC segments for construction of Viaduct between Pier No.67 and 68 was being carried out, the overhead launching Girder along with the portion of under construction Metro viaduct collapsed due to structural failure of cantilever pier-cap of pier No. 67, which supported one of the end of launching girder.

Standards/Statutory provisions not followed

1. The Launching girder along with the lifting equipment mounted there upon used at site, had not been tested and examined by competent person before taking into use.

2. The load bearing capacity of cantilever pier-cap no.67 had not been ascertained to prevent structural failure, before using the same to support launching Girder mounted with the Lifting equipment used for lifting of RCC viaduct segment.

3. Inspection of support structure cantilever was not carried out before the lifting work.

Case study for analysis of accident: falling from height (Case-II)

Establishment	Bharat Aluminum Company (BALCO), Raipur India
Date of Incident	23rd Sept, 2009
Accident Type	Collapse under-construction 275 mtr chimney at a power plant.
Work Location	BALCO, Kobra, Raipur India
Demography	Fatal Injury - 45, Sex - Male/Female Age - Not known
Job Description	Construction worker working at height and ground level.

Description of Incident: Sources quoting witnesses said lightning struck the under-construction chimney at a new power plant being constructed at Bharat Aluminum Company (BALCO) at 1600hrs on 23rd Sept, 2009 bringing down the huge concrete structure. More than 100 labourers were engaged in the work when it had begun to rain. The structure collapsed on a store room where workers had taken shelter from the rain.

Standards/Statutory provisions not followed

1. The company did not take permission from the Korba Municipal Corporation (KMC) for the second chimney. (Business standard, Legal scanner on Balco chimney R Krishna Das / Kolkata/ Raipur September 25, 2009, 0:36 IST)

2. The sub standard material used for construction, technical fault in design, poor workmanship and negligence in supervision and monitoring were the findings of investigation report. (NIT report: source Hindustan times, Jan11, 2010)

Case study for analysis of accident: falling from height (Case-III)

Establishment	Hotel Crown Plaza, Rohini, India.
Date of Incident	21st January, 2010
Accident Type	Collapse of scaffold by falling object from tower crane
Work Location	Under construction Five Star Hotel, Rohini, India
Demography	Fatal Injury - 01, Sex- Male, Age - 25-35
Job Description	Two workers working at height using scaffold.

Description of Incident: On 21st January, 2010, while one bundle of pipe was being lifted by the tower crane, suddenly two MS pipes fell down from the bundle at 16th floor level and hit the scaffold at 4th floor level and collapsed the entire scaffold where two workers were working. In this accident one worker died and another injured due to falling from height. This is a case of multiple incident of accident by falling object and collapse of scaffold.

Standards/Statutory provisions not followed

1. Workers working in scaffold were below the tower crane, which is a dangerous zone. The operating procedure was not followed for lifting of materials by tower crane.

2. The Tower Crane had not been tested and examined by competent person before use.

3. Safety belt/ life-lines for protection of building worker during performance of his work at height were not used by the worker.

4. The Screening nets or wire nets were not used to envelope the scaffold for protecting workers form falling of objects in the danger zone.

The construction related accidents like scaffolding fails, wall/chimney collapse, rail bridge collapse, roof collapse or any fatal accident that takes place in a construction site are to be investigated properly and the safety related issues are to be addressed scientifically. The identification of responsible factors in relation to a specific work environment has not only helped in exploring the etiology but also been useful in planning prevention.

Institutional and legal framework for prevention falling from height

Safety in construction is frequently pushed to the bottom rung of priorities by the builders, contractors and engineers. The investigation report of National Institute of Technology (NIT) about Collapse under-construction 275 meter chimney at a power plant, Raipur claimed that the mishap was caused due to the use of sub standard construction material, lack of supervision, inadequate causing time and poor testing non-conforming to Indian standard code and faulty mechanical design. [Hindustan Times 2010] The cost cutting measures circumvented many construction standards and safety protocols to cut construction cost in India [PTI, 2009, Times of India]. The incident of wall collapse on 17th May, 2008 at a building site in the suburbs of New Delhi, is the effect of using shoddy construction material for the accident followed by a dangerous situation caused by rain and gusty winds on that day. (web:abc.net.au/news).

There is an urgent need to bring legislative stability to employment status, risk reduction by on site safety management and imparting training and skill development as demanded by typical construction sector The central and state rules need to be intensified and the enforcing agencies with technical competencies need to be notified throughout the country for better enforcement of this Act. In 1996, the BOCW Act and Rules made thereunder has been enacted for construction activities in India .Different provisions have been set to protect workers of construction industry from falling from height under chapter VII of the Act. By following the standards of safety in construction site and establishing standard operating procedure, maximum number of accidents and injuries due to falling from height can be minimized. "Proper compliance of the provisions of the said Act and Rules made thereunder" is the principle step towards prevention and control of accidents arising out of falling from height.

Conclusion

It is high time that a construction safety manual is evolved which will be a part of decision making criteria for every construction site related to 'construction safety in India'. It is desirable that adequate staffing and strengthening of regulatory agency, proper implementation and monitoring of safety and health standards laid down in the BOCW Act, 1996 for construction activities, accident reporting and analysis system coupled with environmental risk assessment studies and regular construction site audits should safe guard the interest of construction worker in India. There is a definite need of developing effort to collect data, conduct research, analyze causes and develop models to 'profile the types of accident risks' of falling from height. More intensive efforts are required to prevent and control the accidents in construction sector caused due to falling from height in India.

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Lateral Buckling of Wood Composite I-Joists as a Mechanism Causing Falls from Elevation

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Wood composite I-joists are common materials used for floor and roof joists in residential construction. The shape of I-joists reduces the amount of wood fiber required to carry vertically applied loads. However, these joists have low stiffness in the lateral and torsional directions, requiring bracing by sheathing and additional bridging elements. During construction, workers may walk on these I-joists and induce lateral buckling,which could lead to worker falls. Walking loads contain both vertical and horizontal loading components which could induce lateral buckling. The purpose of this paper was to explore the loading and deflection of workers walking on unbraced I-joists to see if lateral buckling was initiated. A safety platform allowed workers to walk on unbraced I-joists safely. Measurements of the horizontal load and deflection of the top flange at mid span showed increasing load and deflection due to increased worker static weight, respectively. Differences in the load and deflection were observed between I-joists of different lengths and manufacturers. The phenomenon of lateral buckling may be more serious for overweight workers since the addition of horizontal load decreases the vertical load needed for buckling,and increased deflection may increase the tendency of workers to fall from unbraced joists.

Introduction

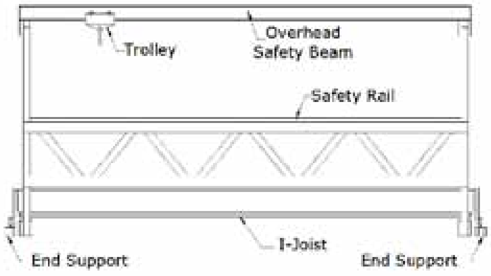
Wood composite I-joists represent a sizeable portion of new residential construction floor systems. I-joists are created from solid sawn, structural composite lumber (SCL) flanges connected with an oriented strand board(OSB) web [Hindman et al. 2005a]. As the complexity of residential housing increases, wood I-joists are used in longer spans, and as continuous and cantilevered beams [Hindman et al. 2005b]. The shape of I-joists tends to produce high bending stiffness in the vertical direction, but low bending stiffness in the lateral direction, and low torsional rigidity. These stiffness properties make I-joists vulnerable to lateral buckling, an instability condition where the joist deflects laterally and twists due to vertical loads. Previous research by Hindman et al. [2005b] and Zhu et al. [2005] studied the effects of static structural loads on I-joists. However,no research has been conducted pertaining to the lateral buckling of unbraced I-joists under construction loads. This condition is commonly seen in residential construction before the sheathing is attached to the joists. Falls are the leading source of injuries and fatalities in the construction industry, accounting for nearly one third of fatalities. Furthermore, fall accidents have been steadily rising over the past several years [Huang and Hinze 2003]. Since 1997, approximately half of all fall accidents have occurred on commercial and single family or duplex construction sites. The average fall height is approximately 11 meters, corresponding to structures of three stories or less. Almost half of fall accidents occur on job sites with a value of less than$250,000 [Huang and Hinze 2003]. These facts indicate that the majority of fall accidents may be occurring on residential construction sites. The motion of walking can be characterized by an ascending and descending movement of the effective mass of the human body as well as lateral propulsion. This motion is periodic with respect to the step frequency. Harmonic loads develop due to the loading of one foot and the simultaneous unloading of the other foot. An increase in the dynamic load is observed due to the impact of the heel. This dynamic load usually results in a vertical load higher than the static weight of an individual. Huang et al. [2006] developed a mathematical model that defines these forces normalized by static weight to describe the force components of a single step.

Materials and Methods

The purpose of this research was to measure the loads and deflections of the I-joist when subjected to walking forces by workers traveling parallel to the length of the I-joist. A safety platform was constructed to allow workers to traverse the unbraced I-joist while being supported by a safety harness and lanyard continuously. Three different sizes of I-joist were used in testing from two different manufacturers. Joist 1 (J1) was 30.2 cm high and 610 cm long. Joist 2 (J2) was 35.6 cm high and 610 cm long. Joist 3 (J3) was from a different manufacturer and measured 30.2 cm high and 731.5 cm long. All materials were conditioned in the Wood Engineering Laboratory at equilibrium moisture content (EMC) of approximately 10%. Three samples of each joist were used for testing based upon the variance of previous measurements. Figure 1a shows the schematic of the safety platform. The platform was designed to accommodate the unbraced I-joist and provide a continuous lanyard connection to workers traversing the joist. The platform is approximately 610 cm long. Figure 1a shows the sides of the platform, which act as safety rails if the participants feel they are beginning to fall. These safety rails are located approximately 150 cm apart. The overhead beam is located directly above the unbraced I-joist. The trolley is clipped onto the bottom flange of the overhead beam and is able to move along the length of the platform on steel rollers. A 152 cm self retracting lifeline is connected to the safety trolley. Participants attached the lifeline to their harness. Preliminary testing of the system was conducted to ensure that the retracting lifeline activated before a participant struck the floor. Figure 1b shows a participant walking on the joist.

Test subjects included male construction workers and students weighing from 60.3kg to 128.3 kg. All data collected from test subjects conformed to the Virginia Tech Internal Review Board guidelines. Test subjects were asked to traverse the beam at their own pace. Each participant traversed the beam two times (forward and back). The participants were instructed to use the safety rails only when necessary to prevent a fall. Two different end supports were constructed to hold the ends of the I-joist. Vishay BHL U3SB-A "S" type load cells with a 22.2 kN capacity and an error of less than 1 percent were be placed at each end of the beam to record the vertical reaction. These two load cells could be used to establish the relative position of the participant along the joist. At one of the supports, two load cells were also attached in horizontal directions at the top and bottom flanges. The horizontal load cells measured the lateral force exerted on the joist, as well as any torsional resistance at the supports. The end reactions combined with the I-joist flange reactions were compiled to produce the combination of loads that each participant applied to the I-joist through walking. A pair of 50.8 cm string potentiometers were placed at the mid-span and quarter-span locations along the joist.

At each location, one potentiometer was attached to the top flange and another was attached to the bottom flange. The change in deflection of



(a)

(b)

Figure 1: Safety Platform, (a) Side View, (b) Participant Walking on Joist

the potentiometers allowed the calculation of both the lateral displacement and rotation of the joist at these locations. This calculation was based on the assumption that the web of the joist does not deform and remained perpendicular to the flanges. Further details of testing and measurement can be found in Timko [2009].

Results

Figure 2 shows the relationship between the weight of the test subject and maximum induced load on the top flange. A linear regression was fit for each joist type. The J1 and J2 I-joists had similar horizontal forces and regression curves. There was a significantly greater amount of variance within the J3 joist results compared to the other two joist types. The J2 joists were the stiffest joists with respect to lateral and rotational stability,while the J3 joists were the least stiff. From the slope values discussed in Timko [2009], the J1 joist horizontal force averaged 9.3% of static weight, the J2 joist horizontal force averaged 16.1% of static weight,and the J3 joist horizontal force averaged 72.1% of static weight. Previous results from static testing found differences in bending properties of different joist manufacturers [Timko 1999]. However, the effect of different joist manufacturers is confounded with the longer length used for J3. The horizontal force tends to induce buckling at a lower vertical load than if no horizontal force is present. As worker static weight increases,standard equations for vertical loading of joists may over predict the buckling load because the horizontal force is not accounted for.

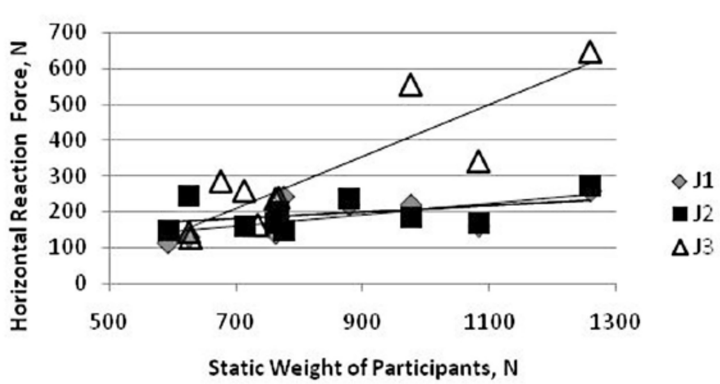


Figure 2: Horizontal Force vs. Static Weight of Participants

Figure 3 shows the relationship between static weight and the top flange deflection of the joist at midspan. Figure 3 shows a similar behavior to Figure 2, where the performance of the J1 and J2 joists was similar while the J3 joist produced much larger deflections. Again, the effects of the different joist manufacturers and joist length were confounded in these results. An analysis of variance of these test results indicated no significant effect was found for the participant static weight or joist type compared to the top flange deflection. No research was found to determine the angle of movement required to induce falls. As the lateral deflection of the beam increases, the opportunity for workers to fall from these joists increases. These results may indicate that overweight workers may be at more risk for falls from elevation from unbraced joists.

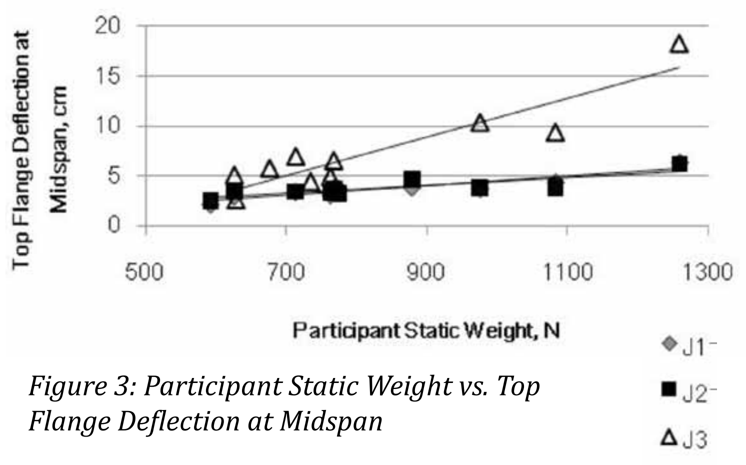


Figure 3: Participant Static Weight vs. Top Flange Deflection at Midspan

Conclusions

This paper describes the measurement of the lateral buckling of unbraced I-joists due to workers walking parallel to the joist direction. As the static weight of a person increases, the amount of horizontal force and lateral deflection of the joist increase. The increase in horizontal force can induce lateral buckling at lower loads than predicted by only considering vertical forces. The increase in top flange deflection creates an unstable surface where the tendency for workers to fall may increase. Lateral buckling of unbraced I-joists may become a more critical for overweight workers due to the dependence on static weight.

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Factors Associated with Falls from Heights in Residential Construction

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Deaths due to falls in construction have risen in the past decade. We surveyed 1,981 apprentice carpenters to identify factors associated with falls from heights. Among 1,351 apprentices with residential experience, apprentices with less than 1 year of experience were 2.1 (95% CI) times more likely to fall compared to those with over 5 years experience. For each 10% increase in number of apprentices compared to journeymen at the residential work site, there was a 7% increase in the likelihood of apprentice falls. Safer crew behaviors and perceived work climate scores were protective of apprentice falls from heights. This work suggests that increased efforts to protect inexperienced workers from falls are needed,including providing adequate amounts of mentorship and training. This study also suggests that organizational changes in building practices and safety culture may decrease worker falls from heights.

Introduction

In 2007 the U.S. construction industry experienced more fatalities than any other industry [BLS 2007c]. Falls accounted for 37% of these construction fatalities, 42% of fatalities in new single-family home construction, and 55% in residential framing [BLS 2007b]. Deaths due to falls in construction have risen in the past decade, contrary to national trends of declining mortality from other occupational fatalities [BLS 2007a; Derr 2001]. The goals of this study were to describe the factors related to fall safety in a large cross-sectional study of apprentice carpenters, and to examine associations between these factors and reported falls from height. Our study focused on residential construction workers, a high risk population that has not been widely studied.

Method

Population

The study population was union apprentice carpenters attending regularly scheduled training at the St. Louis Carpenters' Joint Apprenticeship Program (CJAP) in Missouri, USA between December 2005 and May 2006,and between September 2008 and March 2009. Results from the initial wave of surveys were reported in the Scandinavian Journal of Work, Environment, and Health [Kaskutas et al. 20010], and this paper presents the pooled results. CJAP is supported by the Carpenters' District Council of Greater St. Louis and Vicinity and the Home Builders Association of Greater St. Louis and Eastern Missouri.

Questionnaire development and administration

Development of the survey, domains of the survey, and administration procedures have been previously described [Kaskutas et al. 2010]. The 72-item survey covers demographic and employment data, fall history,task performance and equipment use history and training, risk perceptions, knowledge, confidence, work crew behaviors, workplace safety climate, barriers to fall protection, and training effectiveness. All procedures were approved by the Institutional Review Board at Washington University.

Data Management and Analysis

Descriptive statistics were generated for all variables including frequencies of categorical responses and distributions of continuous variables. Employer size was categorized into small (< 25 carpenters), medium(26-75 carpenters), and large (> 75 carpenters) employers. The percentage of knowledge questions answered correctly was calculated for each participant. In order to calculate scores for the safety climate, crew behavior,risk perception, and confidence domains, we added the score for each item within the domain, assuming equal weighting of each item, and divided the total by the number of items in the domain. For missing items, we computed the mean score for that domain and assigned this mean value to the missing value(s) if at least 75%of the items in the domain were completed.

We entered variables/scales that were significant on the Wald test into a multivariate logistic regression model;variables with p-values less than 0.05 were considered to be statistically significant. Analyses were performed using SPSSS (Version 16.0).

Results

Descriptive Results

The questionnaire was distributed to 2,010 apprentices, and completed by 1,981 apprentices in all stages of training (98.5% response rate). Of the total respondents, 1,351 had recent residential work experience. The mean age was 26 years (SD 5.8, range 18-49). The majority of apprentices were white males. Twenty percent (20%) of respondents were first year apprentices, 29% second year, 31% third year, and 20% fourth year apprentices.

Fourteen percent (n=215) of the 1,351 respondents with residential experience had personally fallen from a height in the past year. Of those who fell, 10% lost work time, 6% returned to restricted work, 14% received medical care, and 7% received prescription medication. The average distance fallen was 2.6 meters, with a range from 0.3 to 9.1 meters. Most of the falls occurred from ladders (33%), 11% from truss, 9% through floor opening/decking and 9% from scaffolds. Loss of balance, slip/trip, equipment set-up, weather conditions, and speed were the most common contributing factors.

We asked about common work tasks and equipment use related to falls or fall prevention. While most apprentices were trained prior to performing these tasks, their training did not align with required work tasks. Use of step and extension ladders were the two most common work tasks reported (98% and 96%), yet the least common tasks apprentices were trained in prior to performance on the job (61% and 63%). Only two thirds of apprentices reported that they were trained before performing other common tasks at height, including roof sheathing and setting trusses and outside walls. Conversely, 99% of apprentices were trained to use personal fall arrest systems (PFAS), yet apprentices reported that these systems were commonly used at only 18% of work sites.

The mean knowledge percentage correct was 60%, ranging from 83% for the height fall protection is required,to 36% for the height where ladder jacks require fall protection. Most apprentices did not know the size of a floor opening that requires covering was only 2” (4.4 cm) in diameter; they thought it was much larger. Sixty-one percent of the apprentices knew that standing on the external top plate (top of the outside house wall) was never permitted. Correct extension ladder setting methods were known by less than two-thirds of apprentices surveyed. Respondents rated step ladders as the task/equipment which posed the least risk of falling, while truss setting and working on the top plate were rated as having a high fall risk. Apprentices reported that they always or often observe crew members performing unsafe acts, such as standing on the exterior top plate (51%), walking on floor joists (52%), and using unopened step-ladders (44%). PFAS were reported as not used at the work site by 42% of the apprentices and used often or always by only 20% of all apprentices surveyed. Despite requirement for controlled access zones to be monitored by a designated worker or foreman, 23% of apprentices reported that unprotected floor openings were never monitored. Regarding safety climate, most respondents agreed journeymen teach them how to do the job safely, safety was a priority with management/foremen, there was adequate time to work safely and meet production deadlines, and they felt free to report safety violations. Among apprentices working residential construction, having less than 1 year of work experience was the strongest independent risk factor predicting falls in the multiple regression models (table 1). For every 10%increase in the percentage of apprentices at the work site, there was a 9% increase in ladder falls. Safer crew behaviors were protective, with a 1 point improvement in crew behavior resulting in an 8% decreased likelihood of all falls from heights. Safer work climates were also protective, with a 9% decreased likelihood of falls noted for every 1 point improvement in safety climate. Contractor size, age, knowledge scores, and number of tasks performed were not significant based on the Wald test.

Variables	**All Falls** **Adjusted Odds Ratio (95% CI)**
Length worked in trade versus	
<5 years	2.05 (1.09, 3.85)
< 1 years	1.76 (1.08, 2.88)
2-5 years	
Percent apprentice, per 10% increase	1.07 (1.01, 1.17)
Safer crew behaviors score	0.92 (0.89, 0.96)
Safer work climate score	0.93 (0.88, 0.98)

Table 1. Predictors of falls from height for residential apprentices, n=1,351

Variables/scales with the Wald test were entered into the multiple logistic regression models, only significant variables are reported.

Discussion

Despite participation in a formal apprenticeship program, many of the 1,981 apprentices performed tasks on the job prior to training, and many lacked essential fall prevention knowledge, suggesting that the timing and content of carpenter apprenticeship training can be improved. Most workers were not trained on ladders,however ladders accounted for most of the falls in our sample. Apprentices reported unsafe ladder climbing behaviors by other crew members, which was confirmed by work site audits [Kaskutas et al. 2009]. Our finding that apprentices perceived the risk of falling from ladders as low is an example of inexperienced workers mistakenly perceiving that routinely used equipment does not require special knowledge or skills [Kines 2003].The low rates of ladder training suggest that contractors and apprenticeship trainers may also underestimate these risks. Our results confirm that carpenters working residential construction, apprentices with less than one year of experience, and apprentices on work crews with a greater proportion of apprentices are at greater risk of falling from heights. Apprentices working on crews that practice safe behaviors were less likely to fall than those working with unsafe crew members. These factors suggest mentorship and peer behaviors can affect apprentice safety. Since falls account for most of the construction worker deaths in residential framing and the highest costs per injury claim [Lipscomb et al. 2003], efforts to address falls in this population are needed. Use of the construction methods outlined in the OSHA residential guidelines [OSHA 1999] can decrease worker falls from heights; however, these methods are practiced inconsistently at best. Increasing contractor and carpenter awareness and understanding of the methods described in these guidelines, and increasing use of available technologies at residential work sites is recommended. Personal fall arrest systems prevent worker falls to lower surfaces, yet they are not widely used during residential framing [Kaskutas et al. 2009].

Previous work by our team [Kaskutas et al. 2009, Lipscomb et al. 2008] suggests that inexperienced carpenters do not receive the type and amount of mentorship they would like from journeymen on their work crews. Limiting the number of apprentices working at residential construction sites will increase the opportunities for mentorship;

however many contractors have increased the number of apprentices on their residential crews in order to remain competitive in the current home building market. In addition, journeymen may underestimate their role in providing supervision and training to inexperienced workers.

The authors would like to thank our collaborators, including the Carpenters' District Council of Greater St. Louis and Vicinity, St. Louis Carpenters' Joint Apprenticeship Program, the Home Builders' Association of St. Louis and Eastern Missouri, and the residential contracting companies and carpentry professionals who participated in this research. Portions of these results have been published in the American Journal of Industrial Medicine and the Scandinavian Journal of Work, Environment, and Health. Permission has been received to duplicate results which have been previously reported.

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Fall Prevention Technology Use at Residential Work Sites

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We measured availability and current use of fall prevention technology at residential work sites, and explored perceived benefits, barriers, and feasibility of using fall prevention technologies. We surveyed 1,981 apprentice carpenters, interviewed 778 residential carpenters, observed 396 residential builds, and interviewed residential contractors. Personal fall arrest systems were available at 81% of the work sites; however they were observed in use at only 8% of sites visited. The main reasons for not using these systems included time, equipment availability, difficult to use in specific work situation, concerns about worker safety during installation/removal, lack of secure anchorage points, and concerns about liability of permanent anchor systems. Contractors were not concerned with the cost of most devices. There are many barriers to overcome in order to increase widespread use of fall prevention technology at residential work sites to ensure the safety of residential construction workers.

Introduction

Falls from height are the most common cause of workplace fatalities in residential construction workers,accounting for 43% of the fatalities in residential building construction and 55% of the fatalities in residential framing in 2007 [BLS 2008]. There are many factors that contribute to the fall epidemic in construction workers. The minimal standards for fall safety at construction work sites described in the Occupational Safety and Health Administration's (OSHA) Construction Standards STD 1926 [OSHA 2006] are often not feasible at residential sites, and OSHA's Interim Residential Guidelines [OSHA 1999] are not widely understood and lack enforceability. Fall prevention methods and equipment are not consistently utilized at many residential work sites. Our research team audited 197 residential construction sites and found a 59%overall rate of compliance, ranging from 28% for truss installation to 80% for roof sheathing [Kaskutas et al. 2009]. Bigelow and colleagues [1998] found 65-70% general safety compliance at 195 home building sites. At residential sites where falls over 6 feet had recently occurred, work site audits by Lipscomb and colleagues [2003] revealed unacceptable scaffolding at 2 out of 3 sites and personal fall arrest systems were available at only half of the sites.

There are many commercially available technological interventions to protect workers from unsafe conditions during the framing process; however their efficacy has not been proven. Fall risk could be reduced by diffusion of available prevention technologies, and compliance with recognized safety procedures.

Methods

We used multiple methods in this project, including written surveys of apprentice carpenters (n=1,981), brief carpenter interviews performed at residential work sites (n=778), and residential work site audits (n=396). In order to identify fall prevention devices we searched the internet, spoke with carpentry experts and safety professionals, and contacted safety equipment suppliers. We designed a written Technology Assessment to rate devices for ease of use, cost, durability, effect on productivity, and overall effectiveness on a 0-10 visual analogue rating scales. The Technology Assessment was administered to carpentry professionals via 4 focus groups (n=18 apprentices, 9 apprenticeship trainers, and 3 safety directors) and individual interviews (n=9 contractors/safety professionals). Participants rated devices on the Technology Assessment and provided feedback about perceived benefits and barriers. Each participant chose the best device in the three priority categories: anchorage for personal fall arrest systems, stable work surfaces, and protection of floor openings. The focus groups were recorded and the results transcribed; notes were taken for the interviews and transcribed. The mean ratings for ease of use, durability, cost, effect on productivity and safety, and overall ratings were computed for each device for the five carpentry professional groups and for all carpentry professionals combined. The transcripts and written notes were combined with the quantitative ratings on a spreadsheet, which were used to choose the top devices to guard unprotected openings, provide anchorage points for personal fall arrest systems, and provide stable work surfaces.

After the top devices were chosen, we reviewed the safety testing data to ensure the device was safe for residential applications. Two expert journeymen carpenters with training and safety expertise developed installation and use training for the devices based upon the manufacturer's installation instructions and safety testing materials. We developed a safety audit for each device to measure if the device was installed and used correctly. We also developed a short worker interview to get their opinions regarding device feasibility; including ease of installation, time required to install and use device, durability, and effect on safety. We recruited small and large contractors to field test the devices. A skilled trainer delivered the training to the crew at the work site. A safety expert performed the safety observation mid-build to assess the installation and use of the device, and at the end of the build to get worker feedback. This research occurred as part of fall prevention research funded by the National Institute of Occupational Safety and Health through the Center for Construction Research and Training and the Heartland Center for Occupational Health and Safety. The Institutional Review Board at Washington University in St. Louis approved the research.

Results

Of the 1,981 apprentices surveyed, 88% reported they had been trained in personal fall arrest systems, 80% knew the height fall prevention is required, and 72% knew the height that fall prevention is required on scaffolds [Kaskutas et al. 2010]. Personal fall arrest systems were reported as being available at the work site by 81% of the apprentices; however 48% reported they were not used. The main reason for not using fall prevention devices described by a subset of 644 apprentices included time (23%), equipment availability (20%), and work situation does not allow for use (19%). During the 396 work site audits, we observed personal fall arrest systems were in use at only 7% of work sites visited [Kaskutas et al. 2009]. At sites where it was being used, the harness was fit and worn properly at 85% of the sites and lanyard attached to secure anchorage correctly at 77% of the sites. Use of other fall prevention devices was very rare at residential work sites. Safety boots were seen at several sites; however they were improperly installed at most of these sites.

Our search for commercially available fall prevention technologies resulted in 43 different devices, which we narrowed down to 13 after receiving carpenter feedback. The ratings for these final 13 devices ranged from 5.6 to 8.0 on a 0-10 scale, with the mean rating of 7.1. Barriers to use identified included worker safety during installation/removal, limited strength of building structure device installed on, ability of device to stop a fall, and liability concerns if device permanently installed. Contractors were not concerned with the cost of most devices. The top-rated device to protect floor openings was the safety boot system by Safety Maker [2009], a plastic housing that supports guardrails at floor openings and stairs. The guardrail protects framers, dry wall installers,and dry wall finishers. The Wall-walker system by Qualcraft Industries [2009] was the top-rated device to provide a temporary working surface. This is a hanging scaffold system that provides an elevated work surface for truss installation and if exterior mounted for roof sheathing. The top rated anchor for personal fall arrest systems was the Anchor Choker, a reusable webbing strap which is secured around truss members, floor joists,or top plates during installation of trusses, sheathing, or other operations. The strap is able to withstand the forces generated in a fall; however, the building member it is installed on must also be able to withstand the forces generated in a fall. Since the forces the trusses are able to withstand prior to final stabilization are unknown, most contractors interviewed were hesitant to apply an anchor for personal fall arrest systems to a truss prior to installation of sheathing on the truss. Therefore we decided not to field test the Anchor Choker or any of the anchors identified in this project.

Summary and Disclaimers

Personal fall arrest systems are available at most residential construction sites, and apprentice carpenters have the knowledge and training to use them; however observation and apprentice self-report confirm that personal fall arrest systems are rarely used during home construction. There are a wide variety of fall prevention devices currently available to protect openings, provide anchorage for personal fall arrest systems, and provide temporary walkways, yet these are under utilized at residential work sites. Carpentry professionals in various roles perceived that many of these fall prevention devices provide safe and feasible methods to protect openings and provide temporary walkways; however anchorage systems for personal fall arrest systems during truss installation continue to pose safety concerns.

There are many barriers to overcome in order to increase widespread use of these devices; however effect of the device on productivity appears to be the main concern. Current field testing of two of these devices will explore the effect of the device on productivity; however long-term testing of the devices will be the best measure of feasibility as the time involved to install and use the device should decrease with practice. We plan to follow the same crew over time to see if productivity can improve with repetition. We also plan to compare building costs with and without the technology. We will disseminate our results and monitor the sales of these technologies in our region to assess if widespread diffusion is occurring. Alternatives to unsafe work practices at heights must be identified and tested to ensure the safety of residential construction workers.

The authors would like to thank our collaborators, including the Carpenters' District Council of Greater St. Louis and Vicinity, St. Louis Carpenters' Joint Apprenticeship Program, the Home Builders' Association of St. Louis and Eastern Missouri, and the residential contracting companies and carpentry professionals who participated in this research. Portions of these results have been published in the American Journal of Industrial Medicine and the Scandinavian Journal of Work, Environment, and Health. Permission has been received to duplicate results which have been previously reported.

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Field Studies and Labeling Research on the Angle of Inclination of Non-Self Supporting Ladders

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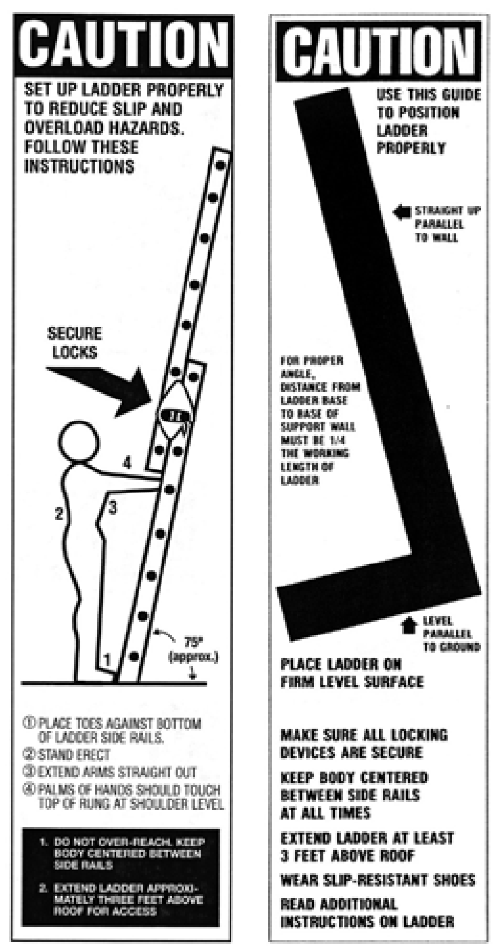
For non-self supporting ladders, setting the angle of inclination of the ladder is a critical step in the set up process, since the angle of the ladder influences the likelihood of a slide out at the base, and the overall strength of the system. A field study was conducted where over 100 real world ladder installations were documented, including angle of inclination, site conditions, and use. Research was further conducted to assess the effectiveness of existing ladder labels for setting the ladder at the instructed 75.5 degree angle of inclination. 45 participants set up extension ladders following the"anthropometric" label (appendices of current ANSI A14 ladder standards), and/or the backward "L" label (historic ANSI A14 label). Results indicate that the current"anthropometric" label resulted in a set up angle consistent with anthropometric calculations and significantly higher than documented in real world ladder use.

Introduction

Since their inception, the American National Standards Institute(ANSI) safety standard for portable metal ladders and the Occupational Safety and Health Administration (OSHA) have instructed that the proper angle of inclination for non-self supporting ladders is 75.5 degrees from the horizontal [ANSIA1956; OSHA 1971]. This angle is the optimum balance between resistance to sliding, strength of the ladder, and balance and comfort of the climber. Setting non-self supporting ladders at angles shallower than the recommended angle of 75.5 degrees has been found to increase the risk of ladder slide out at the base [Axelsson and Carter 1995; Faegemann and Larson 2001].Although Chang et al. [2005] found that angle of inclination was the most critical factor in determining friction requirements at the feet, they also show that the required coefficient of friction to prevent slide out is often well below that of typical floor surfaces.

Methods for achieving the proper set up angle include the "1/4-length rule", and the so called "fireman's method". Both have been used for over 40 years [Hepburn 1958; NFPA 1969]. The fireman's method, also known as the "anthropometric" method,instructs the climber to stand at the base of the ladder with toes against the bottom of the ladder rails with arms outstretched horizontally. The proper angle is achieved when the palms of the hands touch the top of the rung at shoulder level. This method has been illustrated in labels on portable ladders for 20 years(Figure 1a), and is still currently recommended (ANSI A14.2-2007).

Other investigators have studied various methods of setting the angle of inclination of



non-self supporting ladders [Young and Wogalter 2000; Morse et al. 1999; Irvine and Vejvoda 1977; Bloswick and Crookston 1992], but none of these previous studies tested the anthropometric label that has been on portable ladders for 20 years. This study examines the effectiveness of this label at achieving the recommended angle of 75.5 degrees with separate groups of professional and nonprofessional ladder users, and compares the results to real world ladder usage.

Method

Field Study

Researchers drove around in the suburban Chicago area finding examples of single and extension ladders that were already set up and in active use. Notes and photographs were taken to document each ladder setup circumstance. The information gathered included the ladder make, model, size, ground conditions, upper support point, ladder length to the top support point, angle of inclination, activity being conducted on the ladder, and if there were any extenuating circumstances that affected how the ladder was set up. The angle of inclination of the ladder was measured using a portable digital inclinometer (SPI-Tronic Pro 360) placed on the side rail. Data was collected until 100 ladder set ups were documented. Various user comments were also gathered related to set up and use practices. The field data were statistically analyzed, and additionally studied for usage patterns and/or trends.

Label Effectiveness Study

To address whether or not existing ladder labels are effective at instructing users how to set up single and extension ladders at the proper angle, a total of 45 male participants were individually asked to read and follow specific labels placed upon test ladders. In the initial portion of the study, considered a pilot study, 15 participants set up a fully extended 24 foot extension ladder against a wall with the feet on level asphalt after first reading either the "anthropometric" label (described above) or the backward "L" label. The backward "L"label was the ANSI A14 recommended label prior to the anthropometric label. The ladder is set at a proper angle when the upright vertical part of the "L" is parallel with the wall and the bottom horizontal part of the "L" is parallel with the ground (Figure 1b). Participants repeated the set up three times for each label, and the order of which label was presented first was randomized. The ladder was put in a near vertical position prior to each trial. These 15 subjects did not use ladders in their jobs. They were told not to be concerned with whether or not they would feel comfortable climbing the ladder, as this is a potential confounding variable that may alter the set up. The second portion involved 30 subjects who were construction or commercial users of ladders. Participants had an average of 6 years of prior experience using single and extension ladders on the job. Test procedures were modified slightly. Only the anthropometric label was used, as that was the predominant label found on ladders in the field study. Participants were initially asked to set the ladder up as they would normally. This angle was measured, and then they were asked to read and follow the anthropometric label placed on the ladder. In an effort to test real world ladder use situations, the tests were conducted in the field at multiple job sites with available ladders and various site conditions in the suburban Chicago area. A total of 9 different extension ladders were used ranging in length from 20 feet to 28 feet. Varying degrees of extension were used, but most ladders were 1-3 rungs. Ground support conditions included concrete, plywood, dirt, and grass. Upper contact points included both wall and edge support. Each participant repeated the anthropometric set up three times. The ladder was put in a near vertical position prior to each trial.

Results and Discussion

Field Study

Of the 100 ladder set ups that were documented, 77% were on a residential construction site, 21% were commercial use of ladders (e.g. painters), and 2% were non professional use of a ladder. This was more likely a result of obtaining data during weekday working hours. 59% of the ladders were aluminum, while 41% were fiberglass. No wood ladders were documented. 78% of ladders had the "anthropometric" label present and readable, 3% had the backward "L" label, and 19% had either missing or unreadable labels. The angle of inclination for the 100 ladder set ups had a mean of 67.2 degrees, with a standard deviation of 4.8 degrees. The median measurement was 65.5 degrees, and the mode was 67 degrees. The minimum measured angle was 53.6 degrees, while the maximum was 75.8 degrees. Only 3% of the installations were at 75 degrees or above, while 30% were at 70 degrees or above, and 69% at 65 degrees and above.

Data analysis looking at the ladder length to the top support and the angle of inclination did not show a significant relationship (Pearson's = 0.19). Comments gathered from ladder users included that they do not read the label every time they set up a ladder,instead they rely on what looks right from past experiences. Additionally, the ground conditions are considered when evaluating a potential slide out. They indicated that a ladder set up in grass or dirt with the feet spiked was considered adequate protection against slide out. When ground conditions are not considered a safety issue, they indicated that they set a ladder at a shallower angle. Users felt more comfortable climbing a ladder at a shallow angle, because they can lean into the ladder and feel more "on top" of it. Some commented that climbing a steeply angled ladder gives the users a feeling that the ladder will be pulled over backward.

Label Effectiveness Study

Table 1. Label Effectiveness Study – Angle of Inclination Results

Participants			Label	
Type	#		"Anthropometric"	Backward "L"
Non Professional	15	Mean	73.8	72.7
		St. Dev.	3.2	2.7
Professional	30	Mean	74.2	
		St. Dev.	3.3	
Combined	45	Mean	74.1	
		St. Dev.	3.2	

Table 1 contains the angle of inclination results for the study. In the pilot study, the result of the two different labels were not significantly different ($p > 0.3$), despite the fact that several users found the backward "L" label somewhat confusing. For the 30 professional ladder users in this study, their normal set up resulted in an average angle of inclination of 69.1 ± 5.2 degrees. 55% of the normal set ups were at 70 degrees or above .Those same professional users achieved an average angle of inclination of 74.2 ± 3.3 degrees by reading and following the "anthropometric" label. 87% of these results were at 70 degrees or above. The difference between each of the label study means was significantly different from the field study mean ($p<0.001$). The professional users normal set up angle was also significantly lower than their own results in the anthropometric label study ($p<0.001$).

Testing results for the anthropometric label are consistent with calculations using the anthropometric data in Tilley [2002]. Looking first at the body segment data and ignoring ladder interaction, there is a calculated toe to-palm angle of 73.4°, 73.5° and 73.9° for the 1st, 50th and 99th percentile male, respectively. However, this angle is not the angle of the ladder side rail that would result when applying this technique to a ladder set up.

Since the rung is in the center of the rail, the actual ladder angle would be 75.1°, 74.9° and 75.2° for the 1st, 50th and 99th percentile male, respectively. These results differ from calculations presented by Young and Wogalter [2000] of 67.6°, but their data did not factor in the ankle-to-toe length. As a reminder the"anthropometric" technique instructs users to place their toes at the end of the ladder rails. Even assuming an anthropometrically improbable male who has only a 1st percentile shoulder height, a 50th percentile ankle-to toe length, and a 99th percentile shoulder-to-palm length, the calculated set-up angle of inclination is 72.0°. Other factors could influence the angle of a ladder placed according to the anthropometric method. These factors include: the position of the rung within the rail (base or fly), footwear, foot placement, hand placement,ground slope, and standing posture. Even with these variables, the present field study demonstrates the effectiveness of the method when followed.

In Summary, people routinely set up non-self supporting ladders at angles significantly less than the recommended 75.5 degree angle. However, our test data shows that when the current ANSI A14 label concerning set up angle is read and followed then this anthropometric technique allows the user to set up the ladder very near the recommended 75.5 degree angle. The anthropometric data further supports this conclusion.

The authors would like to thank the American Ladder Institute (ALI), the ANSI approved developer for ladder safety standards, for use of the label illustrations. The authors would also like to thank Jennifer Kelm and Janet Cruz for their efforts on this project.

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On the Resistance of the Pre-Contracted Elbow Muscles to an Impulsive Elbow Flexion Moment: Gender, Co-Contraction and Joint Angle Effects

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Flexion-buckling of the arm under the large reaction forces associated with arresting a fall to the ground increases the risk for head and thorax injuries. We tested the hypothesis in 12 healthy young adults that neither gender, triceps co-contraction level nor elbow angle would affect the rotational stiffness and damping resistance to impulsive elbow flexion loading. Data on the impulsive response were gathered using standard kinematic and kinetic techniques. A repeated-measures analysis of variance showed that gender, elbow flexion angle and co-contraction level all significantly affected stiffness, but only the latter affected the damping coefficient. We conclude that the maximum rotational stiffness and damping at the elbow is lower in women than in men, and varies with co-contraction level and initial elbow angle.

Introduction

The goal of this paper was to measure the elastic and viscous angular resistance about the elbow provided by the actively precontracted elbow extensor muscles to small elbow angular perturbations that stretched the extensor muscles. We tested the hypotheses that neither gender, level of cocontraction nor initial elbow angle affect the rotational stiffness or damping coefficients of the extensor muscles acting about the elbow in healthy young adults.

Methods

Six healthy young males of mean (SD) age of 24.8 (4.9) years and six healthy young females of 21.3 (2.3) years gave written informed consent to participate in the study. Mean height and weight for the males were 1.73 (0.084) m and 78.3 (19.1) kg, respectively, and for the females were 1.60 (0.071) m and 57.5 (8.7) kg, respectively.

Each subject was seated with the left upper arm attached to a support and the elbow at either 10o or 25o flexion in the horizontal plane. A strain-gaged load cell (1,779 N capacity) was attached to the wrist via a wrist cuff and then connected via aircraft cable to a weight pan weighing 1.4 kgf. A crossbow release mechanism was used to release a cable to drop a weight of 5.2 kgf onto the weight pan in order to cause the impulsive elbow flexion moment via the wrist cuff. Bipolar surface electromyographic (EMG) electrodes, spaced 2 cm apart, were applied to the short head of the biceps brachii and the lateral and long heads of the triceps brachii and integrated EMG collected at 2 kHz. The kinematic response of the forearm was measured at 150 Hz using marker triads and an Optotrak 3020 (Northern Digital, Inc. Waterloo, Canada) optoelectronic camera system. The impact force was measured by the load cell at 2 kHz.

The subject was asked to exert three 5-second 100% maximum voluntary contractions (MVC) in arm extension with the elbow at 25 degrees separated by 2 minutes rest intervals. Subsequent EMG data were normalized these values. Using EMG biofeedback from the lateral triceps brachii on a screen, the subject was asked to contract her arm extensor muscles to 25%, 50%, or 75% MVC value and to maintain this activation level prior to and throughout the impact response. Test instructions were "not to intervene" when the arm was perturbed. Four trials were performed at each of the three muscle co-contraction levels and two initial elbow angles.

Data Analyses

A second-order, planar, rotational spring-damper model was used to approximate the dynamic properties of the elbow joint: $T=I\ddot{\theta}+B(\dot{\theta})+K\theta$, where T is the applied flexion torque, θ is the angular displacement of the limb, I is the calculated moment of inertia of the limb, B is the damping coefficient, and K is the stiffness coefficient. An optimization program was used to determine K and B for the triceps stretch phase only. A repeated measures analysis of variance was used to test for effects of gender, three different muscle co-contraction levels, and two different elbow joint angles on K and B. A p-value of less than 0.05 was considered statistically significant.

Results

Table 1 shows the mean absolute values of elbow stiffness and damping found during each of the six testing conditions (three muscle co-contraction levels and two different elbow angles) for each gender. Increasing the initial flexion angle tends to increase stiffness, but not the damping coefficient, in both male and female subjects. The males had considerably higher stiffness and damping values than the females. A repeated measures ANOVA led us to reject all three hypotheses: gender significantly affected normalized elbow stiffness ($p=0.026$); stiffness increased significantly with the muscle co-contraction level ($p=0.0001$) and with the elbow angle ($p=0.0086$). A significant gender by co-contraction level interaction was observed ($p=0.006$). Damping behavior was significantly altered by gender ($p=0.004$) and co-contraction level ($p<0.0001$), but not by elbow angle.

Discussion

This study provides the first experimental evidence for males exhibiting greater elastic and viscous resistance of the pre-activated elbow extensor musculature than females to impulsive elbow flexion loading. This finding is consistent with the functional result of 12% less elbow deflection in males when they manually arrest an oncoming ballistic pendulum at chest level [DeGoede et al. 2002], suggesting greater elbow extensor stiffness in males than females. These gender differences in upper extremity responses are also consistent with the gender differences in the resistance of the active musculature of the lower extremities to stretch [Granata et al. 2002], even in size-matched young men and women [Wojtys et al. 2003]. The present findings extend those of Lin et al. [2005] who did not find a gender difference in normalized elbow stiffness or damping in subjects with passive muscles.

Limitations include the fact that only modest deflection behavior was studied, for safety. In addition, while the methods lend themselves to testing older adults, such data have yet to be acquired. This is important given the number of older workers in the work force.

Humans pre-contract their triceps muscles to about 74% MVC just prior to ground impact when arresting a fall onto one or more hands [DeGoede and Ashton-Miller 2002]. The ultimate impulsive end-load that can be resisted by an arm without it flexion-buckling will depend upon the initial elbow angle at impact, the rotational stiffness and damping resistance at the elbow and the level of triceps muscle pre-contraction. In addition, the shoulder protraction muscles will also play a role. The present findings underline the importance of maintaining adequate arm extensor muscle strength capacity in order to prevent arm flexion-buckling in a fall. Given the well known decrease in striated muscle strength that occurs with age, this is particularly important for the older male worker, and especially the older female worker. While the importance of lower extremity exercise is well recognized (i.e, walking, cycling, etc) at any age, the importance of maintaining arm extensor strength in order to handle unexpected falls at older ages is not something that is on most employees' or employers' radar. It should be.

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Effects of Lumbar Extensor Fatigue and Surface Inclination on Postural Control During Quiet Stance

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This study determined the effects of surface inclination angle, standing direction, and lumbar extensor fatigue on postural control during quiet upright stance, in a repeated measures study using 18 gender-balanced young participants. Three inclination angles were examined (0°, 18° and 26°), along with three standing directions (sagittal ascending,sagittal descending, and lateral). Postural control was assessed using the mean velocity of center-of-pressure time series. Significant main effects of inclination angle, direction, and fatigue were observed. The adverse effects of standing on inclined surfaces were found to differ between the directions. A dose-response relationship with inclination angle was most evident in the lateral direction, but least evident in the sagittal descending direction. Further, the destabilizing effects of lumbar extensor fatigue on postural control appeared to be independent of inclination angle and direction. These findings may facilitate the development of fall prevention interventions for work involving inclined surfaces.

Introduction

Falls are a major cause of fatal and nonfatal workplace injuries or illnesses and a loss of balance underlies these in many cases [Gauchard et al. 2001; Hsiao and Simeonov 2001; Leamon and Murphy 1995]. Postural control is affected by both internal (e.g., physiological systems) and external (e.g., environment) factors [Horak et al. 1997; Woollacott and Tang 1997]. Localized muscle fatigue (LMF) is one such internal factor, and its adverse effects on postural control have been well documented for multiple locations (e.g., ankle, low back,neck, and shoulder). Inclined work surfaces are example of an external factor, and which is relevant in several occupational settings (e.g., roofing).

Decreased postural stability has been found with increased surface inclination [Simeonov et al. 2003;Simeonov et al. 2009], and the direction of sagittal inclination (ascending vs. descending) was reported to have differential effects on postural control [Mezzarane and Kohn 2007]. The effects of inclination angle and direction, however, have not been comprehensively investigated. Further, given the adverse effects of LMF on postural control, it remains unclear how the effects of inclination angle and direction would vary with the presence of LMF (e.g., lumbar extensor fatigue, as examined here). Thus, the objectives of this study were:

1) to identify whether there are differential effects of inclination angle when standing in three different directions, and 2) to determine whether there are interactive effects of lumbar extensor fatigue and inclination on postural control during quiet standing.

Methods

A convenience sample of 18 participants, gender balanced, was recruited from the University and local community. The age of participants was limited to 18 – 24 years to represent individuals near the typical beginning of working life. Mean (SD) age, stature, and body mass of the participants were 21.4 (1.7) yr, 169.6(10.8) cm, and 68.7 (11.2) kg, respectively. Participants had no self-reported injuries, illnesses, vestibular diseases, or occurrences of falls within the past year, and completed informed consent procedures approved by the Virginia Tech Institutional Review Board.

A full factorial, repeated measures design was employed with three independent variables: 1) inclination Angle[horizontal (0°), 4/12 (18°) and 6/12 (24°)]; 2) inclination Direction (sagittal ascending, descending and lateral);and, 3) Fatigue (pre- vs. post-fatigue). Participants completed three experimental sessions with a minimum of two days between each, and were exposed to one inclination angle in each session. Presentation order of Angle was counterbalanced using Latin squares, and the order of Direction was randomized within each angle. Each session involved pre-fatigue trials of quiet stance (three trials in each direction), warm-up exercises,maximum voluntary isokinetic contraction (MVIC), fatiguing isotonic exercises, and post-fatigue trials of quiet stance (three trials in each direction). The three inclination angles were achieved with plywood platforms placed over a force platform (AMTI OR6-7-1000, Watertown, MA, USA). Sagittal ascending and descending directions required participants to face "uphill" or "downhill", respectively. In the lateral direction, participants stood on the inclined platforms with their dominant foot in the lower position. Muscle fatigue was induced by repetitive isotonic lumbar extensions (12 repetitions/min) at 60% of the highest observed MVIC value. During quiet stance trials, participants stood with their feet together and eyes closed. Triaxial ground reaction forces and moments were sampled at 120 Hz for 70 s. Forces and moments were expressed in the plywood platform coordinate system (i.e., the z axis perpendicular to the platform). Center of pressure (COP) time series were obtained in the antero-posterior (AP) and the medial-lateral (ML) directions, then low-pass filtered(Butterworth, 5 Hz cut-off frequency, 2nd order, bi-directional) and used to derive mean velocity (MV). MV was selected, as it is among the most reliable COP-based measures [Prieto et al. 1996].Three-way repeated measures analysis of variance was performed separately on MV_{AP} and MV_{ML} to determine the effects of inclination angle, inclination direction, and fatigue. Where relevant, post hoc comparisons were conducted using Tukey's HSD. Statistical significance was set at P<0.05, and Summary values are reported as means (SD).

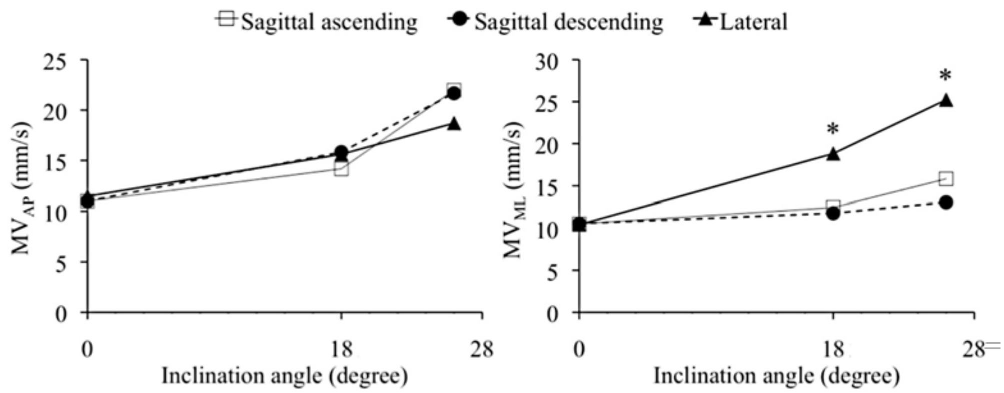

*Figure 1. Interactive effects of Angle and Direction on MV_{AP} and MV_{ML}. Significant differences between directions at the same angle are indicated by *.*

Results

MV_{AP} was significantly affected by Angle and Fatigue (all P<0.0001), as well as the Angle x Direction interaction (P=0.0034). Relative to standing on a horizontal surface (0°), the 18° and the 26° angles caused 36.1% and 86.3% increases in MV_{AP}, respectively. In contrast to linear effects of inclination angle in the lateral direction, the effects of angle in the other two directions were nonlinear (Figure 1). MV_{AP} was larger post-fatigue[17.5 (8.2) mm/s] than pre-fatigue [13.9 (6.4) mm/s].

In the case of MV_{ML}, there were main effects of Angle, Direction, and Fatigue (all P<0.0001). The 18° and the 26° angles caused 35.6% and 71.0% increases in MV_{ML}, respectively, compared to the 0° angle. The post fatigue condition had larger MV_{ML} values [15.4 (6.9) mm/s] than the pre-fatigue condition [13.2 (6.1) mm/s]. A significant Angle x Direction interaction effect (P<0.0001) was found on MV_{ML}, with the effects of Angle being significantly larger when standing in the lateral direction (Figure 1).

Discussion

The objectives of this study were to determine whether the effects of inclination on postural control differ between three standing directions, and also whether the destabilizing effect of lumbar muscle fatigue on postural control is dependent on inclination angle and direction. Inclination angle and direction both appeared to adversely affect postural stability, with effects more evident in the ML direction (Figure 1). These effects,though, did not interact with lumbar muscle fatigue. Larger inclination angles induced higher postural instability, consistent with earlier findings [Simeonov et al. 2003]. Clear differential effects were found between the three directions, with the lateral direction showing the most substantial effects on postural control (Figure 1), and having a larger effect on MVML than MVAP. The latter is consistent with findings in the semi-lateral direction [Simeonov et al. 2009], and is likely a result of an asymmetrical body weight distribution [Genthon and Rougier 2005]. Both of the sagittal inclination directions induced postural instability here, while Mezzarane and Kohn [2007] reported that the sagittal descending (at 14°)led to better postural stability than a horizontal surface, based on spectral amplitudes of COP. Lumbar extensor fatigue increased MVAP and MVML, and this effect was independent of inclination angle and direction. This lack of expected fatigue-related interactive effects may be due to the somewhat low level of induced lumbar extensor fatigue (average MVIC decrease = 25.3%) and an increased reliance onsomatosensory input from the foot and ankle. An enhanced facilitation of somatosensory information has been suggested following lumbar extensor fatigue [Vuillerme and Pinsault, 2007] and during quiet upright stance on an inclined surface [Simeonov et al. 2003]. Here, plantar cutaneous sensation was likely unaltered, and thus could provide sufficiently accurate somatosensory information to assist postural control on an inclined surface.

Several limitations of this work should be acknowledged. First, falling risk or propensity for loss of balance were not directly measured, but postural control was instead evaluated under controlled and quasi-static conditions (standing with feet together). This is not typical in occupational settings or daily life. In addition, our results are not likely generalizable to other populations and other fatigue conditions, since only young healthy participants were recruited and controlled fatiguing procedures were used.

The results of this study, however, do have some practical implications. The differential effect of inclination direction suggests that laterally inclined surfaces induce larger postural instability. There may thus be value in encouraging workers, while working on an inclined surface, to stand in either of the sagittal directions rather than in the lateral direction. Further, localized muscle fatigue potentially compromises postural control independent of surface angle and direction, so fatigue should be minimized or avoided regardless of standing conditions.

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Combating the Risk of Fall From Height: A Holistic Approach

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Among the various types of industrial accident, the fall of person from height continues to be an area of concern over the years as this type of accident is always the source of serious and fatal injuries. The construction industry due to its nature is a hazardous industry which involves a lot of work at height, and construction workers are subject to a much greater risk of fall than those employed in any other industries. To deal with the risk of fall in the construction industry has long been one of the main foci of the Labour Department of the Hong Kong Special Administrative Region Government, which is the occupational safety and health law enforcement agent in the territory. We try to bring about a safer and healthier working environment to the employees by means of a three-pronged approach through law enforcement, education and publicity. We also ally with our strategic partners such other government departments, the Construction Industry Council,the Occupational Safety and Health Council, trade associations, labour unions and building management companies in producing industry guidelines, setting up sponsorship schemes for Small and Medium Enterprises to purchase fall arresting equipment and establishing referral mechanism of hazardous situations, all with a view to remove the risk of fall of person from height in the construction industry.

Introduction

Scaffolding works, the use of truss-out scaffolds for renovation and maintenance works, the use of suspended working platform for construction work at external walls, as well as the use of different forms of ladders and working platforms are examples of work-at-height activities that can be found in almost every construction site. These activities are the common sources of fall of person from height accidents which have a higher chance of causing fatalities among other types of industrial accidents. Preventing falls of person from height is therefore a major area of concern in industrial safety in Hong Kong as in many parts of the world. To control the risk we need a proper regulatory framework, the awareness of those engaged in the construction work and the involvement of the stake-holders.

The regulatory framework

The main pieces of legislation regulating work-at-height safety on construction sites are the Factories and Industrial Undertakings Ordinance ("FIUO"), the Occupational Safety and Health Ordinance ("OSHO"), the Construction Sites (Safety) Regulations ("CSSR") and the Factories and Industrial Undertakings (Suspended Working Platforms) Regulation ("SWPR"). The two Ordinances impose general duties on an employer to protect the safety and health at work of all persons employed by him at the workplace, including the provision and maintenance of safe environment, plants and systems of work. The CSSR and SWPR are subsidiary legislation governing work safety on construction sites and the use of suspended working platforms which are commonly found in construction works.

Under the FIUO, a proprietor of an industrial undertaking has the general duties to ensure the safety at work of all persons employed by him. These include the provision and maintenance of, among others, a safe system of work in relation to work-at-height activities, and the provision of such information, instruction, training and supervision as necessary. An offender is liable to a fine of HK$500,000 and imprisonment for 6 months. Apart from these penalties, there are even more rigorous measures. The Commissioner for Labour is empowered by the OSHO to serve improvement notice or suspension notice on employers or contractors to secure prompt rectification of irregularities or to remove imminent risks of death or serious bodily injury to workers. An employer or a contractor who fails to comply with a requirement of an improvement notice is liable to a fine of HK $200,000 and imprisonment for 12 months. An employer or a contractor who contravenes a suspension notice is liable to a fine of HK$500,000 and imprisonment for 12 months.

The CSSR is the main piece of legislation governing the safety on construction sites. Before 2003, compliance with the Regulations was largely the responsibility of the principal contractor who had a primary function of coordinating all construction activities and site safety matters. In reality, however, there exists a complicated system of sub-contracting in the construction industry, in which sub-contractors may even have more direct control over the work process they carry out on a day-to-day basis. They should have their part to play in safety and therefore in 2003 the amendment to the CSSR was made, which extends the duties imposed on the principal contractor to sub-contractors.

Part VA of the CSSR deals with the risk of fall. Regulations in this part require the principal contractor and subcontractors to safeguard any person working at height against all hazardous conditions, take adequate steps to prevent any person on a construction site from falling from a height of 2 metres or more, and ensure the safety in the design, construction and maintenance of any scaffold, ladder and other means of support. A contractor who contravenes provisions under Part VA of the CSSR is liable to a fine of HK$200,000 and imprisonment for 12 months.

The SWPR governs the safe use of suspended working platforms. Among other things, the owner of a suspended working platform shall ensure its safety in design, construction, maintenance, anchorage and support, as well as test and examination before its use. An owner who contravenes provisions of the SWPR is liable to a fine of HK$200,000 and imprisonment for 12 months.

Enforcement

Under this regulatory framework, officers of the Labour Department ("LD") carry out surprise workplace visits to check compliance with the occupational safety and health legislation. These include regular planned inspections to workplaces and special enforcement campaigns targeting specific hazardous areas such as the work-at-height activities and the use of scaffold. When breaches of law or imminent risks are found, LD officers will take enforcement actions, including the issue of improvement notices or suspension notices where appropriate. In 2008, 47917 construction site inspections were conducted and 765 suspension or improvement notices were issued to contractors. 1140 prosecutions were taken out against them, of which 547 were related to unsafe work-at-height activities. In the same year, 7 special enforcement campaigns targeting work-at height safety had been conducted, resulting in the serving of 349 suspension or improvement notices and the initiation of 350 prosecutions.

Education and publicity

As the fall of person from height accidents have always been a major concern in the construction industry, high priority is therefore attached to this topic in our education and publicity work. This includes a two-year publicity campaign launched in late 2008 homing at work-at-height and renovation, maintenance, addition and alteration ("RMAA") works. The aim of this campaign is to arouse the safety awareness of all parties involved. In particular, we appeal to workers' concern about work safety and associate such with the well-being of their families.

Education and publicity activities are conducted in the form of: (1) safety and health messages, dramas,documentaries broadcasting through television, radio and mobile media, and feature articles in newspapers and on our website; (2) roving exhibitions, banners and posters, mailing promotional items to contractors engaging in work-at-height activities and RMAA works; (3) annual Construction Industry Safety Award Scheme with highlight on the work-at-height safety. Construction sites participate in this Award Scheme will be assessed on their safety performance by a committee and prizes will be given to winning sites as well as individual workers; (4) guides on work-at-height safety and case books based on actual fatal accidents,including those cases related to RMAA and scaffolding works. Common causes of these accidents and their respective preventive measures are included in the case books, which are widely used to promote safety awareness among contractors and workers; (5) safety seminars and talks focusing on work-at-height safety for RMAA contractors engaged by various government departments and public bodies; (6) safety talks targeting bamboo scaffolds with highlights on work-at-height safety and the proper use of personal protective equipment.

The partnering Approach

We partner with the Occupational Safety and Health Council ("OSHC"), District Councils, District Offices and property management companies to organize safety seminars, publicity and promotional activities to promulgate work-at-height and RMAA works safety at the district level for raising the awareness among the property management companies and property owners. As most RMAA works are small in scale and work sites are difficult to discover, we have appealed to the property management companies to report to U.S. risky work at-height activities at properties under their management. A referral mechanism is also established with the Housing Department to refer similar cases to the LD for action.

To encourage small contractors to better protect their workers against the risk of fall by using proper safety equipment, a sponsorship scheme was launched in 2005 in collaboration with the OSHC to subsidize small and medium-sized enterprises ("SME") to purchase T-shape brackets and fall arresting equipment for RMAA works, namely transportable temporary anchor device, safety harness, fall arresting device and independent lifeline. A maximum of HK$4,500 subsidy will be granted to a qualified SME contractor, with a pre-requisite that the subsidized SMEs must send their employees to attend the relevant OSHC safety training courses free-of-charge. More than HK$2.1 million of subsidy had been approved so far.

As the government is one of the major developers in the territory, it has its own duties in monitoring the performance, including the safety aspects of its contractors. There is a mechanism in the Works Branch of Development Bureau, which is responsible for the planning, management and implementation of public sector infrastructure development and works program in Hong Kong, regulating non-performers [Development Bureau 2009]. LD will provide information regarding serious incidents on construction sites and conviction records of site safety offences of contractors on the List of Approved Contractors for Public Works and the List of Approved Supplies of Materials and Specialist Contractors for Public Works to the Works Branch. Based on such information the Panel of Enquiry is conducted from time to time to consider the appropriate regulating actions to be taken against a particular contractor with poor safety records, ranging from the issue of warning letter to mandatory suspension from tendering for public works of a specific category or categories for a certain period of time. The Works Branch also implements the Pay For Safety Scheme ("PFSS") for works contracts and Design and Build contracts with estimated contract sum at HK $20 million or above, and term contracts with estimated expenditure at HK $50 million or above. Normally about 2% of the estimated contract sum / total estimated expenditure will be set aside for safety measures. This sum will only be paid to contractors on successful implementation of the safety measures as spelled out in the contracts. The objective of this scheme is to remove site safety from the realm of competitive tendering [Works Branch 2008].The Housing Authority is another big public sector client which provided and managed about than 694,000 public rental housing flats as at March 2009 [Hong Kong Housing Authority 2009]. It has its own in-house systems to gauge the safety performance of its contractors. Regulatory actions [Housing Authority 2007] similar to those of the Works Branch will be taken against its contractors with poor site safety performance. We also have joint efforts with the Construction Industry Council ("CIC") in drawing up specific guidelines for the construction industry. These guidelines are widely accepted by the industry as they are produced after the consultation with construction companies, trade associations, professional associations and workers' unions. At the moment the guidelines on temporary wall-supported platform inside lift shafts are under preparation. The guidelines will set out measures for reducing the risk of fall due to platform failure.

Safety performance in the construction industry

Over the last ten years, we see a steady improvement in the safety performance of the construction industry interms of both the number of industrial accidents and the accident rate. The number of industrial accidents in the construction industry had been reduced from 14078 in 1999 to 3033 in 2008 (Table 1), representing a drop of more than 78% in 10 years. The corresponding accident rate per 1000 workers had also been reduced from 198.4 to 61.4, a fall of about 69% for the same period. Table 1. Industrial accidents and accident rates in the construction industry

Table 1. Industrial accidents and accident rates in the construction industry

Year	No. of accidents			Employment	Accident rate / 1000 workers
	Non-fatal	Fatal	Total		
1999	14031	47	14078	70941	198.4
2000	11896	29	11925	79599	149.8
2001	9178	28	9206	80302	114.6
2002	6215	24	6239	73223	85.2
2003	4342	25	4367	64112	68.1
2004	3816	17	3833	63520	60.3
2005	3523	25	3548	59266	59.9
2006	3384	16	3400	52865	64.3
2007	3023	19	3042	50185	60.6
2008	3013	20	3033	49422	61.4

SOURCE: Labour Department, Hong Kong Special Administrative Region Government

The fall of person from height accidents in the construction industry follow a similar trend (Table 2). The number had gone down from 1124 in 1999 to 388 in 2008. This meant a 65% reduction in this type of accident.The number of fatalities had been reduced from 24 to 8, equal to a parallel drop of 67%. We also note that the number of fatalities levels between 8 and 9 since 2003, with an intermittent fluctuation in 2005.

Table 2."Fall of person from height" industrial accidents in the construction industry

Year	No. of non-fatal accident	No. of fatal accident	Total
1999	*1100*	*24*	*1124*
2000	*1008*	*13*	*1021*
2001	*762*	*9*	*771*
2002	*637*	*15*	*652*
2003	*494*	*9*	*503*
2004	*439*	*8*	*447*
2005	*409*	*14*	*423*
2006	*396*	*9*	*405*
2007	*351*	*9*	*360*
2008	*380*	*8*	*388*

SOURCE: Labour Department, Hong Kong Special Administrative Region Government

Summary

By taking this holistic approach through vigorous law enforcement, extensive education and publicity programs, RMAA works intelligence reporting channel, fall arresting equipment sponsorship scheme, PFSS, regulating actions by client departments and the production of industry guidelines by CIC, we see improvement in the overall safety performance of the construction industry and reduction in fall of person from height accidents. However, there is no room for complacency. The realm of safety and health is always full of new challenges that require U.S. to explore innovative solutions in response. One of such challenges confronting U.S. now is a new contracting system that degrades the management of safety on site. We need to forge new ways to address this issue.

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Kinematic Response of the NIOSH Developed Safety Rail System in a Laboratory Setting

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Construction-related falls from elevations remain a leading cause of serious injuries, fatalities, and lost time. The National Institute for Occupational Safety and Health, Division of Safety Research developed and patented a roof-pitch adjustable working surface and safety rail system to provide fall protection for residential roofers. Compliance with the existing OSHA regulation that "a force of at least 890 N (200 lbs)" must be supported by the top rail of a guardrail system "in any outward or downward direction at any point along the top edge" was a mandatory target in its development. To comply with the OSHA standard and better understand the system's kinematic characteristics when excited by a worker falling into it, laboratory testing was performed. Laboratory tests were developed to simulate a 91 kg (200lb) worker falling into the system from an adjustable roof pitch surface. To capture the kinematic motion of the system, the PEAK® Motus Motion Measurement System was utilized. Reflective markers were placed on key structural points and the test manikin. The manikin simulated a worker falling in a rotational path pivoting at the worker's knees, and was calibrated to impact the system with a minimum 890N (200lb) force. The manikin was released into the system and the velocity and displacement of the system and manikin were recorded in three dimensions. The safety system performed as designed, thus proving it to be an acceptable form of fall protection for future applications.

Introduction

Many industries engage in work at elevation. In the construction industry it is a daily occurrence, thus a daily hazard. Occupational fall protection is essential to preventing worker related injuries and fatalities. By definition, "occupational fall protection is the backup system [to a worker's reflexes when] a worker … could lose his or her balance at a height; its purpose is to eliminate or control injury potential" [Ellis, 2001]. The National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research, Morgantown, WV conducted research related to falls in residential construction. The project evaluated the effectiveness of existing commercial guardrail edge protection systems to prevent falls through roof and floor holes when used as a perimeter guarding system around a hole in a simulated roof work site.

Fall-related incidents are the primary cause of fatalities in the U.S. construction industry. An analysis of fatality data from the Census of Fatal Occupational Injuries (CFOI), maintained by the Bureau of Labor Statistics (BLS), U.S. Department of Labor (DoL), indicated that in 2007, a total of 1,178 worker fatalities occurred in construction, of which 442 involved falling. Of these 442 cases, a total of 160 involved workers falling from or through a roof, a floor opening, or an existing skylight [BLS, 2007]. These are all situations that could be prevented by implementing a guardrail system near the hazard.

Fall-related Regulations

The current mandatory regulations for the construction industry are contained in the Code of Federal Regulations (CFR), Title 29, Part 1926 (Construction), issued by the Occupational Safety and Health Administration (OSHA). Subpart M includes Sections 1926.500 through 1926.503 and Appendices A through E, and lists the requirements that are related to workplace falls. Section 1926.501 of Subpart M discusses the requirements for fall protection. Subsection 1926.501(b)(4)(i) states that "Each employee on walking/working surfaces shall be protected from falling through holes (including skylights) 6 feet or more (1.8 m) above lower levels, by personal fall arrest systems, covers, or guardrail systems erected around such holes." [Mancomm 2008]. The strength of guardrail systems must also meet OSHA regulation 29 CFR 1926.502(b)(3) which states that "Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge." [Mancomm 2008]. CFR 1926.502(b)(4) states in reference to CFR 1926.502(b)(3) that the "… edge of the guardrail shall not deflect to a height less than 39 inches (1.0 m) above the walking/working level…". In some residential construction activities for work at or over six feet, the OSHA Instruction STD 3-0.1A [OSHA 1999] would be applicable in terms of fall protection.

The use of covers and guardrail systems has been established as effective measures to protect workers from falling through roof and floor holes. Guardrail systems, commercially available and job-built construction, can be used to provide protection for unguarded roof edges, and interior edges during residential and commercial construction or renovation activities.

NIOSH safety rail system fall protection evaluation

Fall protection has a hierarchy, which is listed in the level of importance: 1) Eliminating fall hazards, 2) Preventing fall hazards by guarding, 3) Arresting falls, and 4) Applying administrative techniques [Ellis 2001]. The output of a NIOSH research project was a patented roof bracket and safety rail system with a walking/working surface (U.S. Patent No. 7,509,702). This system can provide fall protection for most of the residential construction situations that expose workers to potential fall-to-lower-level hazards. In order to validate this claim, laboratory testing was conducted in compliance with the OSHA standards. A test procedure and test apparatus were developed. Since the OSHA requirements do not describe the testing procedure, some level of interpretation was necessary. The test designed used a canvas filled manikin attached to a steel support frame. The frame was hinged at the knees of the manikin to simulate a worker falling into the guardrail with a minimum of 890N (200-lb) force [McKenzie et al. 2004; Bobick and McKenzie 2005]. For a sloped roof, it was determined that the worker would fall down slope into the guard rail.

To create the required load of greater than or equal to 890N (200 lbs), the fall distance of the manikin was the control variable. Force data were collected by data acquisition software, along with an A/D board, and a PCB Piezotronics, Inc. 4448N (1000-lb) piezoelectric force transducer. The force transducer was placed in-line between the manikin and an anchor point. The fall distance of the manikin was varied and the resultant force was measured. The drop distance of the manikin was adjusted so the manikin would stop within one inch of the top rail when the desired resultant force (> 890N (200 lbs)) was achieved (Figure 1). The iterative calibration drops approach ensured that the manikin was consistently applying a force of 890N (200 lbs) or more. When three successive

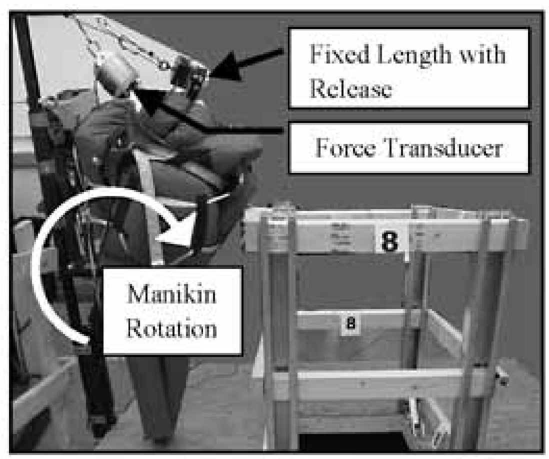

Figure 1 OSHA Drop Test

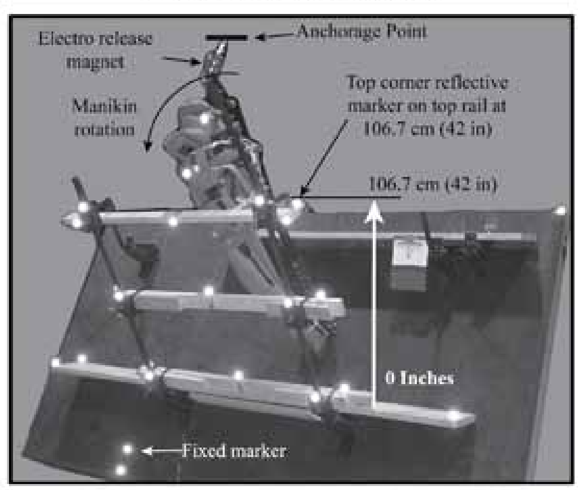

Figure 2 Peak Drop Testing

desired forces were measured, the force transducer was removed and replaced with a fixed length chain to ensure an equal fall distance to the guardrail.

The other aspect of the testing validation was related to the height of the top rail as stated above in CFR 1926.502(b) (4). To validate this requirement a six-camera Motion Analysis System (Peak Motus™, Vicon Corp., Centennial, CO) was utilized to collect the kinematic data of the roof bracket and safety rail system during the testing. A simulated roof surface was constructed in the laboratory, and the roof bracket and safety rail system was installed on it. A set of 23 reflective markers were used to monitor the three-dimensional spatial movement of the roof bracket before, during, and after the manikin drop.

Twenty markers were placed on the key structure points of the roof bracket, including eight on the vertical rails, nine on horizontal rails, and three on the walking working surface. Two additional markers were attached to the roof for reference and one on the head of the manikin. These markers were used with the features of the Peak Motus™ automatic digitization to determine kinematic parameters, including marker displacement, velocity, and acceleration. The 3D marker trajectory data were collected at 60Hz and low pass filtered using a fourth-order Butterworth filter with a 6 Hz cutoff frequency (Figure 2).

Testing Plan

Three different configurations were chosen for testing: 1) a rail with a spacing of 1.22 m (4 ft), 2) a rail with a spacing of 2.44 m (8 ft), and 3) a rail with a spacing of 2.44 m (8 ft), with left and right sides going up the slope. They are shown in Figure 3 below.

Each rail configuration was anchored to the roof structure using three 16d 8.89 cm (3.5 inch) common nails. The load was calibrated three times to deliver the required OSHA load or greater. The manikin was released and the Peak system recorded the deflections, velocities, and accelerations in the x-y-z directions and the resultant values. Four or more repeated drops were completed for each configuration.

Results

- The rail system with 1.22m (4 ft) spacing was subjected to an applied force greater than 983N (221 lbs) and the overall average deflection of the top rail in the z-direction (vertical direction with respect to a fixed marker on the roof structure) was 14.5 cm (5.71 inches).

- The rail system with 2.44m (8 ft) spacing was subjected to a force greater than 1125N (253 lbs) and the overall average z-direction deflection of the top rail was 18 cm (7.09 inches).

- The rail system with 2.44m (8 ft) spacing with side rails was subjected to a force greater than 1112N (250 lbs) and the overall average z-direction deflection of the top rail was 2.59 cm (1.02 inches).

Discussions

The OSHA regulation requires the overall deflection of the top rail to be no more than 7.62 cm (3 inches) with respect to the walking/working level. In all of the cases this regulation was met (max deflection of the top rail was less than 3 inches with respect to the walking/working level). This system absorbed the impact energy of the falling manikin by translating the roof bracket and safety rail system up the roof

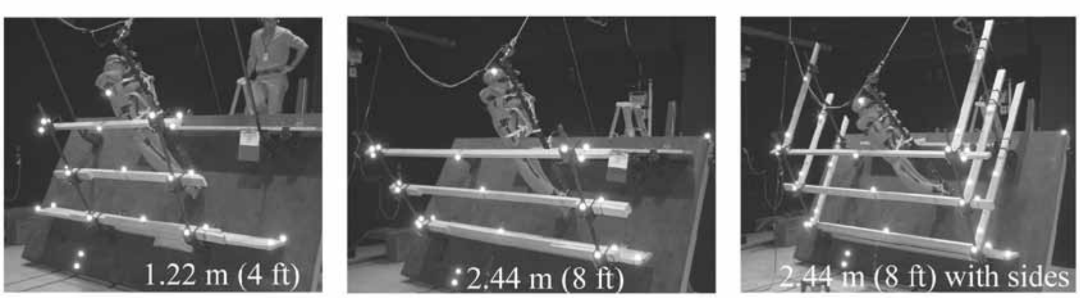

Figure 3 Roof Test Configurations

slope and rotating it away from the roof surface. The distance from the walking/working level during energy absorption stays constant during the test. At the conclusion of the test the walking/working level of the roof bracket and safety rail system was still capable of supporting the weight of a worker greater than 91 kg (200 lbs).

Conclusion

This system complies with the mandatory OSHA standards. It is recommended that if possible this system should incorporate the use of side rails for maximum worker fall protection.

Acknowledgement

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Disclaimer

The findings and conclusions in this report are those of the authors and do not represent the views of NIOSH. Mention of company names does not imply endorsement by NIOSH.

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Study on Fall Protection from Scaffolds by Improved Scaffold Sheeting

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The frequency of fall accidents is one of the most serious problems in construction industries, and the countermeasures for the fall from the scaffolds had been tighten as the guidelines, etc., in Japan. These countermeasures take the particular effect as the decrease of the death accidents by fall from the scaffolds. However, the rate of fatal accidents from falls is still high in the construction industries. In order to examine further countermeasures to reduce such falls, the Japanese Ministry of Health, Labour and Welfare had established a committee in the authors' institute. That committee's work experimentally confirmed the effectiveness of using the scaffold sheeting as a covering around scaffolds to protect against falls of construction materials (a method widely used in Japan). Based on those results, the scaffold sheeting was improved for fall protection, and the effect of the improved sheeting could be confirmed experimentally.

Introduction

Fall accidents are a serious problem in the construction industry in Japan, and approximately 40% of fatal accidents during construction are caused by workers' falls. Therefore, Japan has introduced countermeasures to reduce falls from scaffolds, and strictly enforced these with various safety guidelines. These countermeasures have led to a reduction in the rate of fatal accidents caused by falling from scaffolds. However, the rate of fatal accidents from falls is still high in the construction industry, and possible countermeasures became the main issue of the 11th Labour Accidents Prevention Plan in Japan. In order to examine further countermeasures to reduce such falls, the Japanese Ministry of Health, Labour and Welfare had established a committee in the authors' institute to conduct an investigation of the regulations that exist in overseas countries and to evaluate various construction methods according to present safety guidelines.

From the results and the discussion, it was found that the workers sometimes fell from the space between the hand rail and the work platform. To prevent the fall of the workers from the space, the space have to be made narrow. The scaffold sheeting, which covered around the scaffolds and widely used in Japan, as shown in Photo 1, had a few effects for this purpose according to the experiment by the committee. However, the workers still occasionally fell from the space between the work platform and the scaffold sheeting. One reason is because the space was spread by the workers weight, and the workers fell from the spread space. Therefore, in this study, the scaffold sheeting, of which material was plastic, was improved for fall protection from the spread space, and the effect of the improved plastic sheeting was examined experimentally.

Photo 1. Scaffolds covered with sheeting

Photo 2. Typical prefabricated scaffolds

Improvement of plastic sheeting

Photo 2 shows the typical prefabricated scaffolds used in Japan. It was considered that the plastic sheeting, which envelop the scaffolds, are able to protect the workers from falling, but their effectiveness was not clear. Therefore, their effectiveness was examined experimentally using a human dummy. The human dummy weighed 700 N, the average body size of Japanese males. Table 1 shows the experimental cases.

Table 1. Experimental cases

Case	Posture	Type of scaffold	Photos	Case	Posture	Type of scaffold	Photos
1	Standing	Prefabri cated		7	Sitting and fall to 1 m using slide	Prefabri cated	
2	Crawl on hands and knees	Prefabri cated		8	Sitting and fall to 1 m using slide	Prefabri cated Used sheeting	
3	Sitting and fall from back	Prefabri cated		9	Sitting and fall to 1 m using slide	Pipe	
4	Standing	Pipe		10	Crawl on hands and knees, and fall to 0.2 m using slide	Prefabri cated	
5	Crawl on hands and knees	Pipe		11	Sitting and fall from front	Prefabri cated	
6	Sitting and fall from back	Pipe					

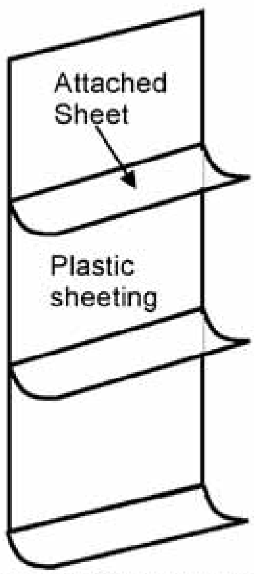

Figure 1. Improved sheeting

Photo 3. Attached sheet sewed with plastic sheeting

These cases were the same as those considered in earlier studies studies [JCOSHA 2003]. An experiment with a used plastic sheeting (Case 8) was carried out to determine the strength of deteriorated sheeting.

In all experimental cases, the human dummy did not fall from the scaffolds, and it was found that the plastic sheeting were effective for fall protection, given a perfectly installed sheeting. However, in some cases, the dummy almost fell from the scaffolds. Then, the space between the plastic sheeting and the work platform was spread widely, and the dummy almost fell from the space.

Thus, in this study, the plastic sheeting was improved for fall protection from the spread space, as shown in Figure 1. The improved sheeting has additional attached sheets, as shown in Photo3, and the attached sheets were sewed with the plastic sheeting near the work platform.

Table 2. Experimental conditions

Case	Fixed by	Fall Height	Fallen object
1	Fiber rope	640 mm	Sand bag
2	Wire(1.0mm)	640 mm	Sand bag
3	Wire(2.3mm)	640 mm	Sand bag
4	Wire(2.3mm)	640 mm	Human dummy
5	Wire(2.3mm)	1000 mm	Human dummy
6	Non	640 mm	Human dummy
7	Twisted pare fiber rope	1000 mm	Human dummy

Experimental Method

Table 2 shows experimental conditions for examining the effect of fall protection by the improved sheeting. The attached sheets were fixed to the work platform by four kinds of materials.

1: Fiber rope

2: Steel wire with a diameter of 1.0 mm

3: Steel wire with a diameter of 2.3 mm

4. Twisted pair fiber rope

The experiments were performed by using a sand bag and a human dummy. The sand bag or human dummy were fallen from the height of 640 mm above the work platform into the spread space by using a slide. In only cases 5 and 7, the human dummy was fallen from the height of 1000 mm for confirming the further safety, as shown in Photo 4.

The weight of the sand bag or human dummy was 735 N, but in only case 7 the weight was 835N. The space between the plastic sheeting and the work platform was set to be160 mm, as shown in Figure 2.

Results of experiment

Table 3 shows the results of experiment. For cases 1-2, the sand bag fell below the work platform. Therefore, the fiber ropes and the steel wire with 1.0 mm diameter were cut by mass of the sand bag. However, the sand bag did not fall below the work platform for case 3, as shown in Photo 5.

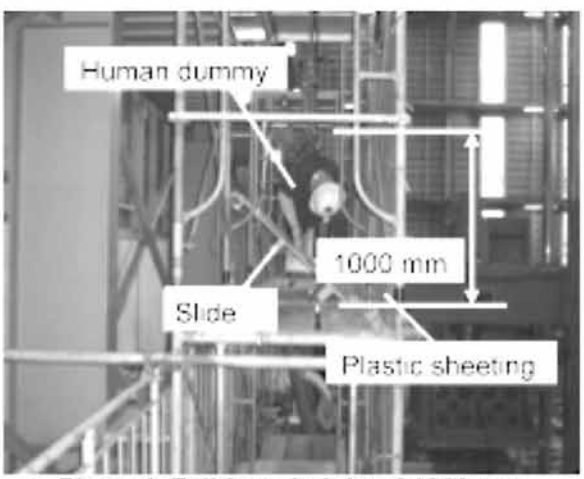

Photo 4. Fall from height of 1000 mm

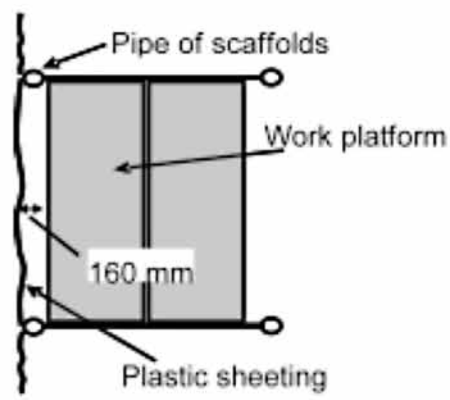

Figure 2. The space of 160 mm

Table 3. Results of experiment

Case	Fixed by	Fall Height	Results(Fell / Not fall)
1	Fiber rope	640 mm	Fell, sand bag
2	Wire(1.0mm)	640 mm	Fell, sand bag
3	Wire(2.3mm)	640 mm	Not fall, sand bag
4	Wire(2.3mm)	640 mm	Not fall, human dummy
5	Wire(2.3mm)	1000 mm	Not fall, human dummy
6	Non	640 mm	Fell, human dummy
7	Twisted pare fiber rope	1000 mm	Not fall, human dummy

Photo 5. Result of case 3

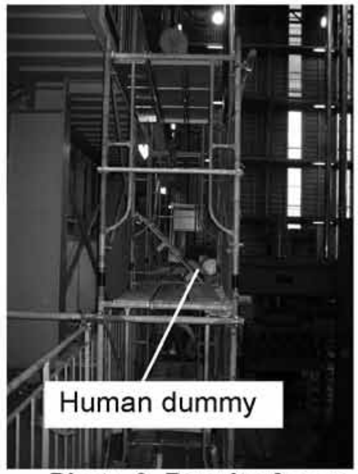

Photo 6. Result of case 5

Photo 7. Result of case 6

From the results of cases 1 and 2, the fiber ropes and the steel wire with 1.0 mm diameter would not be used as the materials for fixing the attached sheets to the work platform. Therefore, the steel wire with 2.3 mm diameter was used as the material for fixing the attached sheets, in cases 4 and 5. Continually, the human dummy was used for the fallen object.

For case 5, the human dummy did not fall below the work platform, even if the fall height was 1000 mm, as shown in Photo 6. However, for case 6 which the attached sheets were not fixed to the plastic sheeting as same as the normal construction condition, the human dummy fell below the work platform, as shown in Photo 7. Therefore, it can be concluded that the improved sheeting was effective for fall protection from the scaffolds when the attached sheets were fixed by the steel wire with at least 2.3 mm diameter.

Case 7 was performed for improving the work efficiency, and the fixing material was changed from steel wires to twisted pair fiber ropes. Then, the weight of the human dummy was increased from 735 N to 833 N for confirming the further safety. In this case, the human dummy also did not fall below the work platform, and the work efficiency could be slightly improved. Consequently, the sheeting has been planned to be improved continuously.

Conclusion

In this study, the scaffold sheeting was improved for fall protection from the scaffolds, and the effect of the improved sheeting was examined experimentally. From the results of the experiments, it can be concluded that the improved sheeting was effective for fall protection from the scaffolds.

Acknowledgment

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Fall Prevention and Protection for Scissor Lifts

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The goal of this multidisciplinary study was to analyze fall prevention and protection strategies and to validate intervention approaches for the workers at risk of fall injury from scissor lifts while performing work at elevation. There were two study components: (1) computer modeling and (2) drop tests. A multibody dynamic model of the scissor lift was developed using ADAMSTM. A lift operator model was incorporated into the scissor lift model using LifeMOD Biomechanics Human Modeler. Drop tests were conducted to evaluate lift stability and health impacts on operators during the drop/arrest. An advanced dynamic anthropomorphic manikin was used for testing. Using the validated scissor lift model, fall protection harness/lanyard deployment forces were simulated and assessed. The experimental results indicated that the scissor lift maintained structural and dynamic stability for all drop test conditions when fully extended. Regarding the health effects on operators, this study found that maximum arrest forces from four collaborative manufacturers' harnesses/lanyards were all within 1800 lbs for a 6-foot drop, which meets the ANSI Z359.1 standard. Further, lanyard deployment forces measured in the lanyard products from four manufacturers were all similar. Findings suggested that fall arrest systems may be beneficial when using scissor lifts as part of the overall risk mitigation plan for fall injury prevention and protection.

Introduction

The fall hazards associated with work on scissor lifts are well recognized within the scaffolding industry [Burkart et al. 2004]. Surveillance data reveals the increasing risk of severe injury and death associated with the adoption of this equipment in construction, telecommunication, and other industries [Pan et al. 2007]. Pan et al.'s [2007] review of these data indicated that extensibility factors—the extended height of the lift or the vertical position of the worker as a result of extension of the lift—were significant contributing factors for fatal injury. These height factors accounted for 72% of the scissor lift cases in the Bureau of Labor Statistics Census of Fatal Occupational Injuries (CFOI) data; 83% of scissor lift cases investigated by the Occupational Safety and Health Administration and the NIOSH Fatality Assessment and Control Evaluation Program involved falls/collapses/tip overs within the height categories of 10–19 feet and 20–29 feet. According to CFOI data, 72% of scissor lift fatalities occurred in the construction industry; in the OSHA and NIOSH investigation data, 74% of scissor lift fatalities occurred in construction. Based on these data, NIOSH developed an aerial lift project focusing on a laboratory study of a commercially available 19-foot electric scissor lift. Since there is no body of scientific knowledge that establishes the efficacy of personal fall protection systems for use on scissor lifts (OSHA depicts scissor lifts as mobile scaffolds), the utility of fall protection equipment on scissor lifts has not been universally accepted by lift safety experts as an effective safety control practice for reducing fall-risk exposure for operators. Results from Pan et al's study [2007] indicated that, for a significant percentage (82% for OSHA and NIOSH investigation data) of fall-from-elevation incidents, safety controls did not protect workers because existing fall protection systems were not in use at the time of the incident. Only 4 out of 13 scissor lift injury/fatality cases from OSHA/FACE reports showed the use of additional personal fall protection systems. Guardrails on the scissor lift platforms are enough to meet the OSHA mobile scaffold requirement (1926.451(g)(4)) for fall injury prevention for scissor lifts, and additional requirements for using personal fall protection systems currently are undecided by industry and standard committees (ANSI A92.6

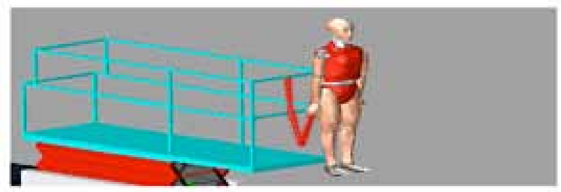
and ANSI A10.29). This represents a serious concern for the lift industry. The objective of this study was to examine the structural and dynamic stability of a scissor lift subjected to fall arrest forces. Second, a dynamic simulation model of the scissor lift was developed to evaluate/predict the effects of scissor lift stability associated with various fall harnesses and lanyards during drop tests.

Methods and Results

A commercially available 19-foot, electric scissor lift (Model SJIIIE 3219, Skyjack Inc., Ontario, Canada) was slightly modified to accommodate the existing laboratory equipment at the NIOSH Morgantown, WV and Pittsburgh, PA facilities. In previous physical experiments, the dynamic effects upon structural flexibility on the static and dynamic stabilities of the lift were analyzed [Ronaghi et al. 2009; Dong et al. 2010].

Computer Modeling: The computer model was generated using a commercial software package, Automated Dynamic Analysis of Mechanical Systems (ADAMSTM 2008r1, MSC Software Corporation, Santa Ana, CA). The model was refined based on experimental data obtained in three standardized ANSI-required dynamic tests—curb impact speed, braking distance and deceleration, and pothole depression. The computer model mass distribution was validated using lift center of gravity measured at four elevated heights [Ronaghi et al. 2009]. The connection stiffness and damping parameters of the model were estimated based on the experimental data obtained individually from a curb impact test, a braking evaluation test, and a depression test of the scissor lift in the NIOSH Pittsburgh Research Laboratory. The model was also validated and refined using the time histories of the lift dynamic responses measured in these physical experiments. The modeling results indicate that decreasing the stiffness of the scissor lift generally reduces both static and dynamic stabilities of the lift. This study showed that lift instability could be achieved by increasing the flexibility of the scissor-lift ground system, which commonly occurs from severe wear and decoupling of structural joints, damage to the joints resulting in decoupling of rigid frame members, and the use of the lift on deformable or uneven surfaces. Simulated operator information was also incorporated into the completed scissor lift model using 2008 LifeMOD Biomechanics Human Modeler (LifeModeler Inc., San Clemente, CA), which is a plug-in to ADAMS. Using this joint human/lift model, simulated fall-protection harness/lanyard deployment forces were assessed (Figure 1).

Figure 1: A refined computer model for simulating a fall protection harness/lanyard application during a drop



test using a manikin

Drop Tests: Tests were conducted under two test conditions—a dead weight drop and a manikin drop. The purpose of the tests was to assess the structural stability of the lift under dynamic loading conditions.

Dead Weight Drop: The basic test conditions consisted of a free-standing and fully elevated scissor lift which was subject to kinetic energy exposure through the release of secured dead weights. The weight was controlled by an electromagnet (capacity 700 lb, Model SE-35352, Magnetic Products Inc., Highland, MI); the release of the weight produced a sudden-load condition, with potential for scissor lift destabilization and tip over. Data on loading conditions was obtained through a load cell (3,000 lb S-type, Interface Inc., Scottsdale, AZ) and logging of data occurred through data acquisition software on a laptop computer. Data acquisition occurred in the LabVIEW software package (National Instruments Corporation, Austin, TX). Previously, test arrest forces were applied to Nystron rope (5/8 inch, Samson Rope Technologies Inc., Ferndale, WA, and Gravitec Systems Inc., Bainbridge Island, WA) and the scissor lift to evaluate structural and dynamic stability. Stability was evaluated for the two orthogonal and major tilt axes in the horizontal plane of the scissor lift. Test conditions were designed to reflect common exposure scenarios in "real world" operation, so test conditions were conducted on sloping ground. A well-accepted fall arrest equation [Sulowski 1981] was used to estimate the pre-drop weight and free-fall height requirements necessary to generate the desired arrest forces for this study component [Harris, et al. in press]. Fall arrest loads of approximately 2,400 lbs—an amount which was chosen as a conservative measure as it exceeded the ANSI Z359.1 requirement (i.e., 1,800 lb)—were applied to various anchorage point locations in the platform. In addition, potential fall scenarios were evaluated by conducting 6-ft and 11-ft drops. Eleven-ft drops were chosen for test conditions due to common misuse scenarios that occur when lift operators position their feet on the mid rails. A 95th percentile male (by height) was assumed as a test subject; the dead weight was positioned at a height equivalent to standing on the mid rail with the fall arrest system anchored to either the mid rail or top rail. It was assumed that lanyard-harness connection of the fall arrest system was at chest (nipple) height, 53.7 inches under the MILSPEC standard [DoD 1989]. Total fall height was 139 inches when anchored to the mid rail and 122 inches when anchored to the top rail. The results indicated that the scissor lift maintained structural and dynamic stability for all drop tests when fully extended and on an incline; energy absorption by the lift structure itself lessened the transmission of energy to the platform [Harris et al., in press].

Manikin Drop

The basic conditions for this test were similar to those in the dead-weight drop tests; a manikin was used instead of dead weights for this component, and anchorage conditions did not consist of multiple locations. A single anchorage (see Figure 1) was used, and fall location occurred only from the front of the platform, instead of various locations. An advanced dynamic anthropomorphic manikin (1998 ADAMTM, Veridian, Dayton, OH) was used as the surrogate. Embedded triaxial accelerometers within the manikin measured acceleration on three axes, and acceleration measures were used as surrogates for force measurements. Test conditions included the energy-absorption effects of four energy-absorbing lanyards (EAL), secured at a common position in the platform, together with their safety harnesses. Fall-arrest forces were logged by a load cell (Model SSM-S, Series 1000, Interface Inc., Scottsdale, AZ). Data was recorded as stated in the preceding section describing dead weight tests. The manikin was dropped three times from each of the two heights, 6 ft and 11 ft. Data analysis is underway; this will involve a systematic approach in which an additive model of the energy dissipated in the EAL and in the human body during the fall impact will be developed. The kinematics of the human body and EAL during the impact was derived using the data of the time histories of the arrest force, which was measured experimentally. Results from the computer simulation model indicate that reducing the stiffness (and stiffness ratio) of the scissor lift significantly reduces both static and dynamic stabilities of the lift. The four preliminary results of the manikin drops are listed below:

a. Lanyard deployment forces among four manufacturers were all similar (~800 lbs).

b. Maximum arrest forces in all but one case were under 1,800 lbs (6-ft and 11-ft drops).

c. Deployment forces were nearly constant for different drop distances (6-ft and 11-ft drops).

d. Repeated test trials for the same harnesses/lanyards produced similar results.

Discussion

Findings indicated that fall arrest systems may be beneficial when used in scissor lifts as part of the overall risk mitigation plan for fall injury prevention and protection. This study also identified that guardrails may serve as anchorage points without increasing the risk of scissor lift tip-over hazards. However, some drops produced deformation of guardrails. In addition, a refined scissor lift computer simulation model of this study may provide an efficient tool to predict and evaluate structural and dynamic stability of the scissor lift. Since all the measures of the maximum arrest forces were less than 1,800 lbs, this study suggested that all four collaborative manufacturers' harnesses/lanyards met the ANSI Z359.1 standard requirement. This study also identified that the arrest force calculated using the kinematic data agree well with those measured directly via a force sensor during the drop tests, and the accelerations calculated using the force data agree well with those measured directly from the ADAM manikin. These analyses indicated that the kinematics of the falling surrogate can be determined using measured arrest force, and vice versa. The arrest force in the EAL can also be determined using the accelerations measured at the surrogate. An ongoing study component will explore this important finding and further examine its implications to evaluate performance and select appropriate fall protection systems for this workforce on the basis of the impact energy absorption.

Acknowledgement and Disclaimer

We would like to acknowledge the contributions of SkyJack Inc., which provided the study with the use of a new scissor-lift and other critical technical and design data. We would like to extend our appreciation for the contributions of the following companies: DBI/SALA, Elk River, Inc., MSA, SafeWaze, who generously provided the study with the use of new harnesses/lanyards. We acknowledge the International Safety Equipment Association to provide constructive comments at various stages of this study. The authors also want to express our gratitude to Randall Wingfield and Gravitec Inc., who generously provided constructive comments of the drop tests. The findings and conclusions presented herein are those of the author and do not necessarily represent the views of NIOSH. Mention of any products does not constitute the endorsement of NIOSH.

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Appropriate Dimensions to Prevent the Accident on the Stair

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Fall accidents could occur in the workplace as well as daily life, and it is very well known that the stair is one of the main causes. As a basis research on preventing the fall accidents, this study was designed to analyze the causes of the fall accidents on the stair and to modify the stair standards related to such accidents.

Through the experiments for 10 subjects(5 male and 5 female), the clearance between nose of the stair and heel or nose of the stair and toe was measured and analyzed. It showed that going of the stair should be larger than the foot size(260~270mm) of the walker to prevent the fall accidents and there is some consideration in the provisions of ISO 14122-3 for the stair.

Introduction

Though the possibility of fall accidents on stairs are commonly experienced in workplaces, as well as in daily life, the causes cannot be easily found. Historically, studies regarding stairs began in the era of the Roman Empire (100 B.C.) from an technical architecture book by Vitruvius, which states, "A building should be designed so as to let the right foot step on the first stair of which adequate height should be 22.5cm-25cm, and the going should be 45cm-60cm." Since the 19th century, numerous studies have been conducted in each country in the field of architecture. Recently, characterization of human walking on stairs is actively conducted.

In this study, for safety on stairs, the dominant physical factors of fall accidents, such as minimum toe clearance and minimum heel clearance, were measured and the change was analyzed to see the effects of step gradient, step height, and safety design factors.

Method

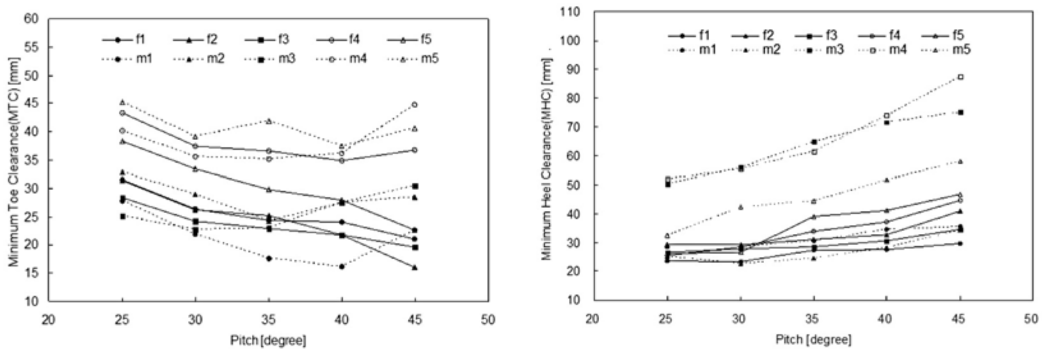
Five adult males and five adult females were selected for a walking experiment on bumps and stairs. With respect to the ethical standards of the Helsinki Declaration, the participants were given an overall explanation about the experiment, as well as the related risks and ethical matters, and they gave consent in written documentation. For the walking analysis, markers were attached to specific body parts, and the motion capture system was established to trace the location of the markers. The equipment used in the experiment was an OPTOTRAK CERTU.S. model of NDI. The signal analysis was performed by using a Visual3D of C-motion and 3-D motion analysis software.

Stairs of which the gradient is freely controllable in the range of 25 - 70° as well as the step height in the range of 5 - 40 cm was prepared for the experiment with stairs.

Results

To assess the risk of fall depending on the gradient, height and going of the stairs, minimum toe clearance (MTC), and minimum heel clearance (MHC) were calculated based on the measurements of the 3-D trajectory of the tiptoe and the heel, as well as the relative distance to the stair nosing when the participants were walking up and down the stairs.

The results showed that MTC decreases as the gradient increases when walking up the stairs, while MHC decreases as the gradient increases when walking down the stairs.



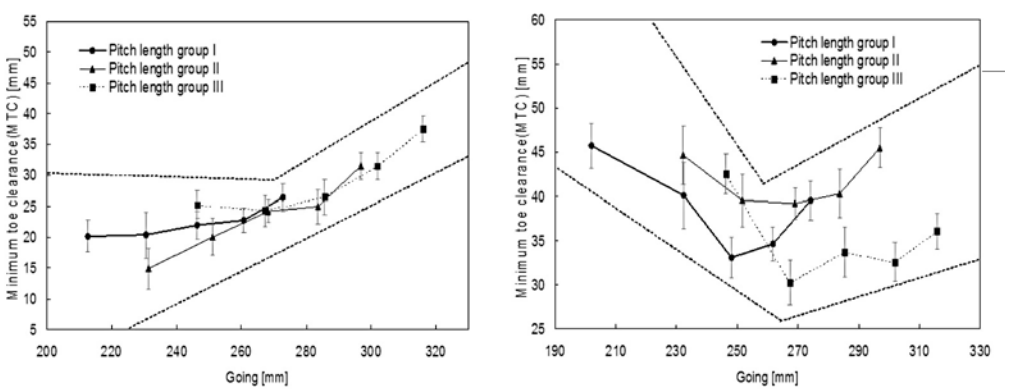
(a) Walking up (b) Walking down

Figure 1. Change of MTC and MHC depending on the gradient of the stairs during walking

Walking Up

Figure 1 (a) The MTC of the female participants (f1-f5), the dotted line, increases as the gradient increases, while that of the male participants (m1-m5) decreases from 35 to 40 degrees but it increases from 40 to 45 degrees. The deviation among the participants was about 15mm-45mm, showing a difference depending on their walking habits and physical specifications. The tendency of higher MTC at high gradients over 40 degrees is assumed to be the result of an intentional motion to climb up the high step, but the exact cause cannot be found in the results of this study. However, the overall tendency in all gradients show that MTC decreases as the gradient increases, which indicates a higher risk of accidents when viewed from the probability of falling.

To discuss the cause of MTC change, the characteristics of the participants were analyzed depending not only on the step gradient, but also on the step height and going. Figure 2 represents the change of MTC depending on the going, dividing the participants into three groups with different pitch lines, and showing the mean value and 0.5*standard deviation.

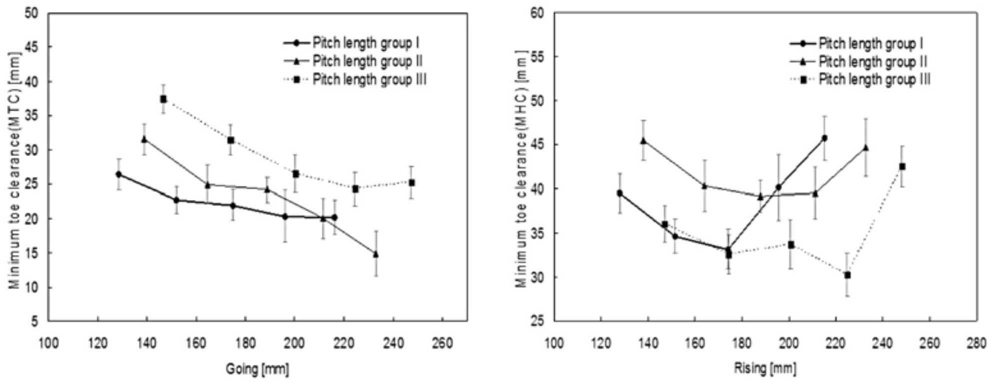


(a) female (b) male

Figure 2. MTC depending on the step going during walking up

Figure 2 (a) shows that MTC linearly increases as the going increases. One notable thing is that while the deviation increases and the linearity is maintained in the range of 260-270mm, regardless of the step gradient, the pitch line length, and the step height, though MTC, continuously decreases. This means that the going and the foot size of the participants are correlated, and, if the going is not sufficiently wide, normal walking is difficult and the probability of falling in contact with the nosing increases.

Figure 2 (b) also has the interval where the tendency is converted, and the interval is between 260-270mm, just as in figure 2 (a). However, in the range under 260mm, there is a transient interval where MTC increases, in addition to the increase in the deviation, which is assumed to be the result of the intentional motion of the participants, that is, keeping MTC higher as they recognize the risk, as previously mentioned.



(a) female (b) male

Figure 3 MTC depending on the step height during walking up

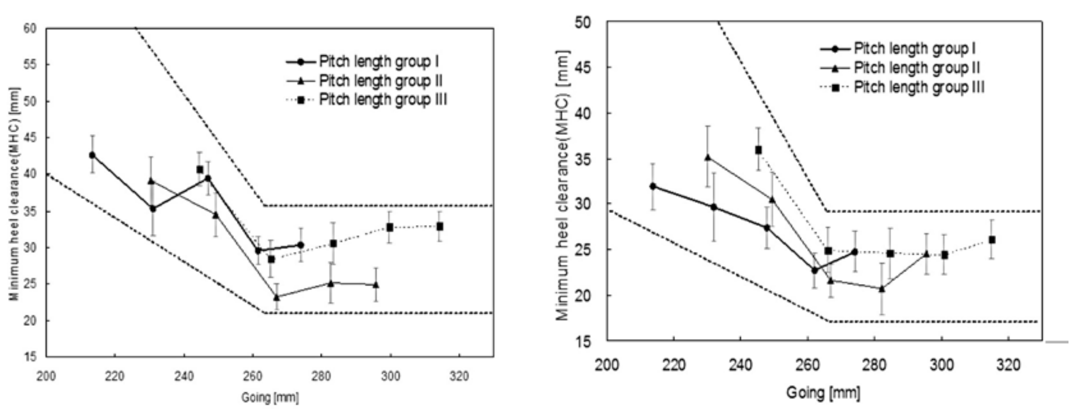
Figure 3 shows the change of MTC depending on the step height. Different from the result dependent on the step going, MTC decreases as the step height increases, while the tendency alters from reducing to increasing again in figure 3 (b). However, it is baseless that the step height is considered as the major factor influencing MTC change; rather, the tendency can be regarded as the result of the decreasing step going with the increasing step height in the data groups (I, II, III) with the same pitch line length.

Walking Down

When walking down stairs, the point where the distance from the step nosing is the least is the heel. Thus, minimum heel clearance (MHC) was measured under each test condition to analyze the characteristics of walking when the participants were walking down stairs. As shown in figure 1 (b), for all the participants, MHC decreases as the step gradient increases. It cannot be reasonably concluded that the risk of an accident on stairs increases simply because MHC increases, as based on the conventional research, which reveals that approximately 80% of the accidents on stairs occur when walking down.

Figure 4 shows that the mean value and 0.5 standard deviation of MHC change depending on the step going for the groups of the same pitch line length.

As in the case of walking up stairs, there is variation among the participants depending on the individual walking characteristics, but there is a transient interval in between 260mm and 270mm of the step going. However, while the rate of MHC change is low in the range over 270mm, MHC abruptly increases in the range less than 260mm and the deviation of the data also increases. Although the direction of data tendency is the opposite from that of the



a) female (b) male

Figure 4 MHC depending on the step going during walking down walking up experiment, the transient interval is the same. The interval in between 260mm to 270mm is also associated with the size of the participants' feet.

In other words, the increase of MHC depending on the increase of the step gradient reduces the trip risk, but MHC increases, if the ground contact area is insufficient due to the narrow going on the steps with the same pitch, depending on the walking characteristics of the pedestrians. As can be deduced from the increase of data deviation, the trip risk increases when moving from the nosing of the step and making contact with the next step, and the risk of losing balance also increases as the tiptoe moves out from the step surface and slips on the step.

Therefore, sufficient step going should be secured in order to reduce the potential risk of accidents when walking up and down stairs.

Conclusion

In this study, for safety on stairs, the dominant physical factors of fall accidents, such as minimum toe clearance and minimum heel clearance, were measured and the change was analyzed to see the effects of step gradient, step height, and going on safety design factors.

1. The analysis of the relations among the step gradient, going, and height when walking up shows that MTC decreases as the step gradient increases. In the going range between 260-270mm, MTC maintains the decreasing tendency, while the deviation increases and the linearity changes.

2. When walking down, MHC increases. Although deviation was found among the participants depending on their walking habits, there was the transient step going interval in between 260-270mm, regardless of the step gradient. While the rate of MHC change is low in the range over 270mm, MHC abruptly increases in the range less than 260mm, and the deviation of the data also increases.

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Hazard Associated with Construction Sites in India and Various Techniques for Preventing Accidents due to Fall from Height

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In India construction is the most dangerous sector showing the maximum accidents. It is very difficult to regulate the employment in construction industry which plays a vital role in causation of accidents. The accident rate in construction is four to five times higher than that of the manufacturing sector on the global scale. The prevalent unsafe acts and unsafe working conditions in construction workers include falling from height, slips, trips and falls on stairways and ladders, breakage of handrail and stair rail system and scaffold, fall due to energized electrical equipment at height. Other related injuries that are particularly common include violence and aggression as well as more common Break-down of lifting machinery, manual handling injuries, back injury due to unsafe lifting of article, injury caused by falling object etc. Most of the time the hazards are known but it becomes very difficult to control the hazards due to constantly changing work environment. The Government wants to establish the safe work culture at construction sites in India and has introduced The Building and other Construction Workers welfare (Regulation of Employment and Conditions of service) Act, 1996 1996, [Government of Puducherry Labour Department 1996] to enforce the provisions of the statutory requirements in construction site.

Introduction

The construction industry, which is labour intensive, generates demand for unskilled, semi-skilled and skilled labour force. Working group of planning commission of India for the eleventh plan estimated the growth in demand for employment by 8-9% per annum. This work force shall comprise 55 % of unskilled labour, 27 % of skilled labour and rest the technical and support staff and the employment in construction sector in India was 40 Million by the year 2007.

Though India has the human resource, it requires training in various skills for absorption in the construction industry. The work force in construction sector is most vulnerable because employment is permanently temporary, the employer and employee relationship is very fragile and most of the time short-lived, the work has inherent risk to life and limb due to lack of safety, health and welfare facilities, coupled with uncertain working hours. Construction labour form 7.5% of the world labour and contributes to 16.4% of total fatal global occupational accidents. In India it is the largest economic activity after agriculture and mostly the workers employed at construction sites come from poor family background.

Health and Safety is the most neglected area in this sector and accident and occupational disease statistics are not accurately available. Falls are the leading cause of worker's death in construction, and have been for many years. The working conditions and facilities provided at the sites are far from satisfactory. In many cases the employers compelled the workers to complete the projects in hurry asked them to work in night with a dim light and very often it leads to accident. The latest injury statistics show that 40% of all workers' death in construction are caused by a fall from height. Long working hour without proper rest coupled with lack of nutritional diet due to low income results in poor health of the construction workers. The workers especially women carry heavy load on back and head which would responsible for muscular and skeletal problem in the old age.

Research Methodology

The purpose of this research was to examine the causes of construction fall accidents and to identify any trends related to fall accidents. The statutory agencies of different provinces took initiative to investigate the work related accidents of construction sites in India. Government over the years also has noticed the challenges faced by the construction workers and in the year 1996 enacted the Building and other Construction Workers (Regulation of Employment and Conditions of Service) Act, 1996. To provide basic welfare and social security to the construction workers, the Building & Other Construction Workers Welfare Cess Act, 1996 was also enacted. Several accidents due to fall from height and accidents due to falling objects were investigated keeping in view of the said Act and root causes of the accidents were established.

The practical remedial measures were suggested for effective implementation to prevent re-occurrence of such accidents. Accidents statistics of different parts of India were taken into consideration and accidents pattern due to fall from height and falling objects were closely monitored. The most general type of falls involving buildings was found to be "falls from roof". Falls from roof can be from "unprotected" walking surface, that is, no guard rail or no parapet wall of proper height. This is quite common, and can be easily avoided.

A contributing factor in one-third of the fall accidents was the working surface. The accidents included typical situations where workers slipped on sloped roofs and fell to the ground, workers fell through floor openings, and workers slipped on the walking surface of scaffolds and fell. Inadequate fall preventive equipment in buildings/structures, and/or failure of buildings/structures also caused some workers to fall. It was also observed while investigating and analyzing the falls that the active and passive measures which were supposed to be taken were not taken into use. Though in most of the places the scaffolds provided for working at height were of sound construction but guard rail and toe boards were found missing at the sites. This situation further worsens when the job is entrusted to a petty contractor. In an effort of speedy completion of job and taking maximum profit out of it, it is very likely to compromise with the safety norms/standards. In many cases safety net system was not found provided at the scaffolds leading to injuries and even deaths.

The workers were thoroughly examined and interviewed to know about their problems faced by them while at work. Since most of workers engaged in construction sites were poor and illiterate, little they knew about safe practices, do's and don'ts and their rights. The long working hours, their will to earn more and thereby working at overtime further aggravated the problem. Some of them were found overconfident and shown casual attitude when the dangers associated with the falls from height were communicated.

The table 1 given below is only the illustrative example of the accidents occurred at construction sites in different parts of India:

Table 1

City/ State	Month and year	Death/ injuries	How it happened	Cause
Goa	25 Nov. 2009	2/3	crushing underneath the debris (TOI 25 Nov 2005)	Weakening of wall
Channai	4-Dec-09	2/-	Fall from 11th floor of under construction IT park building (TOI 6 Dec 2009)	Iron sheet fell on them followed by snapping of safety belts
Delhi	22-Jul-09	1/-	Hit by steel beam while being lifted by a crane at Delhi Metro construction site (TOI 22 July 2009)	Guiding the movement of beam from unsafe place

Delhi	25-Dec-05	3-Nov	Loose earth and Soil dug up at an area of 600 sq m for constructing mall came down (TOI 25 Dec 2005)	No shoring
Pune	27-May-04	2-Jan	Fall from sixth floor of residential construction site (TOI 27 May 2004)	No safety belt
Delhi	12-Jul-09	15-Jun	under-construction Metro viaduct collapsed along with a portion of the girder launcher (TOI 13 July 2009)	Crack in pillar due to design fault
Gurgaon	17-May-08	17/20	Wall of a under construction warehouse collapsed (TOI, IMD 19 May 2008)	Shoddy material of construction, Gusty wind and rainfall
Delhi	21-Jan-10	2/-	M.S. pipes being lifted by tower crane fell down on scaffolding causing it to break (Police report, 21 Jan 2010)	Improper lifting of material and unsafe working condition
Delhi	13-Jan-10	1/-	Wall of a under construction hotel collapsed (Police report, 13 Jan 2010)	Municipal water seeped into earth
Delhi	31-Jan-10	1/-	M.S. plate being lifted by hydra crane fell down (Police report, 31 Jan 2010)	Improper lifting and unsafe working condition

Preventive Measures

These falls can be effectively prevented by the use of the appropriate fall preventive equipment. The fall prevention cannot be attributed to any single method that would prevent all falls due to heights. Personal fall arrest system (PFAS) was found to be very effective to stop such falls. It was also noticed during investigations that the active measures such as guard rails and toe board are very good protection system and it was also concluded that combination of active and passive measures contributed towards reducing fall injuries. Sometimes it was also seen that even guardrails, safety nets, and PFAS also become inadequate in peculiar situation. Other methods include the elimination or substitution of the operations and situations which can lead to falls, the use of engineering controls to guard against falls, informing/reminding workers to avoid fall hazards (through warnings and administrative controls such as training and inspections), and the appropriate use of personal protective equipment (PPE). Compilation of the number of work-related fatal injuries, determined the means of death, and gathered additional information for each fatality.

It's a common fact that workers coming together in a large construction project have different levels of experience and training. The key persons for preventing accidents are the supervisors. By getting the supervisors to put their work steps and procedures in writing, responsible persons can use this method to reduce incidents of workers taking shortcuts in safety. It was noted that the most common work tasks included roofing, erecting structural steel and exterior carpentry. Most of the tasks were conducted at elevation or on temporary structures, where fall hazards are often present. Implementation of innovative engineering measures to strengthen the safety requirements at design stages to achieve safe working environment during construction.

Results

Falls are the most frequent accidents that occur on construction sites. Results show that fall accidents in the construction industry are the cause of many serious injuries and fatalities. At the same time, the data analysis shows that falls have certain properties, which may help to devise preventive approaches. It was also noticed that many time the material fell onto the worker causing injuries and deaths.

It is evident that many fall hazards go unnoticed or that efforts to prevent falls are not effectively implemented. Fall hazards on sites should be identified through rigorous inspections and auditing of construction sites and eliminated through effective preventive approaches. The sensible use of information gathered from previous accidents can disclose the most common hazards on construction sites. Situations and work practices particularly susceptible to falls include roofing, erecting structural steel and exterior carpentry. Falls are often associated with workers on roofs, scaffolds, ladders, and on floors with openings. Falling material was also responsible for various injuries and deaths and the most common was the collapsing of under construction wall.

Providing fall preventive equipment to workers, including full-body harnesses, safety belts along with the proper training, can reduce the number of falls to a great extent. The lack of safety training is often the root cause for many falls. According to the analysis, misjudgment and sometimes overconfidence of workers may account for so many construction worker falls. Fall prevention training can be effective in addressing numerous causes of accidents. Addressing worker's safety at design stage of a construction site will reduce the occurrence of fall at implementation stage.

Conclusions and Recommendations

Short term training courses on safety for unskilled workers should be organized by construction companies. The government should play a more concerted role in ensuring a high standard of safety by enforcing provisions of law on construction safety. Temporary accommodation with proper sanitary facilities at the site itself must be made for workers staying at the construction site so that they can live their life without stress. Workers should be made aware of the need to use personal protective equipment. Constant review and up gradation of the statutory legislations, safety standards, organizational policies, training programmes are essential for successful safety and health management system. The workers should be imparted practical demonstration of active and passive measures being undertaken at construction sites. Strict supervision, regular monitoring and safety audit of construction site can drastically bring down the number of accidents involving falls from height.

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The Influence of Heavy Truck Egress Tactics on Ground Reaction Force

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Slips and falls during cab egress are an important cause of injuries to truck drivers. Previous work has shown that the egress tactics may influence risk. Inward-facing tactics (driver faces the truck) are universally recommended, but biomechanical evidence supporting this recommendation is sparse. As part of a laboratory study of truck driver ingress and egress behavior, the ground reaction forces during first contact with the ground on egress were recorded for both inward and outward facing egress tactics using either interior or exterior hand holds and four step configurations. Twenty-five male and five female truck drivers with a wide range of body size participated. Peak vertical ground reaction force (PVGRF) averaged 1.44 times body weight for the inward-facing tactic and 1.85 times body weight for the outward-facing tactic. Handle position (interior vs. exterior) and step configuration did not affect PVGRF. Drivers with high body mass index choose inward-facing tactics more frequently than other drivers. The average 28-percent increase in peak ground reaction force with the outward-facing tactic may indicate an increased risk of both cumulative and acute injury.

Introduction

Truck drivers are frequently injured entering and exiting tractor-trailer cabs. Lin and Cohen [1997] studied data from injury reports obtained from U.S. trucking companies. Of the slip-and-fall injuries reported, approximately 25% occurred while workers were mounting, dismounting, entering, or exiting vehicles. Egress injuries were three times more common than ingress injuries. Jones and Switzer-McIntyre [2003] identified 352 cases of falls from non-moving vehicles as part of a workplace safety study in Ontario. In 24% of these cases the driver slipped or fell from a step on the truck.

Drivers are routinely trained to enter and exit the truck facing inward, toward the cab, but drivers often exit facing away. In a study of firefighters exiting a truck, ground reaction forces were significantly higher when facing away from the vehicle than when facing the vehicle [Giguere and Marchand 2005]. Using a sample of 10 men, researchers at Liberty Mutual Research Center demonstrated that truck egress tactics affected ground reaction forces, with vertical forces up to 12 times body weight observed for men jumping down from a high cab-over-engine truck [Cotnam and Fatallah 1998; Fathallah and Cotnam 2000].

As part of a broader effort to develop improved design guidelines and assessment tools for truck ingress and egress, a laboratory study was conducted with experienced drivers. This paper presents an analysis of the influence of step configuration, hand hold position, tactic, and driver characteristics on ground reaction force.

Methods

Mockup

A reconfigurable laboratory mock up was constructed to represent the critical features of the ingress/egress system of a conventional tractor cab (Figure 1). A force platform was located in the floor adjacent to the mock up as well as on the adjustable steps and hand holds. The force platform on the ground and the surrounding platform area were covered with a concrete tile material (Hardiboard) with a coefficient of friction similar to concrete pavement. The hand hold at the rear of the door opening was either within the door opening (internal) or outside and rearward of the door opening (external). The internal rear handle was presented with an internal front handle at approximately the same height.

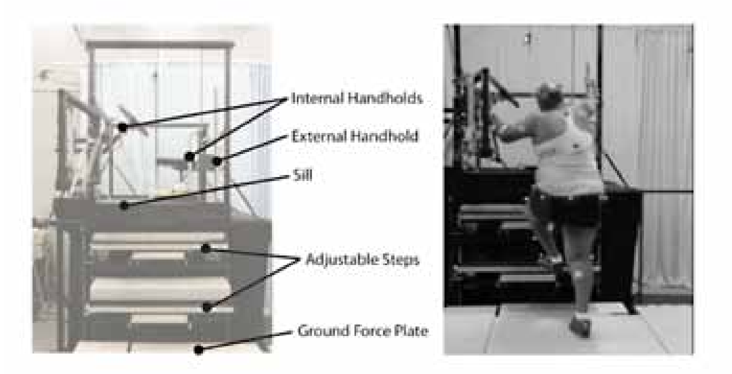

Figure 1. Laboratory mock up, showing handles, adjustable steps, and ground force plate

Subjects

Testing was conducted with 25 male and 5 female truck drivers, all licensed to drive tractor-trailers in Michigan. The drivers' statures ranged from 1554 to 1902 mm (median 1763 mm) and body weight from 69 to 179 kg (median 90 kg). Body mass index (BMI), calculated as body weight in kg divided by stature in meters squared, ranged from 22 to 50, with a median of 30 kg/m2. Drivers ranged in age from 22 to 65 years (median 50 years), and had between one and fifty years of driving experience (median 12 years).

Test Conditions and Procedures

Participants were tested with four step configurations selected to span a substantial percentage of the U.S. truck fleet with respect to the lateral step placement. Each step configuration was tested with internal hand holds and with external hand holds (see Figure 1). The hand holds on the door were always available.

In the first trial in each condition, no instructions as to tactic were given, and the tactics chosen by the drivers (inward or outward facing) were recorded for each egress event. Following undirected trials in all conditions, each test condition was repeated, except that on egress the driver was directed to use the alternative tactic. For example, a driver who chose to exit facing outward in a particular condition was instructed to face inward for the corresponding directed trials.

Data and Analysis

Ground reaction forces were recorded at 3 kHz and low-pass hardware-filtered at 100 Hz, then down sampled to 100 Hz for analysis. The highest peak vertical force was generally observed immediately following the initial foot contact with the force plate. The forces at the maximum vertical peak were extracted for analysis. Data from 28 trials were excluded because the participant's foot partially missed the force platform. The vertical reaction force was normalized by dividing by body weight. The required coefficient of friction was calculated by dividing the resultant horizontal force by the vertical force.

Analysis of variance (ANOVA) was conducted to assess the effects of step configuration, hand hold placement, tactic, and tactic instruction (directed vs. undirected). The effects of stature and BMI were also investigated. Statistical analyses were conducted in the software package R (www.r-project.org).

Results

Table 1 shows the selection of inward/outward tactic for undirected trials by BMI category. Drivers with high BMI were significantly more likely to choose inward-facing egress tactics (2(1) = 13.6, $p < 0.001$). Tactic selection was not significantly affected by step or hand hold configurations.

Table 1. Egress tactic selection in undirected trials

Number of Trials	Body Mass Index (kg/m2)	
	< 30	≥ 30
Inward Facing	56	92
Outward Facing	57	33

Figure 2 shows peak vertical ground reaction force (PVGRF) across conditions. PVGRF was significantly affected (p<0.001) by egress tactic, investigator direction, and BMI. ANOVA showed a significant three-way interaction (p<0.001) among these variables, which is made apparent by the box plots in Figure 3. The overall mean PVGRF was 1.64 times body weight (BW) with a large scatter across trials. The mean was higher for directed than for undirected trials, 1.76 BW vs. 1.53 BW. PVGRF was higher for outward-facing than for inward-facing egress, but the magnitude of the increase differed across BMI groups and whether the trial tactic was directed or undirected.

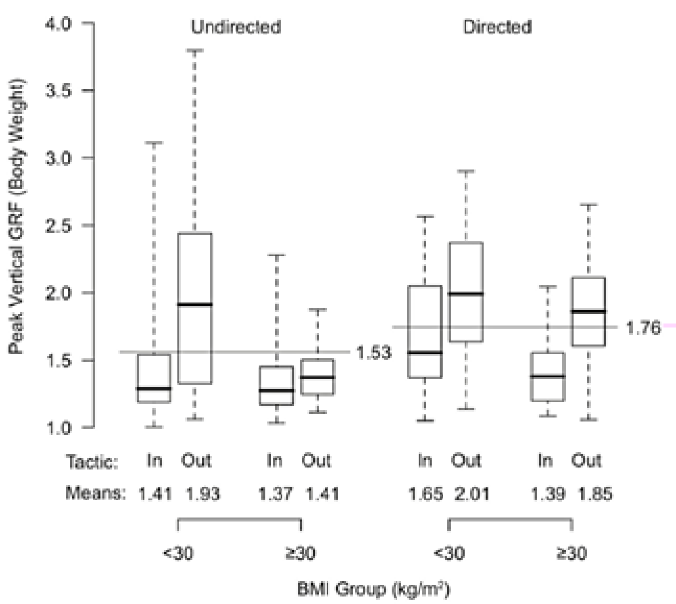

Figure 2. Effects of BMI, inward/outward-facing egress tactic, and investigator direction on peak vertical ground reaction force normalized by body weight. Boxes show median and interquartile range, whiskers span the range of the data. Numeric values on the plot are group means.

In the undirected trials, with drivers choosing their egress tactic, non-obese drivers (BMI < 30 kg/m2) showed much larger average increases in PVGRF than obese drivers. In the directed trials, which forced the heavier drivers who had chosen inward-facing egress to switch to outward-facing, both high and low BMI groups showed similar increases in mean PVGRF between inward- and outward-facing tactics. Overall, in undirected trials, drivers who exited facing away from the steps experienced average peak ground reaction forces of 1.75 times body weight, compared with 1.25 times for those who exited facing the steps. Averaging across all trials captures the same number of inward- and outward-facing egress events for each driver, and hence gives the best estimate of the within-subject increase in force resulting from a change in tactics (excepting missing data). Using these values, PVGRF in outward-facing egress was 28% higher (1.85 vs. 1.44 times body weight).

RCOF was significantly affected only by tactic (p<0.001) and the effect was small. The mean RCOF was 0.085 for inward-facing and 0.07 for outward-facing egress.

Discussion

The lower ground reaction forces observed with inward-facing egress provide a biomechanical justification for recommending that tactic, since lower ground reaction forces are associated with reduced tissue stresses. In undirected trials, drivers with higher BMI were more likely to chose the lower-stress tactic, providing some evidence of risk compensation. Surprisingly, step and hand hold configuration did not affect either tactic selection or ground reaction force. A more detailed analysis is needed, but one possibility is that driver tactic preference based on years of experience tends to override any effects of short-duration exposure to a new step and hand hold configuration. The data show large inter-subject variability, however, and tactic changes may have occurred within the broad categories used here.

These data are limited by the laboratory setting and test equipment. Some drivers moved more slowly than is typical for drivers in their own trucks, which likely makes the current conclusions conservative – higher-speed egress would lead to higher PVGRF and an increased risk for outward-facing egress. The postures at the time of ground contact also differ substantially between tactics and may lead to different stress even with the same ground reaction force.

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Hazard Recognition for Ironworkers: Preventing Falls and Close Calls – Updated Findings

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This is an update of preliminary findings [Scharf, et al. 2009] from a study to: 1) evaluate two hazard recognition training interventions to prevent falls and close calls in construction;2) investigate the situations, hazards, and precursors for falls and close calls;3) develop a taxonomy of precursors to increased risks for falls & close calls; 4) identify the barriers to reporting and correcting these risky situations; 5) connect these observations to the complex interrelationships of productivity, work-load, safety, and risks for injury in hazardous work environments; and to 6) recommend crew-based organizational changes to promote communication about, and rapid mitigation of such workplace hazards.

Preliminary results from the curriculum evaluation are limited to a report of participants' work experiences. A summary of the preliminary findings from the focus groups and a proposal for a study of incidents, injuries, and illnesses situated within local unions are both described.

Introduction

Falls continue to cause the largest number of fatalities and a major proportion of injuries in the construction industry every year [BLS 2009; NIOSH 2004]. Constantly changing hazardous work environments like construction impose a dual-attention demand on workers [Kidd, et al. 1996; Kowalksi-Trakofler, et al. 2003; Scharf, et al. 2001]. As the work day extends, fatigued workers may be less cognizant of developing or changing hazards in their immediate surroundings. This update addresses hazard recognition for ironworkers, with an emphasis on barriers to reporting hazards, incidents, injuries, and illnesses on the job.

The current project derives from a 1999 request by safety personnel at the Paul Brown Stadium construction site in Cincinnati to produce training materials for hazard recognition for risks for falls in construction. These materials were modeled on curricula already in existence for underground mining [Cole 1997; Kowalski et al. 1995; Perdue, et al. 1994; and Rethi et al. 1999]. The hazard recognition component of the curriculum consists of thirteen stereo images, and a title slide, suitable for use in a classroom or on the job site. The instructor's guide was completed in 2001, [Ramani, et al.]; the companion simulation exercise was completed in 2004, [Wiehagen et al. 2004].

Objectives and Methods

The study reported here is evaluating both the hazard recognition photographs and the simulation exercise with Ironworker journeymen and apprentices. Then, risks for falls and close calls, and barriers to reporting and correcting safety hazards were explored through a series of focus groups with the participants. Important note: participants reported a wide range of definitions for an "injury" and a "close call." Specifically, the interpretations of a close call and an injury vary among participants, from extremely serious events that may occur a few times in a career, to hundreds of examples of everyday injuries and potential incidents. These varying interpretations are addressed in Table 2 and the Discussion.

This study has been conducted in collaboration with the International Association of Bridge, Structural, Ornamental, and Reinforcing Iron Workers, and with CPWR – The Center for Construction Research and Training. The evaluation of the training curricula includes, pre-, post- and delayed post-tests, including an assessment of safety climate with both apprentice and journeymen Ironworkers. The investigation of close calls for falls has been conducted using focus groups of third- and fourth-year apprentice ironworkers and experienced journeymen who are also apprentice trainers at their home locals.

Results

A total of 409 ironworkers have completed the demographics intake survey; results are reported in Table 1. The median age of the apprentices is 28, with 2.5 years' experience as an ironworker. The median age for journeymen is 45, with 20 years' experience. Table 1 also lists the median number of falls, close calls, and injuries reported by the ironworker participants. The median has been selected because some of the results are highly skewed.

Three hundred sixty-three ironworkers have participated in the evaluation of the training curricula, (33 journeymen, 330 apprentices) in a total of 21 evaluation groups (2 groups of journeymen, 19 groups of apprentices). In addition, 16 focus groups have been conducted: 11 exploratory, 5 confirmatory, with 127 participants. Twenty-five journeymen participated in a focus group only, for a total of 388 participants out of the initial 409 volunteers who completed the demographic intake form. (See Appendix Tables 1 and 2 for a further breakdown of participation in this study.)

Table 1. Median (and range: min.-to-max.) number of: Ironworker falls from above ground level (AGL) and other demographic information

Ironworker Demographic Information	n	Age	Experience (years) as an Ironworker	Falls from AGL (#)	Co-worker falls from AGL (#)	Close calls for a fall from AGL (#)	Injuries, NOT from a fall from AGL (#)	Close calls, NOT from a fall from AGL (#)
Apprentices	226	28 (19-53)	2.5 (0-10)	0 (0-20)	0 (0-44)	0 (0-30)	1 (0-500)	1 (0-1000)
Journeyman	58	45 (27-68)	20 (4-44)	1 (0-12)	2 (0-43)	4 (0-100)	5 (0-500)	10 (0-1124)
Combined groups	284	30 (19-68)	3 (0-44)	0 (0-12)	0 (0-43)	0 (0-100)	1 (0-500)	1 (0-1124)

The exploratory groups have used the traditional approach of asking broad, open-ended questions and gradually adding specificity to questions as each group proceeds [Krueger 1994]. The confirmatory groups began with a series of explicit findings from preceding exploratory groups. The participants in the confirmatory groups were asked to comment on those findings. Table 2 summarizes the focus group findings based on the preliminary analyses to date.

Table 2: Summary of the focus group findings
1. Close calls are distinguished from an actual incident only by the severity of injury. The precursors to the incident, possible causes, and potential for prevention are no different. A close call may be an injury that did not happen, or an injury that occurred where a fatality could have occurred.
2. Barriers to reporting injuries or hazards and improving safety include:
a. fear of layoff, followed by inclusion on a company's "do-not-hire" list;
b. jeopardizing the progress of the job, e.g. safety "interferes" with productivity;
c. Ironworker culture, e.g. cultural changes affecting safety over the past 3 decades;
d. competing against non-union bids;
e. not anonymous, plus drug testing for injured worker and immediate crew;
f. some union stewards are friends with contractors, i.e. apprentices who report a problem are worried that they will be identified and subject to layoff;
g. employer-driven monetary incentives for no OSHA-recordable injuries;
h. contractor concerns regarding insurance rates;
i. employers' requests to injured employees to use personal health insurance to cover medical treatment for a workplace injury;
j. assignment to light duty, followed by a layoff;
k. Conclusion: Until there is a no-fault system for reporting hazards and improving safety on the job, there will always be too many barriers to reporting hazards and injuries and to improving safety. Only the most serious OSHA-recordable injuries will be reported with any degree of reliability.
3. Experienced journeymen who train apprentices in their local unions have agreed to test out a method to collect incident, injury, and illness data through an anonymous survey of their apprentices every three months.
4. Ironworker Local 769, Ashland, KY, has established a comprehensive approach to contract bidding that includes specifications for the number of crew, schedule, and safe work practices on every job, including: 1) 100% tie-off of personal fall arrest harness and lanyard to a 5,000 lb. (min.) anchor point, 2) 100% injury reporting, and 3) extensive pre-planning. Other locals and a few companies have been described as utilizing some similar practices of work organization.

Discussion and Conclusions

The transcripts from the focus groups will not be available for systematic analysis for several months. However, upon reaching apparent saturation with the exploratory focus groups, a confirmatory approach was begun. This method has been illuminating.

One of the most robust and consistent findings from both the exploratory and confirmatory focus groups concerns the concept of a "close call." As noted in the abstract, one of the original goals of this study was to develop a taxonomy of the most common or frequent precursors to increased risks for falls and close calls in construction. Consistent with Heinrich's classic safety pyramid (a.k.a. accident pyramid, 1931 and 1959) [Heinrich1959] it was anticipated that an inquiry into close calls and "near misses" would open up a wealth of new observations and insights into the causes and precursors of falls and other injuries experienced by ironworkers.

The clear finding from the current study is that the only difference between a close call and an actual injury event is the existence or extent of the injury. Thus, a fall with a serious injury that could have resulted in a fatality may be described as a "close call," rather than an injury. The conclusion is: to investigate the precursors to injuries and fatalities, we must expand our data collection to include all incidents on the construction work site, regardless of any injury consequences. With respect to an investigation of safe work practices, introducing the concept of a "close call" or "near miss" may create a distraction from the critical sequence of events in an identified incident. (The obvious follow-up question concerns the definition of an "incident." Until the focus group transcripts are analyzed in detail, we offer no new insight into a coherent and workable definition of an "incident.")

Reporting injuries is a serious and complex problem for ironworkers. Most ironworkers will make a report to the steward or foreman regarding any serious injury, even if the injury is not immediately apparent (e.g. a severe strain or sprain). Some apprentices worry that their steward (union representative) will identify them to their employer and are wary of making any injury report. Further, there is a strong reluctance to report all but the most serious injuries to employers unless such a report is unavoidable. Ironworkers describe how contractors maintain "do not hire" lists of employees who have been injured on the job. They believe that if they report an injury, they will be laid off as soon as they are released from medical treatment or "light duty."

Journeymen have concluded that some system of no-fault reporting is essential to be able to both report workplace hazards and to promote safety on the job. The interlocking relationships among contract bids and schedules, insurance rates, OSHA-recordable rules, and fear of layoff make it impossible for union members to report hazards and for contractors to be open and receptive to such reports. The conclusion is: until there is a no-fault system for reporting hazards and improving safety on the job, there will always be too many barriers to reporting hazards and injuries and to improving safety. Only the most serious, OSHA-recordable injuries will be reported with any degree of reliability.

To address the hazard, safety, incident, injury, and illness reporting problem, journeymen who train apprentices have suggested developing an anonymous survey of apprentices within their locals to be completed every three months. By including hours of work during the preceding quarter, it will be possible to calculate rates of exposure to all of the hazards and incidents reported. Further, by coordinating this survey through the apprentice trainers, the participants will not be known outside their locals and the results will be aggregated and reported for all the participating local unions. A draft of this proposed survey is currently under development.

As noted in Table 2, Ironworker Local 769, Ashland, KY, has established a comprehensive approach to contract bidding and safe work practices, notably including 100% tie-off and 100% injury reporting. Details including sample job bids and injury records will be disseminated to experienced instructors in other Ironworker locals. The goal is to identify the components of the safe work practices used by Local 769 that can be adopted by other Ironworker locals throughout the U.S. and Canada. Other locals and a few companies have been noted as utilizing some similar practices of work organization. These practices will be explored and compared to the approach used by Local 769.

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Disclaimer

The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health, the International Association of Bridge, Structural, Ornamental, and Reinforcing Iron Workers, or of CPWR – The Center for Construction Research and Training..

Notes

* This paper was originally prepared for the International Conference on Fall Prevention and Protection (ICFPP), sponsored by the Division of Safety Research (DSR), NIOSH, Morgantown, WV, May, 2010. Data collection for this study concluded at the end of June, 2010. Participant information has been updated from the information reported at the ICFPP conference to reflect the most recent results available. Data entry and analysis continue; results reported here are preliminary.

Research instruments and additional descriptive results are available from Ted Scharf: tscharf@cdc.gov. The NIOSH Human Subjects Review Board has oversight for this study.

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Electroadhesion Technology for Extension Ladder Slip Control

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Extension ladders are inherently unstable structures, and ladder stability failure is a major cause for ladder fall injury. Insufficient friction at ladder legs combined with sub-optimal positioning angle is a common precursor of ladder fall incidents. The objective of this study was to develop and evaluate an innovative device for improving extension ladder stability using a novel technology – controlled electroadhesion (EA). EA pads with several electrode patterns were built to evaluate the effect of design on clamping force under several voltage conditions. Clamping forces were tested on a variety of common floor surfaces using a force gauge attached to a linear motor. A mechanical model was applied to estimate the effect of EA on the required coefficient of friction (RCOF) at the ladder feet. EA pads with broader pattern and higher voltage demonstrated the best clamping performance, meeting or exceeding the requirement for clamping pressure (0.05 N/cm2) on most surfaces, and far exceeding this value on the smoothest materials which are most prone to slippage. The results demonstrated that EA reduced substantially the RCOF at ladder feet on many surfaces. At this "proof-of-concept" stage, the study demonstrated that the EA pad system reduced the risk of slipping, and allowed safer ladder use under various positioning angles. The study shows the promise of using the EA pads system for enhancing extension-ladder stability.

Introduction

An extension ladder allows for quick and easy access to different height levels and is especially convenient and useful as a temporary support surface for short term tasks at elevation. That is why extension ladders are widely used by workers across many industrial trades for a variety of construction, maintenance, and repair tasks. Among the other advantages of this simple tool are its light weight, adjustability, and easy operation. Despite their perceived simplicity, extension ladders have their associated risk. During 2008 in the US, work-related falls from ladders resulted in approximately 116 fatalities and an estimated 17,540 serious injuries [BLS 2009a, b]. Slipping of ladder base and tipping of ladder top have been identified as the two leading causes for ladder fall incidents [Hsiao et al. 2008].

From a mechanics stand point, the extension ladder is an inherently unstable structure. It relies on friction at its top and base support locations to remain static and maintain its position while transferring the loads generated from ladder user movements during task performance. Insufficient friction at the ladder legs combined with sub-optimal positioning angle is a common precursor of ladder fall incidents. To improve the safety of ladder users, the American National Standards Institute (ANSI) and Occupational Safety and Health Administration (OSHA) standards recommend that ladders should be positioned at an optimal angle and be secured both at the top and the bottom. However, these recommendations are not always practical – tie-off points often are not readily available in work environments, and tying-off requires additional time and effort. Furthermore, in many cases the ANSI and OSHA recommendations remain unknown, neglected, or ignored by ladder users.

The goal of this research effort was to improve the stability of an extension ladder by providing means to automatically secure the ladder at preferred locations with electroadhesion (EA). EA is an innovative technology developed at SRI International with a broad range of potential application, e.g., climbing robots [Prahlad et al. 2008], enhanced-traction shoes [Pelrine et al. 2008]. As the name implies, EA is an electrically controllable adhesion technology. It involves inducing electrostatic charges on a floor or wall substrate using a power supply connected to compliant pads situated on the EA pads. EA can deliver relatively high adhesion forces (up to 1.5 N/cm2) with very small energy requirements on a variety of surfaces. Furthermore, EA devices are generally compact, lightweight, and with very low expected manufacturing cost. The characteristics of EA for improving ladder stability are promising. At this "proof-of-concept" stage, the objective was to develop an EA device that can accommodate environments with simple geometry (horizontal floor and vertical wall). Based on the literature, a clamping force of 20 kg (196N) between the EA pad (attached to the ladder) and the floor or wall substrate was selected as a goal performance level at each support location. However, it was recognized that the EA performance may vary with surface properties and conditions and that even smaller forces may also be beneficial for enhancing ladder safety.

Method

Development of electroadhesive pads – electrode design

Electroadhesive pads with several types of electrode patterns were built to evaluate the effect of the design on clamping force. In particular, evaluated were a fine pattern with 1mm lines and 1 mm spacing, and a broad pattern with 25mm lines and 25mm spacing. EA uses high voltages (several kilovolts) but extremely low currents (microamperes), often below the threshold of human sensation. In the current tests, the pads were operated at 3 kilovolts (kV) and at a "peak" voltage of 6-7 kV. A clamping force of 20 kgf corresponds to a clamping pressure of 0.05 N/cm2 on a square pad 61 cm on a side.

Mechanical testing – clamping force measurement

To evaluate the clamping forces provided by electroadhesion on a variety of common floor surfaces, tests were conducted on smaller representative coupons (electroadhesive pads with approximate dimensions 10 cm x10 cm). Several samples of floor materials were held fixed against a tabletop surface. The electroadhesive pads were then attached to a Mark 10 Force gauge (223 N maximum), which was in turn attached to a linear motor that was also grounded against the tabletop surface. Both voltage on and voltage off tests were conducted, and the force difference between them was calculated to isolate the effect of electroadhesion.

Surface roughness measurement

The floor materials were characterized by measured surface roughness using a "Pocket surf" PS1 surface profilometer (Mahr Corporation). The traditionally applied measure of surface roughness Rz (average maximum height of the profile) was chosen for the characterization.

Results

Effect of electrode pattern and surface roughness on clamping force

Figure 1 shows the variation of electroadhesive pressures with surface roughness for the three electrode pattern and voltage combinations. The results demonstrate that surface roughness is a key factor affecting EA performance. The broad electrode pattern met or exceeded the clamping pressure goals for this application on most surfaces tested, and far exceeded this pressure on the smoothest materials which are most prone to slippage. This electrode pattern was hence chosen for the final design of the EA pads. If higher performance is required on rougher materials, other pad configurations or patterns more optimized for rough materials can be demonstrated in the future.

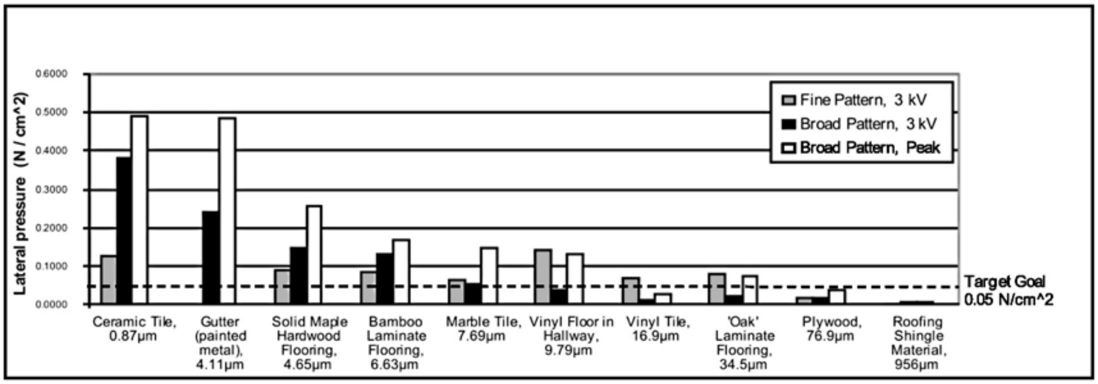

Figure 1. Lateral clamping pressures due to electroadhesion on a variety of floor and wall materials, arranged according to increasing surface roughness (Rz).

Design and construction of the EA pads

EA pads with size 61 cm x 61 cm using a broad electrode pattern were constructed and fitted onto a commercially available 4.9m (16 foot) extension ladder. The bottom pad was attached to the existing swivel foot of the ladder without structurally modifying it. The final assembly allowed the top and bottom pads to naturally contact the floor and wall, as shown in Figure 2. The EA pads themselves were made from a thin (38 micrometer thick) plastic film with electrodes patterned on it using a spraying technique. This plastic film was then attached to a rigid acrylic frame with nine square pockets cut out of it. The frame was designed to provide sufficient rigidity for operation and stowage of the entire pad, while still allowing the thin plastic sheet in the individual pockets to conform around the contours of the floor or wall. Each EA pad had an integrated power supply mounted on the other side of the acrylic plate. The power supply used 2 AA lithium batteries and was equipped with a radio frequency (RF) receiver controlled from a remote switch. Each of the electronics boxes steps up the battery voltage to about 6800 Volts, with a nominal maximum of approximately 50 microAmps using an EMCO model Q-101-5 DC-DC converter.

Figure 2. Ladder (at an otherwise unsafe angle) with electroadhesive pads active

Effect of EA force on the RCOF and the corresponding safe setup angles

To estimate the effectiveness of the EA pads in preventing ladder slip under various scenarios, a mechanical model of ladder slip was constructed. This model incorporated the anti-slip forces exerted by the EA pads on the floor. As seen from Figure 3, when the ladder is set at the recommended (75.5 deg) angle, an EA force of 89 N reduces the RCOF in half, and an EA force of 178 N completely eliminates the need for friction at the ladder base to keep the ladder in balance. Alternatively, an EA force of 89 N at the ladder base allows the ladder setup angle to be lowered to 67 deg for the same level of the RCOF; i.e., with the EA the risk of the ladder sliding-out is significantly reduced even when the ladder is set not at the optimal angle.

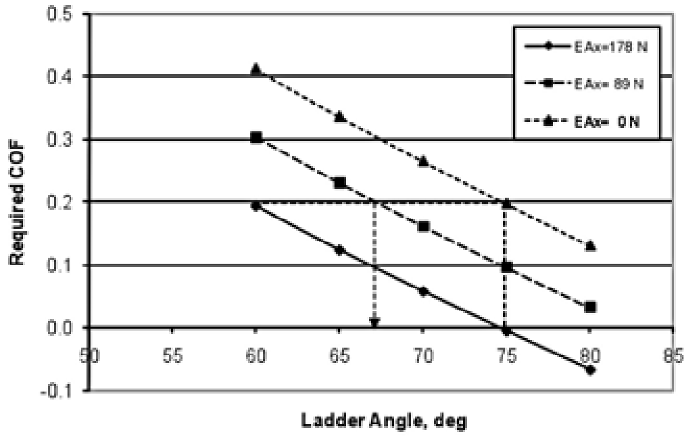

Figure 3. Required coefficient of friction (RCOF) at the ladder base as a function of ladder angle and clamping force for an EA positioned at floor.

Discussion and future work

Although the current project clearly demonstrated the promise of electroadhesion for enhancing ladder stability, further research and development efforts are required to mature the technology for this application. In particular, the following are some of the R&D needs: improved ruggedness/durability of the EA pads; easy attachment and replacement design; automatic activation; improved adaptability to more complex surface profiles; comprehensive evaluation; and consideration of input/feedback from ladder users, industrial partners, and safety professionals.

Conclusion

The study demonstrated that electroadhesion technology may be very beneficial for improving extension ladder stability. A "proof-of-concept" prototype of an EA device was developed and its performance was analyzed using a mechanical model. The results demonstrated that an EA device can significantly reduce the required coefficient of friction at the ladder base for a given ladder angle, or allow using the ladder at non-optimal angles without danger of slipping. In addition to demonstrating for the first time the concept of ladder safety enhancement using electroadhesion, the study showed at this "proof-of-principle" stage that: EA pads can be designed and integrated into an existing ladder in a way that doesn't obstruct the normal use of the ladder; EA can significantly reduce the risk of slipping of an extension ladder on most floor surfaces; and a kinematic model of the ladder can be used to predict the EA effects on ladder stability performance.

Disclaimer

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Effect of Using Rungs or Rails on Hand Forces While Ascending and Descending Fixed Ladders

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This study investigated the forces the hands exert on rungs versus rails when ascending and descending fixed vertical ladders. Most of the work to support and lift the body in the vertical direction comes from the feet. Longitudinal (fore-aft) forces are exerted with the hands to resist the moments produced about the feet by the weight of the body; particularly at the beginning and end of each propulsive hand exertion. Greater vertical forces were applied when climbing with the rungs. Lateral (side-to-side) forces were significantly greater for the rails than the rungs. This suggests that hand forces are related to hand placement and that subjects tend to place their hands where it will minimize hand force.

Introduction

Falls from ladders are a major cause of worker injuries and fatalities [BLS 2009]. In order to understand the mechanisms of ladder injuries, we must first understand the biomechanics of climbing ladders. By examining the forces we exert on ladders we may be able to identify specific behaviors, methods of climbing, or points during the climbing cycle that may be the most risky.

Fixed ladders are widely used to provide access for maintenance and operation of equipment. Fixed ladders are more stable than mobile ladders, but are often mounted vertically. Vertical ladders cause the climber's center of gravity to be aft of the center of pressure on their feet, and a horizontal hand force is required to prevent falling backwards. Bloswick and Chaffin [1990] reported climbing forces for both feet and hands on several different ladder slants and rung separations and showed that hand forces exerted while climbing a ladder using rungs increase as the ladder becomes vertical. However, they did not examine forces when climbing using the side rails, though this is a commonly observed climbing method [Dewar, 1977; Hakkinen, 1988].

In a previous study [Armstrong et al, 2009] we examined ladder climbing for twelve subjects while climbing with the hands using the rung or the rails on differently oriented ladders. It was found that the feet provide the majority of the force required to lift the body when climbing (>94% body weight). Overall peak resultant forces on the hands that occurred at any time during climbing were significantly lower for climbing with the rails than with the rungs for all ladder orientations (10-15% body weight on average). Average peak resultant hand forces ranged from 32-39% and 28-31% of body weight during ascending and descending, respectively. It was also observed that the hands exerted a significant amount of lateral force when climbing using the rails; however orthogonal forces were not examined systematically. The purpose of this study is to examine how climbing with either the rungs or the rails affects orthogonal force components that the hands exert while climbing on fixed vertical ladders.

Methods

A custom-made, instrumented, fixed vertical ladder 10′ in length was constructed. Nine 16″ wide rungs were spaced 12″ apart (OSHA, 1910.27 Fixed Ladder Standards). Ladder rungs and rails were 1-inch diameter cylindrical steel rods and were cleaned with steel wool before testing. The ladder rungs were attached to the ladder frame at the center post so the rungs could be mounted on 3-axis force and 3-axis moment transducers (AMTI® MC3 and ATI® Theta). Four of the rungs were instrumented: two for the feet (rung 2 and 3) and two for the hands (rung 7 and 8). Each rail (left or right), which was continuous over the length of the ladder, was also instrumented.

Subjects were instructed to climb a vertical fixed ladder at a comfortable speed using one of two climbing styles: grasping the rungs or the side rails. From a bipedal stance on the ground, subjects climbed 5 rungs, paused, and then returned to the ground. There were 3 repetitions for each treatment yielding a total of 6 ascend/descend climbing trials. The dependent variables measured in the study are orthogonal forces on the rungs and orthogonal forces on the rails. All forces are normalized as a fraction of body weight.

This study will provide further analysis on a subset of data presented in Armstrong et al. [2009]. In addition to peak forces, the forces exerted on rungs and rails by the climber has been examined over the time-course of a complete load/unload exertion profile for both hands and feet on the rungs or rails. Because climbing method varied greatly among the original twelve subjects and this analysis requires a complete load/unload cycle representative of the normal climbing gait (subjects needed to climb past the 7th and 8th rung while still climbing and not stopping on them), a subset of six subjects (three male, three female) was chosen for this more detailed analysis (Table 1). All subjects were right handed. Average height, weight, age, dominant hand grip strength, and reach span were 171±7 cm, 66.7±9.5 kg, 27±5 yrs, 47±13 kg, and 150±10 cm, respectively. Males were on average 10 kg heavier and 11 cm taller than females.

As the subject climbed, the forces on the rung or rail were recorded. A "load/unload force profile" is defined as beginning when the hand first touches a hand hold until the hand lets go of the hand hold. Force profile starting and ending times corresponded to that time at which the force on the rung or rail increased from zero and decreased to zero. For trials where the subject climbed with the side rails, a single force profile from the steady-state climbing period (i.e. not at the beginning or end of an ascent or descent) was chosen for analysis. Because the length of load/unload force profiles were slightly different for different subjects and trials, profiles were sampled at 50 equally spaced points over the total profile period in order to compare across subjects and treatments. Peak orthogonal and resultant forces that occurred in each trial were recorded and averaged over repetitions and subjects. In order to graph force load/unload profiles, forces at each of the 50 sampled time-points were averaged over rep and subject. Please note this will have a smoothing effect on the displayed data.

Results

Average peak forces for climbing with the rungs or rails when ascending and descending vertical ladders are reported in Table 2 and 3. Lateral force components (left/right) for the rungs are reported as a range because each subject grasped the 7th or 8th rung with either the right or left hand and lateral force exerted is different depending on which hand grasped the rung.

Table 2. Peak hand forces (%BW) averaged for all subjects while ascending

	right(-)/left(+)	down(-)/up(+)	out(-)/in(+)	Resultant
Right Rail	12.8±3.3	-18.1±5.5	-20.4±3.4	27.3±3.6
Left Rail	-11.6±4.7	-15.9±7.0	-20.6±7.0	26.6±7.8
Rungs	5.7±2.9/-5.2±2.3	-23.8±10.0	-21.7±5.8	31.0±11.6

Table 3. Peak hand forces (%BW) averaged for all subjects while descending

	right(-)/left(+)	down(-)/up(+)	out(-)/in(+)	Resultant
Right Rail	11.9±3.2	-15.7±3.8	-23.6±4.9	28.5±4.3
Left Rail	-10.5±4.0	-15.1±6.1	-19.4±6.4	24.8±7.6
Rungs	5.6±2.9/-3.9±3.4	-22.2±15.2	-21.1±16.0	30.6±21.7

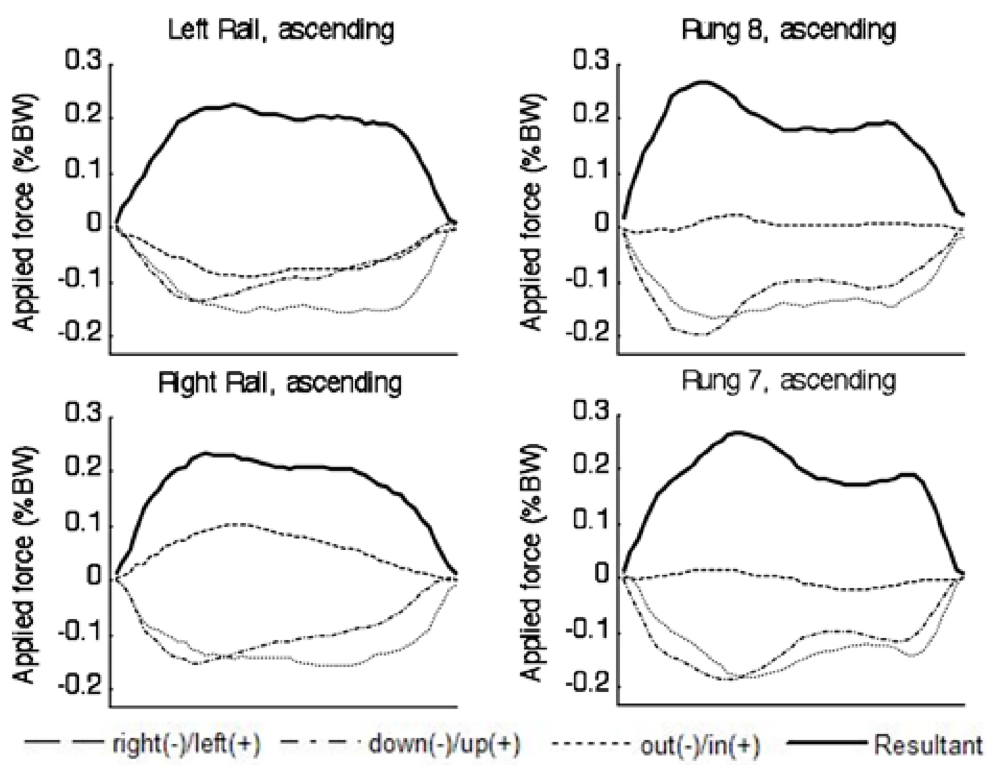

Figure 1. Hand force profiles applied to rails (left) or rungs (right), ascending

lessens over time. The latter half of the force profile is dominated by outward force. Lateral forces (left/right) are greater for the rails than the rungs and appear to be greatest during the first half of the load/ unload profile. Resultant forces display to peaks, one at the beginning of the profile and one at the end. The peaks are more pronounced when climbing with rungs. The first peak is larger than the second.

Figure 2 shows rung and rail forces during descent of the ladder. In contrast to ascent, outward forces are generally largest throughout the entire load/ unload profile. Downward force increases over time and is greater in the latter half of the profile. Lateral forces (left/right) are greater for the rails

For both ascending and descending phases, lateral forces were significantly higher for the rails than for the rungs. The right rail was pulled to the left and the left rail was pulled to the right. Peak downward forces were greater when climbing with the rungs than with the rails. Downward forces were slightly lower for descending than for ascending. Outward force on the ladder was similar for both rungs and rails and for ascending and descending.

In Figures 1 and 2, the average component and resultant force at each sampled time-point in the force load/unload profile are plotted. Figure 1 shows rung and rail forces during ascent of the ladder. After initial contact, downward force is greatest and

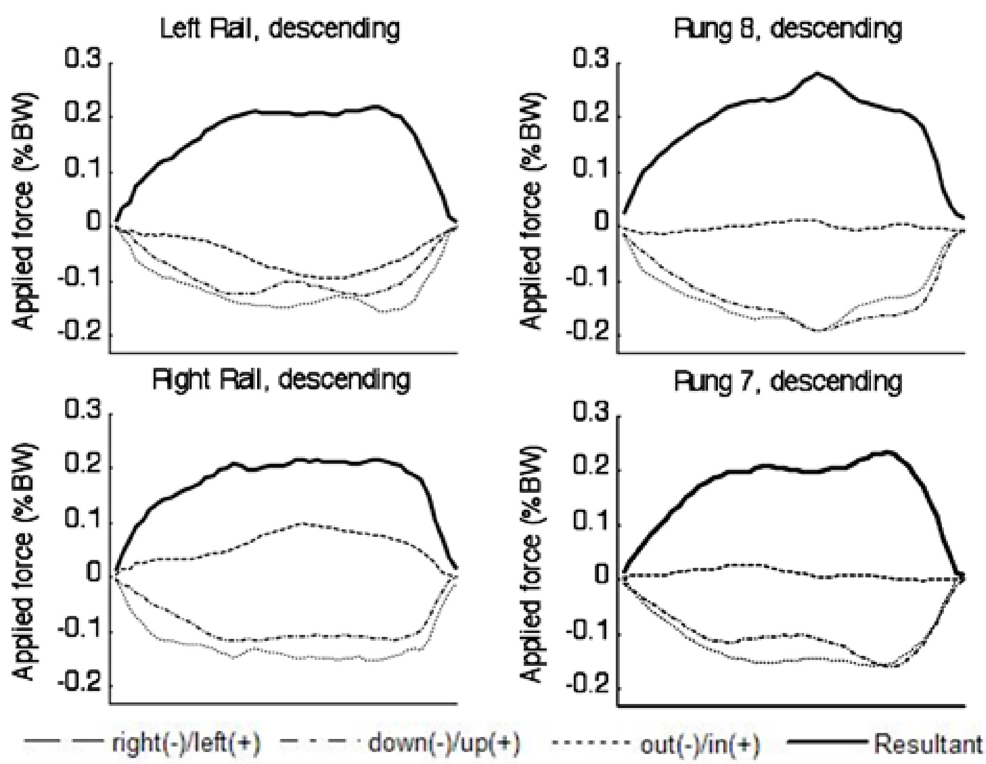

Figure 2. Hand force profiles applied to rails (left) or rungs (right), descending

and the rungs and appear to be greatest during the second half of the load/unload profile. Resultant forces do not display distinct peaks as in ascending profiles, and in contrast to ascent, the greatest resultant force appears in the latter half of the profile. It seems that ascending and descending force load/unload profiles are rough mirror images.

Discussion

Our results show that there are increased peak vertical forces (lifting force) for climbing with rungs than with rails. This suggests that more of the body weight is lifted by the hands using this method and would be more fatiguing for the upper limbs. However, peak lateral forces are much greater when using the rails. These lateral forces may cause the center of mass of the body to oscillate from left to right of the midline of the ladder. If a slip were to occur, the climber would likely pull his body toward the grasped rail.

Looking at the applied component forces in the vertical ladder hand force profiles, we see that during ascent (Figure 1), initial forces are dominated by the vertical component and then give way to the outward component. This suggests that initial propulsive hand forces are up and in, followed by a mostly inward force to bring the body center of mass back to the ladder. During ladder descent, hand force profiles (Figure 2) indicate the hands are primarily pulling inward, stabilizing the body as its moves down the ladder. Hand forces are more variable during descent, which may indicate that the climber has less control when backing down the ladder than when climbing up.

The greatest resultant forces are observed at the beginning of a hand exertion when ascending, and at the end of a hand exertion when descending. This suggests that most upper-limb force occurs when the arms are outstretched upward. This point also represents the times in the climbing cycle when the feet are transitioning.

We hypothesize that there exists an optimal hand location that will minimize the strength demand for the elbow and shoulders when climbing. Hand positions on the rungs are constrained by the geometry of the ladder (rung spacing) and may not be optimal for all individuals. Climbing with the rails enables all climbers to place their hands at the most comfortable or optimal vertical locations. However, climbing with rails constrains the hands to the farthest lateral position from the midline of the ladder. The component forces examined in this study largely reflect the configuration of the climber in these two scenarios.

Acknowledgments

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Effect of Handhold Orientation, Size, and Wearing Gloves on the Ability to Hang On

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The aim of this research is to quantify the effect of hand hold orientation, size (diameter), and wearing gloves on hand/hand hold breakaway strength. Six male subjects attempted to hold onto fixed overhead cylindrical hand holds in low-speed simulated falls as forces on the hand hold were recorded. Results show that hand hold orientation ($p<.001$), hand hold diameter ($p<.001$), and wearing gloves ($p<.001$) significantly affect breakaway strength. Breakaway strength is increased 75-94% as the orientation of the hand hold moves from vertical to horizontal. Breakaway strength is decreased 8-13% for large diameter hand holds as compared to smaller diameters. Wearing gloves may increase or decrease the ability to hang on depending on frictional properties of the glove/hand hold interface.

Introduction

Hands are used to support the body when climbing on ladders or getting in and out of elevated cabins on heavy equipment, trucks, or machinery. In the event the feet slip, the hands may serve as the primary means of support. Coupling between the hand and a grasped hand hold will determine if a person is able to arrest an impending fall. When climbing on vertical structures the center of body mass produces a moment that causes the body to rotate away from the structure that must be counteracted by coupling between the hands and the structure.

The design of hand holds in the workplace is not standardized. In many cases workers may improvise handles from the structures on which they are climbing. Consequently hand holds have many different orientations, sizes, and shapes. Hand holds may be made out of different materials or be improvised or constructed on the job. The surface of these hand holds may have differing frictional characteristics or be subject to surface contaminants and inclement weather. Furthermore, workers may be wearing gloves. Previous studies show that hand hold variations will affect the coupling forces between the surface of the hand and the hand hold and consequently the ability to hold onto that hand hold in the event of a fall.

Young et al. [2009] showed that breakaway strength on average was 1.52-1.58 times greater than isometric grip strength for a 25mm fixed horizontal cylinder and 1.26 times grip strength for a 25mm low-friction cylinder. This indicates that surface interactions play a significant role in the hand/handle coupling force. Additionally we showed that the strength capability was greatly decreased (0.77-1.02 times grip strength) for vertically oriented hand holds. Finally, it was shown that breakaway strength cannot be predicted by grip strength measures alone; it is also necessary to consider the effects of friction and hand hold orientation.

We hypothesize that factors that affect grip strength will also affect breakaway strength between a hand and a hand hold. Isometric grip strength has been measured extensively via grip dynamometers and cylindrical split-cylinders and is found to be affected by wearing gloves [Tsaousidis and Freivalds 1998], grip span [Edgren et al. 2004] and deviation of the wrist [Pryce, 1980]. Wearing gloves will alter the friction at the hand/hand hold interface.

Breakaway strength has been investigated for very few hand holds that may occur in the workplace. The purpose of this experiment is to examine how the generalized hand hold design factors of orientation and size and the how wearing gloves will affect a worker's ability to hang onto a hand hold in climbing or fall situations. This will create knowledge that can be used to develop biomechanical models of hand/hand hold coupling. Results can be used to establish design criteria for handles and hand holds on ladders, fixed equipment, stairwells, tools, and other safety critical items.

Methods

To achieve the aims of this study, two overhead breakaway strength experiments were performed on a single set of human subject volunteers. The first experiment tested the effects of hand hold orientation and size (diameter) for only the dominant hand of the subjects and the second experiment tested the effects of hand hold orientation and wearing gloves on only the non-dominant hand of the subjects. The breakaway strength measurement apparatus and test procedures are very similar to those described in Young et al. [2009], so they will be described briefly here with any differences noted.

Breakaway strength was measured by having subjects perform a "simulated fall". Subjects stood on a platform and held onto an instrumented handle mounted overhead with one hand. The platform was then lowered slowly while the subject held onto the handle as long as they could until the subject let go or the handle slipped from their grasp. The maximum applied vertical force was considered the breakaway strength for that specific handle.

The subject wore a fall harness attached to a fall arrestor for additional safety; this did not interfere with the subject's range of motion. A handle attachment structure was mounted to the load cell that allowed for different cylindrical handles to easily be interchanged and oriented at increments of 15 degrees between horizontal and vertical.

In order to control for fatigue, each subject performed the experiment in three sessions, each at least five days apart. In each session, one repetition of all test conditions was performed in a randomized order. The three experimental sessions correspond to three treatment repetitions. When grasping the handle in any orientation, the subject's forearm was pronated. This resulted in an ulnar deviation of the wrist when the handle was at an angle other than horizontal (90°). Twelve subjects (six male, six female) completed the experiment. Only one subject was left hand dominant.

Design

For this study, each hand (dominant or non-dominant) performed a different experiment. This was done because it is assumed that each upper limb is independent of the other and differences in overall strength between the dominant and non-dominant hand will only affect the total breakaway strength and not the effects of treatment variables. Also, because of the two-minute rest between trials, both experiments could be performed in half the time of doing each separately by testing one hand while the other was resting. For the dominant hand, breakaway strength was measured for three different size aluminum cylinders (22mm, 32mm, 51mm diameter) at four different handle orientations (0° vertical, 30°, 60°, 90° horizontal). A Jamar grip dynamometer was used to measure overhead isometric grip strength in two grip spans as a comparison.

A three-way repeated measures analysis of variance was performed to determine whether breakaway force was significantly affected by the fixed effects of handle size, handle orientation, and session (rep), with subject as a random effect. Post-hoc Tukey tests were then performed on significant main effects to compare breakaway strength between treatments.

For the non-dominant hand, breakaway strength was measured for a single cylinder while bare-handed or wearing one of two different common work gloves at four different handle orientations (45°, 60°, 75°, 90° horizontal). The two gloves that were tested included Home Depot® brand "All-Purpose Brown Jersey Gloves" (70% polyester/30% Cotton) and Home Depot® brand "Jersey Mini-Dotted Gloves" (70% polyester/30% Cotton with PVC dots on the surface). Each subject was given a new set of gloves at the beginning of the experiment and used only that pair for the 3 experimental sessions. A Jamar grip dynamometer was used to measure overhead isometric grip strength while wearing gloves or bare-handed.

A three-way repeated measures analysis of variance was performed to determine whether the measured force was significantly affected by the fixed effects of hand-interface, handle orientation, and session (rep), with subject as a random effect. Post-hoc Tukey tests were then performed on significant main effects to compare breakaway strength between hand-interface and orientation.

Results

Mean breakaway force measured for the dominant-hand for each size handle at each orientation are presented in Figure 1. Peak force differences were significant for main effects handle diameter (F(2,187)=7.71, p=.001), orientation (F (3,187)=177.31, p<.001) and session (F (2,187)=30.21, p<.001). There were no significant interactions between main effects. Average isometric grip strength measured at position 1 (36mm) of the dynamometer was 336±59 N; at position 2 (48mm), average grip strength was 454±55 N.

Post-hoc analysis indicates breakaway strength observed for the largest handle (51mm diameter) was significantly less than both the 32mm handle and the 22mm handle (p<.01). However, breakaway force measured for the 32mm and the 22mm handles were not significantly different (p=.99). Breakaway force was significantly lower for vertical hand holds than for 30° hand holds (p<.01); 30° hand holds were significantly lower than the 60° and 90° orientations (p<.01). Breakaway force for 60° and 90° orientations was not significantly different (p=.16). Breakaway strength decreased significantly in each successive experimental session (p<.01).

Mean breakaway force measured for the non-dominant hand for each hand-interface at each orientation are presented Figure 2. Peak force differences were significant for main effects hand-interface (F (2,187)=173, p<.001), orientation (F

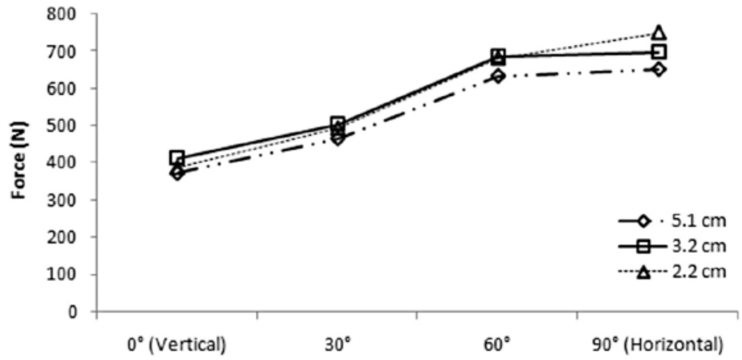

Figure 1. Breakaway strength by orientation and diameter (dominant hand)

(3,187)=81, p<.001) and session (F (2,187)=39, p<.001). There was a significant interaction between hand-interface and orientation (F (6,187)=8, p<.001): force was more decreased for the jersey glove at steeper angles than for the other hand-interfaces. The interaction between hand-interface and session was significant (F(4,187)=2.7, p<.04): breakaway force was less for bare hands after the first session than for other hand interfaces. Average isometric grip strength measured at position 2 (48mm) of the dynamometer was 411±59 N for dotted gloves, 429±70 N for bare hands, and 398±55 N for jersey gloves.

Post-hoc analysis indicates that breakaway force for the 45° handle orientation was significantly lower than 60° handle orientation (p<.01), which in turn was significantly lower than the 75° handle orientation (p<.01). Breakaway force for the 75° handle orientation, however, was not significantly different than the 90° (horizontal) handle orientation (p=.33). Breakaway force

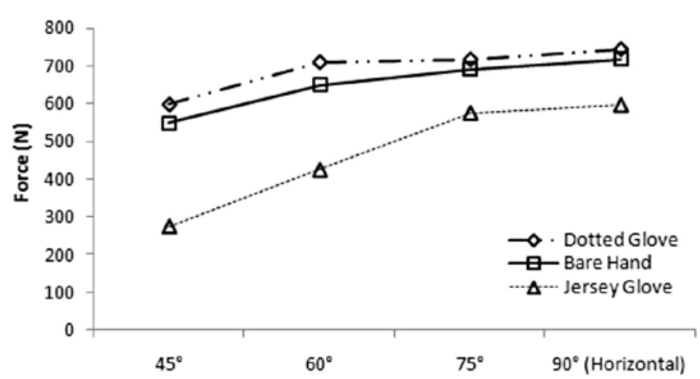

Figure 2. Breakaway strength by orientation and glove (non-dominant hand)

was significantly lower for subjects wearing the plain jersey gloves than for bare-handed subjects ($p<.01$). Breakaway force was significantly lower for bare-handed subjects than for those wearing the PVC dotted gloves ($p<.01$). Breakaway strength decreased significantly in each successive experimental session ($p<.05$).

Discussion

Results from both Experiment 1 and Experiment 2 show that the coupling between the hand and the hand hold is decreased as the orientation of the handle moves away from being perpendicular to the applied load (away from horizontal in this experiment). When this occurs, force from flexing the fingers doesn't act in the direction of the loading and coupling increasingly relies on friction. Previous studies have shown that wrist postures away from neutral will decrease grip strength, so some of the decrease in breakaway strength for non-horizontal handles may be explained by reduced ability to flex the fingers in ulnar-deviated postures.

Edgren et al. [2004] found grip strength to be greatest for cylindrical handles 38.1 mm in diameter and is diminished for handles larger or smaller. Our data shows that breakaway strength increases for smaller hand holds with 32mm and 22mm handles not being significantly different. However, for horizontal (90°) handles, breakaway strength was greatest for the smallest handle. This suggests that if the hand hold long axis is perpendicular to the applied force, smaller cylinders will provide better coupling.

Smaller hand holds may afford greater breakaway strength because the fingers are closed around a smaller surface, reducing the moment arm of surface forces acting against the internal flexion moment from muscles at each finger joint. As the cylinder size increases, so does the distance of the surface acting on the finger and hence increases the moment against the finger flexors. Also, when pulling on a hand hold, the fingers are free to open and the handle does not need to be pressed into the palm to create force; this is a fundamental difference between breakaway strength and grip strength.

The results show that wearing gloves with PVC dots will increase hand/hand hold coupling. This result is likely due to friction. Increasing friction will increase breakaway force. Plain cloth gloves decreases friction and therefore coupling. However, this may not be the case for handles that have rough or knurled surfaces, where the cloth may actually have greater friction. Specific handle/glove friction properties need to be considered for the best choice of glove.

The effect of session was significant, indicating that subjects were either fatigued in successive sessions or their motivation to perform maximal exertions was decreased. Because the decrease in breakaway strength was uniform over the three sessions and interactions with other main effects were not present, conclusions about orientation, size and wearing gloves are not influenced by the session effect. However, future studies should allow for greater rest periods (more than 5 days) between sessions.

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A Comentary on Research to Practice

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CPWR is affiliated with the Building and Construction Trades Department of the AFL-CIO, and leads a consortium as the U.S. National Construction Research Center supported by the National Institute for Occupational Safety and Health (NIOSH) grant #U60 OH009762. Opinions stated here are the sole responsibility of the author.

Approximately four U.S. construction workers are killed each day, and about a third of those are due to fatal falls. Although our understanding of causes and circumstances continues to improve, the overall rate of fatal falls in the construction sector has changed very little since the U.S. Census of Fatal Occupational Injuries was initiated in 1992. The papers in this issue reflect a sea change in the occupational safety and health research agenda over the past decade in which the U.S. has, perhaps, trailed our colleagues in the European Union. This new agenda focuses on moving injury and illness prevention interventions from research to practice (R2P), and allocation of significant research resources to address industry-sector-specific priorities. The National Institute of Occupational Safety and Health (NIOSH) has established national multi-stakeholder sector councils, including one for construction; has established a small but valuable national construction office within the NIOSH Office of the Director, and has continued support for an extramural national construction center. It further initiated an independent evaluation of its construction programs through the National Academies, which scored this program highly in relevancy and impact.

This issue demonstrates the extension beyond the laboratory of this research agenda. Starting with pursuit of epidemiological surveillance for the purpose of guiding and evaluating field R2P interventions (Dong, et al) and economic assessments for the purpose of identifying incentives and overcoming barriers to action (Biddle et al); continuing with development of technologies and evaluation of efficacy (Bobick et al); field evaluation of training and actual work practices (Evanoff, et al); followed by dissemination or technology transfer through codes and standards (Pauls on design of stairway handrails). Post-market case studies on harness suspension trauma (McCurley) illustrate the need for ongoing applied research, even beyond commercial field adoption of innovative technologies and practices.

Dissemination of information to the public, technology transfer and the transition from research to practice (R2P) have long been the focus of initiatives in traditional public health practice, but have received little attention in occupational safety and health.

Injury and illness prevention in small employer dominated industry sectors like construction demand that we focus on overcoming these barriers to change. A quarter of the U.S. construction workforce is self-employed, and another quarter are employed by the 80% of construction employers with fewer than 10 employees. Dissemination of information and creating incentives to change in such a dispersed and dynamic workforce is difficult.

Changes to eliminate fall hazards include: improved design/engineering, site-wide approaches to improve risk communication on multi-employer sites, and major changes in work practices and equipment such as replacing ladders with aerial work platforms, scaffolds and stairways. Management systems increasingly address pre-project and pre-task planning to identify foreseeable hazards and how to control them. NIOSH's Prevention through Design (PtD) initiative encourages changes such as fabrication to facilitate anchorage for fall arrest, adoption of passive fall arrest systems such as guard rails and personnel nets instead of fall arrest harnesses which each worker must properly don and connect to appropriate anchorage points, and redesign of skylights and atriums to support the weight of workers. The list can go on, but adoption of change is challenging. Research to demonstrate feasibility and efficacy in the field, and to help overcome resistance to change is critical. Departure of our rapidly aging workforce and increasingly precarious employment threaten to increase the number of inexperienced workers, which adds to the urgency to reduce fall hazards. Working together, we can prevent many, if not all, fall-related deaths and injuries. To achieve this goal those of us in the research community must recognize and value applied research, field intervention studies, R2P, dissemination of information, and post-market effectiveness studies as planned integral components of our research protocols.

Cost of Fall-Related Fatal Occupational Injuries in Construction, 2003-2006

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Fall-related incidents remain the primary cause of fatalities in the U.S. construction industry. An analysis of fatality data from the Census of Fatal Occupational Injuries, maintained by Bureau of Labor Statistics, U.S. Department of Labor, indicate that for 2003-2006, a total of 4,864 workers were killed in construction from all causes (annual average 1,216). During the same period, one third of those construction fatalities resulted from a fall to a lower level, with falls from roofs accounting for 35% of those incidents.

To better understand the impact of occupational fatalities on society, a cost estimation model was developed by researchers from the Division of Safety Research, National Institute for Occupational Safety and Health. This model estimates the impact on the U.S. Gross Domestic Product from occupational fatalities in the construction industry to be $5.1 billion. The mean cost for each of these fatalities was nearly $1.1 million, with falls to a lower level having a similar mean value. Other cost estimates by case characteristics demonstrate the enormous toll of occupational fatalities in construction borne by U.S. society.

Introduction

The construction industry is dynamic, complex, employs a large number of workers, and plays an important role in the U.S. economy. This industry builds our roads, houses, and workplaces, and repairs and maintains our nation's infrastructure. Unfortunately, this sector, with many dangerous jobs, continues to have high numbers of fatal occupational injuries. The primary cause of fatal injuries in the construction industry is due to workers falling to a lower level. Typically one-third of all fall-related deaths involve workers falling from roofs and interior edges, or through roof openings or skylights. An analysis of the Census of Fatal Occupational Injuries (CFOI) database,maintained by the Bureau of Labor Statistics (BLS) for the period 1992-2000, indicated that during that 9-yearperiod, a total of 9,606 fatal injuries occurred in the construction industry, of which 3,058 (31.8%) of these fatalities were fall-related [Bobick 2004]. That same trend is still occurring a decade later.

Methods

This study uses occupational fatal injury data from CFOI from 50 States (excluding New York City) and the District of Columbia for the period 2003 through 2006 as the base for the counts and cost estimates. This system compiles data using multiple sources, such as death certificates, medical examiner records, workers' compensation claims, and reports to OSHA for decedents of any age as long as the death was a work-related fatal injury.

The cost to society of an occupational fatality was estimated using the cost-of-illness approach, which combines direct and indirect costs to yield an overall cost of an occupational fatal injury [Biddle 2004; NIOSH 2009]. For this study, direct costs include only a single nominal value for medical costs which was obtained from the National Council on Compensation Insurance [NCCI 1992–1995]. The indirect cost is derived by calculating the present discounted value of loss per person due to an individual occupational fatal injury (PVF) summed from the year of death until the decedent would have reached age 67, accounting for the probability of survival were it not for the premature death. Mathematically this is represented as follows:

$$PVF = \sum_{n=y}^{67} P_{y,q,s}(n)\,[Y_{s,j}(n) + Y_s^h(n)] * (1+g)^{n-y}/(1+r)^{n-y}$$

Where:

$P_{y,q,s}(n)$ = probability that a person of age y, race q, and sex s will survive to age n
q = race of the individual
s = sex of the individual
n = age if the individual had survived
$Y_{s,j}(n)$ = median annual compensation of an employed person of sex s, specific occupation j & age n (includes benefits by industry & wage growth adjustments)
j = specific occupation of individual at death
$Y_s^h(n)$ = mean annual imputed value of home production (h) of person of sex s & age n
g = earnings growth rate attributable to overall productivity
y = age of the individual at death
r = real discount rate (3%)

The wage component of the cost model consists of four parts: base wage, benefits, economy-wide productivity growth, and life-cycle wage growth. The base wage of the decedent at the time of death was derived from the BLS Occupational Employment Statistics, a Federal-State cooperative semi-annual establishment survey,which produces State-based occupational wages. Because this survey does not provide wage data by age,the wage value was adjusted to account for the age of the decedent at the time of death. The base wage was adjusted to include the value of employee benefits using BLS Employer Cost for Employee Benefits data from the National Compensation Survey Program. The BLS Employment Cost Index was employed to estimate the amount that wages rose in concert with the growth of the U.S. economy as a whole. To account for the final component of wage growth, estimates of the life-cycle growth – the salary growth due to individual worker experience – were used to adjust the base wage. Non-market losses or loss of household production were derived from time-diary data captured in The National Human Activity Pattern Survey study commissioned by the Environmental Protection Agency (Triplett's work,as cited in Expectancy Data [2000].

Results

Over the four-year study period, the total cost of fatal occupational injuries in construction was $5.1 billion in 2006 dollars. The highest number and the greatest cost of fatal occupational injuries in this sector resulted from Falls, accounting for just under 1/3 of all fatalities and costs. However, the mean cost for Falls in construction was lower than all event or exposure categories except Other. Fall to lower level accounted for

Table 1. Number and Costs of Fatal Occupational Injuries in the U.S. Construction Industry Sector by Event or Exposure, 2003-2006 (2006 Dollars)

Event or Exposure	No. of Fatalities	Total Cost (millions)	Mean Cost (thousands)	Median Cost (thousands)
All events or exposures	4,864	$5,113	$1,051	$1,045
Contact w/object & equip	952	1,005	1,055	1,009
Falls	1,582	1,602	1,013	1,029
Fall to lower level	1,543	1,572	1,019	1,031
Fall on same level	14	10	745	883
Other Falls	25	20	793	820
Exposure to harmful substance/environment	700	811	1,159	1,131
Transportation accidents	1,352	1,379	1,020	1,021
Fires and explosions	132	143	1,087	1,064
Assaults and violent acts	140	167	1,195	1,172
Other	6	5	857	962

nearly all, 98%, of the fatal injuries from Falls and the total costs for those incidents.

A closer inspection of the number and costs associated with Fall to lower level fatalities reveals that the 2-digit event code, Fall from roof, accounted for 35% of those incidents and the same percent of their associated costs. Two event categories at this hierarchical level, Fall from ladder and Fall from scaffold or staging, each contributed 16% of total cost resulting from Fall to lower level fatal injuries. The mean cost of Fall to lower level incidents varied substantially from a low of $482,000 for Fall down stairs or steps to a high of $1,194,000 for Fall from building girders/ other structural steel. The 3-digit event code, Fall thru floor surface experienced the highest mean cost of all Fall to lower level fatalities.

Of the 3-digit industry subsectors, Specialty Trade Contractors experienced nearly 2/3 of Fall to lower level fatal injuries, or more than twice the number found in the Construction of Buildings subsector and more than 14 times the number in the remaining subsector. The pattern was similar for the resulting total costs. However, the mean and median costs were highest for the Heavy and Civil Engineering Construction subsector. Among industries, Roofing Contractors experienced the greatest number, in addition to the highest total, mean, and median costs. While Residential construction Roofing Contractors had more fatalities and higher total costs, Nonresidential construction Roofing Contractors had slightly higher mean and median costs. No other industries exceeded an average cost of $1million per occupational fatality.

Table 2. Number and Costs of Fatal Occupational Fall Injuries in the U.S. Construction Industry Sector, 2003-2006 (2006 Dollars)

Fall Injury Category	No. of Fatalities	Total Cost (millions)	Mean Cost (thousands)	Median Cost (thousands)
Fall to lower level	1,543	1,572	1,019	1,031
Fall down stairs or steps	9	4	482	450
Fall from floor, dock, or ground level	104	112	1,075	1,084
Fall thru existing floor opening	61	67	1,099	1,103
Fall thru floor surface	12	15	1,228	1,200
Fall from ground level to lower level	18	17	926	913
Other falls from floor, dock, or ground level	13	13	1,024	969
Fall from ladder	271	259	956	984
Fall from roof	538	553	1,027	1,013
Fall thru existing roof opening	49	55	1,117	1,111
Fall thru roof surface	39	41	1,051	1,008
Fall thru skylight	71	72	1,020	1,001
Fall from roof edge	240	250	1,040	1,024
Other falls from roof	139	135	971	969
Fall from scaffold, staging	254	255	1,003	1,046
Fall from building girders/ other structural steel	91	109	1,194	1,167
Fall from nonmoving vehicle	80	80	1,005	1,055
Other falls to lower level	196	200	1,022	1,033
Fall on same level	14	10	745	883
Fall to floor, walkway, or other surface	9	6	706	652
Fall onto or against objects	5	4	816	907

Table 3. Number and Costs of Fatal Occupational Fall from Lower Level Occupational Fatal Injuries in Selected U.S. Construction Industries, 2003-2006 (2006 Dollars)

Construction Industry	No. of Fatalities	Total Cost (millions)	Mean Cost (thousands)	Median Cost (thousands)
Construction of Buildings	413	$ 387	$ 938	$ 955
Residential Bldg Construction	58	54	933	957
New Single-Family Housing Const. (ex Operative Bldrs)	95	91	962	1,046
Residential Remodelers	63	51	812	884
Commercial and Institutional Building Construction	90	89	987	1,009
Heavy & Civil Eng. Construction	75	88	1,177	1,178
Specialty Trade Contractors	1,007	1,054	1,047	1,038
Roofing Contractors	145	156	1,075	1,056
Residential construction	77	74	958	902
Nonresidential construction	51	50	984	982
Paint & Wall Cover Contractors	50	45	903	969

Conclusions

Falls are not only the leading cause of death within the construction industry, but they exact the highest toll on the U.S. society. These fatalities represent a $1.6 billion loss to the U.S. Gross Domestic Product, the measure of the country's overall economic output. While the number of fatalities has been the traditional measure used to direct public policy over the years, the cost of fatal injuries can also be used for this purpose. The total costs identified in this work suggest that Fall from roof, and more specifically Fall from roof edge,should be the focus of attention. However, Falls do not have the highest mean or median cost of fatal injury in construction but rather have the lowest. Examination of the costs at more detailed levels of event or exposure and the industry revealed similar variability in ranking based on measures of magnitude versus measures of cost. These cost estimates can be used to identify additional prevention efforts needed and the amount of savings from adopting interventions. For example, a guardrail system developed by NIOSH to prevent falls from unguarded surfaces, such as roofs,would provide benefits that far exceed the costs. A typical sloped roof consists of two roof surfaces, one in front and one in back. A roof surface of 50 ft x 16 ft would require a guardrail system costing about $1400 for each side, compared to the cost per fatalities of just over $1 million. Different, lower-cost, system configurations can be used to protect other unguarded edges. Finally, costs can help plan, augment, and prioritize occupational injury prevention and control efforts, evaluate safety and health interventions, and advocate for a safer work environment. Additional costs using this model could be generated to accomplish this goal.

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Overview of NIOSH-Designed Guardrail System

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The primary cause of fatal injuries in the U.S. construction industry is workers falling from heights. In 2004-2007, a total of 4,843 workers were killed in construction, of which 1674 (34.6%)involved falling to a lower level. Previous NIOSH research developed a unique, patented, multifunctional guardrail system. The initial design was developed for residential roofing and was adjustable from flat to seven roof slopes, from 6/12 (27°) to 24/12 (63°). Subsequent modifications were developed for flat and vertical surfaces that need guarding during construction and renovation activities. Lab tests verify the current design supported a dynamic load to the top rail of more than twice the required 200 lbs specified by OSHA. Future plans involve an extended field study to evaluate the system in different work settings. When correctly installed, this system should help prevent fall-related injuries and deaths.

Introduction

Fall-related incidents are the primary cause of fatalities in the U.S. construction industry. An analysis conducted by the National Institute for Occupational Safety and Health (NIOSH) of fatality data from the Census of Fatal Occupational Injuries (CFOI), maintained by the Bureau of Labor Statistics (BLS), indicate that during the period 2004-2007, a total of 4,843 workers were killed in construction from all causes [BLS 2005–2008]. During the same period, 1,674 construction fatalities occurred due to falling to a lower level; this is 34.6% of all construction-related fatalities that occurred in the period 2004-2007. Further analyses of CFOI data indicated that construction-related falls from roof edges, through roof and floor openings, and through skylights resulted in a 4-year total of 652 fatalities, or 38.9% of all construction fall-to lower-level fatalities. These types of situations can be modified with a guardrail system to prevent workers from falling to a lower level.

The current mandatory regulations for the construction industry are contained in the Code of Federal Regulations (CFR), Title 29, Part 1926 (Construction), issued by the Occupational Safety and Health Administration (OSHA). Specifically, Subpart M lists the requirements that are related to workplace falls. In addition to Subpart M, OSHA issued Directive No. STD 3.1 (dated December 5, 1995) that provided an interim enforcement policy on fall protection for certain residential construction activities. Directive 3.1 has been superseded by current Directive No. STD 3-0.1A (dated June 18, 1999). Section 1926.501 of Subpart M discusses the requirements for fall protection. Subsection 1926.501(b)(4)(i) states that "Each employee on walking/working surfaces shall be protected from falling through holes (including skylights) more than 6 feet(1.8 m) above lower levels, by personal fall arrest systems, covers, or guardrail systems…" [Mancomm 2008]. The strength of guardrails must meet OSHA regulation 29 CFR 1926.502(b)(3) which states that "Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction, at any point along the top edge."[Mancomm 2008].

Figure 1. Test set-up with manikin ready to fall against top rail.

The use of covers and guardrail systems are effective measures to protect workers from falling through roof and floor holes. Commercial and job-built guardrails can be used to provide protection for unguarded roof edges(both steep and low slope) or interior edges, including balconies or stairways, during residential construction and renovation activities.

Initial guardrail design for sloped configurations

Research conducted by the Division of Safety Research, NIOSH, Morgantown, WV has developed a patented multi-functional guardrail system that can provide protection for many construction situations that expose workers to potential fall-to-lower-level hazards (U.S. Patent No. 7,509,702; Canada patent-pending). The initial design was developed for use on residential roofs and was based on the footprint of a commonly used roof bracket, 3. wide by 18. long, which uses three 16-d nails to attach it to a sheathed roof truss.

Resultant dynamic force was 435 lbs, more than twice OSHA The roof bracket base is designed to be used on flat surfaces and can be adjusted to seven roof slopes from 6/12 (27°) thru 24/12 (63°). As the roof slope increases in steepness, the vertical tube, which supports the top rail and midrail, will lean back from vertical, and may result in the top rail height being less than the 39-inch minimum required by OSHA regulation 29 CFR 1926.502(b)(1). To ensure this height is met, the NIOSH system has been designed so the fixtures that support the top rail and midrail can be adjusted upward. The fixtures are loosened with a handle at the back that permits it to be slid up the vertical tube to the required OSHA height. Lab testing verified that hand tightening is quite sufficient to ensure that cross-members will not slip down the vertical tube when contacted with a 200-lb force, as specified by the OSHA standard. The system has successfully supported an impact force of 435 lbs from a test manikin that fell against the top rail (Figure1), more than twice the OSHA requirement, without slippage or failure of any components. The test procedure and manikin have been described in McKenzie et al. [2004] and Bobick and McKenzie [2005].

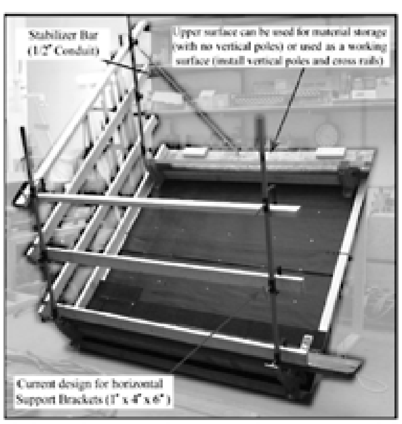

Figure 2. Lab set-up to show 3-sided protection for chimney or dormer work (3rd side not in place yet)

Because of this adaptable design, a guardrail can be installed literally anywhere on a residential roof, either to assist with shingle installation or afterward when a worker has to spend multiple shifts in one location, such as for chimney or dormer work. As shown in Figure 2, this multi-functional guardrail will be ideal to provide 3-sided protection for masons, carpenters, laborers, and other roof workers.

Follow-up flat and vertical designs

During one of the initial field tests of the roof system in Florida, the construction contractor wanted to use the system for edge protection inside the residence under construction. The initial design of the base plate was not practical for use on stair treads. Additional bases (Flat and Vertical, Figure 3)were developed with smaller footprints – 6. by 6. for the flat and 3 by 12. for the vertical. These two bases are ideal for temporary hand rail construction during house framing. When any of the three bases are installed on the job site, proper fasteners must be used and correctly and securely inserted into the wood structure. When the base of the roof system is installed, three 16-d nails, which are 3½" in length,should be used. Screw fasteners (3. length) are recommended to install the flat and vertical bases to ensure the system is properly mounted to the structure to provide adequate worker protection. Also, a nail gun should never be used to install nails with metal base plates. A slight misalignment can easily result in a nail ricochet that can injure the nail gun operator or

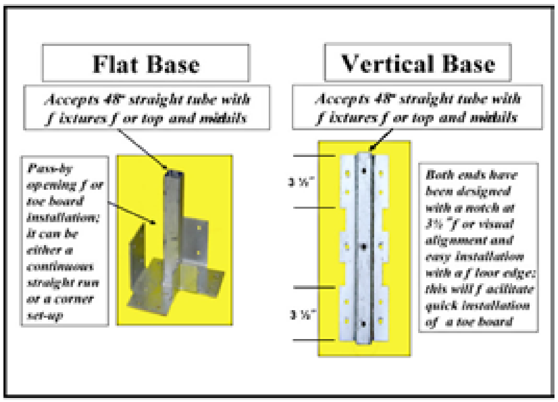

Figure 3. Flat base (6" x 6" footprint) and vertical base (3 1/2" x 12" footprint) for the guardrail system.

nearby co-worker. It is also harder to be sure the nail driven by an air gun was correctly inserted into the wood structure. If the air-driven nails miss the roof truss, floor joist, or wall stud underneath, the protective guardrail is not properly mounted and secured. Feedback from safety professionals in the bridge construction industry indicated that the flat base system could easily be used in bridge construction. Bridge contractors commented that this re-usable guardrail system, when installed along the length of the bridge deck during new or repair work, would reduce guardrail installation time and reduce labor and raw material costs, when compared to building and installing stick-built guardrails. Figure 2. Lab set-up to show 3-sided protection for chimney or dormer work (3rd side not in place yet) Figure 3. Flat base (6" x 6" footprint) and vertical base (3 1/2" x 12" footprint) for the guardrail system. Figure 4. Temporary guarding of floor opening using flat and vertical bases. Both the flat and vertical bases use the same pocket to receive the straight end of the 60° bent rail tube or a 48" straight rail tube to support the fixtures for the top rail and midrail cross-members. Figure 4 shows the flat and vertical bases being used to install temporary guarding around a large floor opening. Other designs are also being developed by the NIOSH research team for additional uses in the construction industry.

Field evaluation study

In an effort to gain real-world experience over a lengthy period of usage, arrangements have been made to evaluate the guardrail system during an extended field study with two West Virginia residential construction contractors, along with the West Virginia University (WVU) Safety and Health Extension and the North-Central West Virginia Home Builders' Association. During the first two months of the planned field study, the work crew will be observed as they normally conduct their work. This will serve as the baseline. Construction specialists from WVU Extension will train the crew on the correct and safe use of the guardrail system. During the six months following the baseline, the guardrail system will be used where appropriate to install and evaluate various system components. WVU specialists will monitor installation and system usage during construction activities. The NIOSH-developed roof guardrail system provides a level walking-working surface with a secure guardrail system directly behind the work location. This provides a more secure work station that: (a) improves the workers' posture and stability, (b) could be touched for reassurance; or (c) could prevent a fall to a lower level. The field evaluation study will collect information on worker posture and stability, and whether the guardrail is used for reassurance, resting, or protection. Other data to be collected include – time to install the system initially; time to install the system after four months of using it; digital photos to document workers' postures during the baseline period compared with postures after the system has been installed; and feedback from crew members and management regarding modifications they feel might improve the functionality of the guardrail system.

Figure 4. Temporary guarding of the floor opening using flat and vertical bases.

Summary

The primary cause of construction fatalities is workers falling to a lower level. Typically one-third of all fall-related deaths involve workers falling from roofs and interior edges, or through roof openings or skylights. These falls can be prevented by using guardrails. The output of a previous NIOSH project was a unique, patented, multi-functional guardrail system for use on a variety of unprotected workplaces in construction. The initial design was developed for use on residential roofing and is adjustable to seven roof slopes. Subsequent modifications have been developed for flat and vertical surfaces that need guardrail protection, such as stairs or balconies, decks, and holes that need protection. The current design will be field-tested by two WV residential contractors, with WVU Safety & Health Extension and WV Home Builders' Association during typical construction activities. Installation times, photos,videos, and worker feedback will be collected.

Conclusion

Laboratory testing verified that the current design supported a loading to the top rail of more than twice the strength requirements of 200 lbs, as specified by OSHA regulations. Once this multi-functional guardrail system is commercially available, temporary guarding will be able to be installed at numerous locations on construction and renovation work sites. This innovative system should help to prevent fall-related injuries and fatalities.

Acknowledgement

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The Typical Scenario: Towards Extension of STF Analysis

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Slips, trips and falls (STFs) associated with accidents referred to by some authors as "minor"or ordinary, can be compared with other occupational accidents (OAs) from the standpoint of their causal factors, except for those that are directly antecedent to injury. Research into typical STF scenarios is therefore wholly justified. We describe two methods for developing these scenarios based on data collected from two different work activity sectors. Only the second method, whose empirical content is curtailed in favour of a more systematic approach, allows U.S. to envisage developing prospective and probability-related STF scenarios.

Introduction

In France, the typical scenario concept developed for road traffic accidentology research purposes [Fleury et Brenac 2001] is currently applied to occupational accidents within the "Slips, Trips and Falls"group. "Typical scenario" is a generic expression, which means integrating, in this case, a number of similar accidents based on the definition provided by Khan and Abbasi [2002], namely that "A scenario is neither a specific situation, nor a specific event, but a description of a typical situation that covers a set of possible events or situations".

This approach is justified to the extent that our research is directed towards studying, in depth, accident genesis with the aim of acquiring knowledge that will enable prevention actions to be more accurately targeted. Whilst creation of an "STF" OA category emerges from a concern for consolidation, it has very often prompted action on factors directly antecedent to injury. However, what is relevant for facilities, at which STF risk is present due to the type of work activity (e.g. in the meat processing industry), is in fact irrelevant where the risk is less obvious, despite its presence.

Combinations of factors common to several STFs were empirically identified within all accidents analyzed at a regional power distribution facility [Leclercq and Thouy 2004] and a rail transport company [Leclercq et al. 2007]. The work described here is a methodological contribution to building typical STF scenarios, which goes beyond the exclusively empirical stage of this building process. Our research therefore falls within the framework of a systemic accident model [Hollnagel 2004], which has proved beyond any doubt its value in relation to STF prevention [Bentley 2009]. Both contributing factors and so-called root causes are integrated into an accident genesis model by considering:

- Facts necessary to accident occurrence, which are delimited by the socio-technical system and involve all the system components: I (the individual), T (the task he performs), Ma (the machine heuses) and Mi (the environment in which he works) (I, T, Ma, Mi);

- Logical relationships (antecedences) between these facts.

Method

Data

The data used were extracted from an existing sample of accident-on-the-level reports, which provide at least injury contributing factors upstream of the immediate factors. However, the range of the analysis still remains limited in prevention terms because these data do not cover all factors explaining the accident.

Identifying generic factors

Only report passages containing information concerning one of the system components (I, T, Ma, Mi) and expressing a fact that played a part in accident occurrence, are retained as relevant facts to be analyzed. Most of these can be consolidated into equivalence classes under a generic factor heading. These generic factors are not a priori defined. They emerge during the analysis. Their formulation and number ares tabilised when new accident reports read provide no further data. This research stage requires specialist involvement.

Analyzing accident reports

The frequency at which generic factors appear within all the accident reports is then evaluated. When generic factor formulation is stable, these factors are subjected to a second analysis involving existence of logical relationships between them. The logical relationships between factors are extracted from both the report and specialist knowledge.

Results obtained using the empirical method and comments

The method described above was first partially implemented on a limited number of STFs which occurred at a rail transport company [Leclercq et al. 2007]. Table 1 displays the results of 2 of the 8 typical scenarios reported by the authors and both are linked to an individual accident report that contributed to development of that scenario.

This scenario-based approach reveals accident situations that are firmly founded in the specific characteristics of certain jobs: inspection prior to train departure, brake failure or an unusually high railway sleeper. On the other hand, other situations are less specific: walking in a corridor, talking to a colleague, tripping on a step. This approach integrates factors, whose accident causing characteristics are circumstance-related [Monteau and Pezet-Langevin 2006]. For example, in the second scenario (Table1), unfamiliarity with location and the unexpected nature of the obstruction (a step in a corridor) are shown to be accident factors in this case. In other situations, unfamiliarity with location can be paradoxically a safety factor, when a person is walking on a site (where obstructions and uneven ground are often expected) and concentrates fully on locations unknown to him.

Table 1. Two individual accident cases and their typical scenarios (on same line)

Individual reports that contributed to typical scenario development	Typical scenario (number of accident cases that contributed to its development)
The inexperienced train driver replaces the sick assigned driver in the locomotive. When inspecting the train prior to departure, he detects a brake failure, which he has never encountered on this machine. To prevent any delay and to deal with the failure, he hurries along the track and trips on an unusually high sleeper. He collides violently with the machine.	A driver inspects the train before departure. The situation is unusual and he is concerned by a problem he has to solve to ensure the train leaves on time. He hurries along the train or track. He trips or twists his ankle (4 consolidated accident cases).
The railway employee goes to a meeting at the same station each month. He walks down a corridor divided by a single step. When talking to a colleague behind him, he trips on the step and falls.	An employee walks normally in a place he goes occasionally, but which is not his usual workplace. The corridor features a difference in level, on which he trips and loses balance (6 consolidated accident cases).

Accident comparison and consolidation are empirical, so we observe that the number of factors common to several accidents is small. The analyst in fact compares the accidents overall and excludes systematically taking into account factors and their logical relationships. Moreover, Table 1 shows that the information "An inexperienced driver replaces the sick assigned driver in the locomotive", which contains factors only necessary to occurrence of the specific accident, is excluded from the corresponding recurrent scenario. The number of accidents considered is small, so the contribution of this information cannot be checked from a probabilistic point of view.

Results obtained using a systematic method and comments

Seventy one reports of generally serious, occupational accidents on the level in the building and civil engineering sector were retrieved for usage from the INRS database [Ho et al. 1986]. The activity sector and seriousness are considered uniform enough to justify combining the accidents. The empirical part tends to decrease, thereby opening the way to a more systematic approach. The principles underlying comparison of generic factors and development of scenarios are described and illustrated by examples.

Identification of 21 generic factors

In this case, 25 out of the 71 accident reports were enough to identify 21 generic factors within the four component classes I, T, Ma and Mi. The number of individual factors consolidated under these different generic factors ranges from 2 to 17. We illustrate this by recording a few generic factors in Table 2 below.

Seeking logical antecedent relationships between generic factors.

Having identified and classified all the individual factors, the specialist returns to each accident report and records the logical antecedent relationship existing, according to the report, between factors compared two by two. Table 3 displays the different possible relationships between factors X and Y.

Table 2. Number of generic factors identified for each system component, followed by an example

Component	No. identified generic factors	Example of generic factor
I	3	Years of service or experience limited in building and civil engineering sector
T	9	Task performed involves cooperation of 2 or more operators together who were required to coordinate themselves
Ma	5	Equipment required by regulations or good working practice for performing planned task is missing
Mi	4	Presence of open cavities, grouted starter bars or projecting parts in working area of a construction site in progress

Table 3. Antecedence relationship logic table

X is antecedent of Y	Y is antecedent of X
1	1
0	1
1	0
0	0

Antecedence matrix

Results of these inter-factor tests are recorded in a (21,21) matrix, which is shown partially in Table 4 for reasons of space. The matrix content shows that:

- Generic factor 1 ("a machine or vehicle used on the site caused the injury" is antecedent of no other factor in any of the reports: this is one of the factors intervening at the end of the accident process.

- Factor 2 "an equipment item or material on site was of no use and obstructing" was found to be antecedent of factor 3 "equipment or a part thereof appearing as a potential hazard" in at least one report, as well as of factors 1, 5, 6, etc.

- Factor 5 "an element in the work surrounding situation had an unfavourable effect on the victim's activity"was recorded from at least one report as antecedent of factors 1, 2, 3, 4, etc., revealing the possibility of reciprocity in the antecedence relationship studied from one accident to another.

no passing from one factor to another, observable from absence of an antecedence relationship, could be confirmed or denied by examining additional accident cases. This type of outcome already enables U.S. to envisage developing prospectively and on the basis of realistic data, typical accident scenarios in the building and civil engineering industry after taking into account information on passing or not passing from one factor to another. The following scenario has been built in this way using generic factors: "A fairly inexperienced worker is in charge of monitoring the level of masonry material in a hopper. He climbs onto the hopper because he cannot check this level from the ground. But, in this position, one of his feet slips and is trapped in a moving part of the operating ancillary installation, which has no guard."

The next methodological research stage leading to scenarios closer to real, probability-based accidents is to consider more complex logical combinations and the frequency of these combinations for a representative set of accidents, in this case fatal STF accidents in the building and civil engineering sector.

Table 4. Partial antecedence matrix (to be read in the direction of the arrow)

Component	No. identified generic factors	Example of generic factor
I	3	Years of service or experience limited in building and civil engineering sector
T	9	Task performed involves cooperation of 2 or more operators together who were required to coordinate themselves
Ma	5	Equipment required by regulations or good working practice for performing planned task is missing
Mi	4	Presence of open cavities, grouted starter bars or projecting parts in working area of a construction site in progress

This way of systematically studying data from the 71 accidents used allows U.S. to understand the possibilities of passing directly or indirectly from one factor to another in causing an accident in the building and civil engineering sector. Conversely,

Conclusion

This research, whose aim is essentially methodological, confirms the significance of pursuing developments aimed at locally characterizing (by activity sector, company) typical STF scenarios. Systematic processing of more detailed analyses of all STFs, which have occurred over a limited, recent period, will allow U.S. to reveal prevention targets that are both efficient and specific to the study area.

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Fatal Falls in the U.S. Construction Industry, 1992-2008

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This study analyzed trends of fatalities resulting from fall injuries in the U.S. construction industry from 1992 through 2008. Three large, nationally representative datasets, the Census of Fatal Occupational Injuries, the Current Population Survey, and the Medical Expenditure Panel Survey, were analyzed. The deaths from falls among construction workers totaled 6,304 during the study period. More than 60% of the fatal falls occurred among small construction establishments with 10 or fewer employees. Rates of fatal falls varied among construction occupations, in which ironworkers and roofers ranked the highest in fall fatalities. Hispanic workers, especially foreign-born workers, younger and older construction workers also had a higher risk of fatal falls.

Introduction

CPWR - The Center for Construction Research and Training, formerly known as the Center to Protect Workers' Rights, has conducted construction safety and health research funded by NIOSH since the 1990s. Falls are the leading cause of death in the U.S. construction iindustry [Dong et al. 2009; Sokas et al. 2009, 2007; CPWR, 2008; Derr et al. 2001; Becker et al. 2001], and the second cause of nonfatal injuries in this industry [CPWR 2008; Courtney et al. 2002; Cattledge et al. 1996]. Falls not only cause a great deal of suffering for construction workers, but also bring financial burdens to workers' families, employers, and society [Bunn et al. 2007; Gillen et al. 1997; Leamon and Murphy 1995]. Therefore, injuries from falls remain a research and training target and priority at CPWR. This study examined the patterns and trends of fatal falls in construction, analyzed demographics and characteristics of fatal falls among construction workers, and identified high-risk occupations and populations while providing updated statistics for fall protections and interventions.

Methods

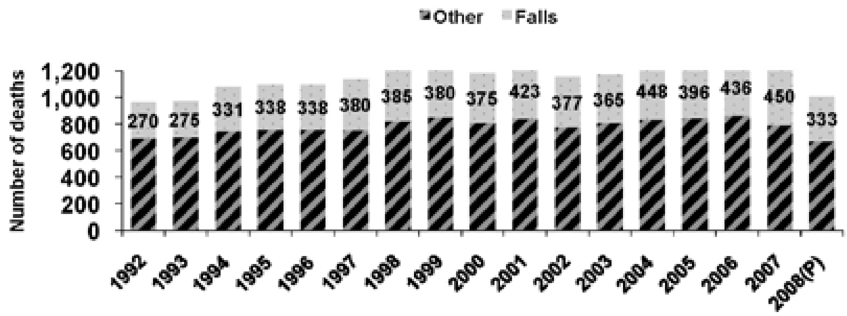
Fatality numbers were obtained from the Census of Fatal Occupational Injuries (CFOI). The CFOI is a federal-state cooperative program implemented in all 50 states and the District of Columbia [Jacobs EE 2004]. The CFOI data for 1992-2008 were used for the overall trend analysis. The number of workers in the construction workforce was taken from the Current Population Survey (CPS), a national monthly household survey with a sample size of 60,000 households. Both the CFOI and CPS are conducted by the U.S. Bureau of Labor Statistics (BLS). Employment by establishment size was estimated based on the self-reported data from the Medical Expenditure Panel Survey (MEPS) conducted by the Agency for Healthcare Research and Quality (AHRQ). MEPS is a set of large-scale surveys of families and individuals, their medical providers, and employers across the United States. MEPS respondents were asked, "How many persons are employed by (EMPLOYER) in a usual week at the location where (PERSON) works/worked)?" Only data from 2003 to 2008 were used for the detailed data analyses in order to reduce the effects of the data system changes (such as the industrial classification) across the study period.

Risk of fatal falls was measured by deaths per 100,000 full-time equivalents (FTEs) assuming a full-time worker works 2,000 hours per year (40 hours*50 weeks). In addition to computed death rates, a risk index was created in order to compare risk of falls between subgroups and the construction industry as a whole; where the average risk of fatal falls for the construction industry was used as the reference (risk = 1). All statistical analyses were performed with SAS version 9.2 [SAS Institute 2008].

Results

From 1992 to 2008, about 6,304 deaths in construction were caused by falls. Although the overall death rate of construction workers declined during the study period, the proportion of fatal falls in construction increased from 28% in 1992 to 33% in 2008 (Figure 1). About 99.5% of the fall decedents were male workers in construction, and more than 60% of them were employed in establishments with 10 or fewer employees. Many fall decedents lacked experience in construction work. More than 50% of such deaths were among construction workers who were employed less than one year with their current employers.

Figure 1. Number of fatal falls in construction, 1992-2008



Source: 1992-2008 Census of Fatal Occupational Injuries. P = Preliminary

Table 1. Risk index from falls by selected characteristics, 2003-2008

	2003	2004	2005	2006	2007	2003-2007
Age						
16-19	0.86	1.33	1.63	1.07	1.41	1.26
20-24	0.95	0.72	0.69	0.62	0.66	0.73
25-34	0.78	0.64	0.73	0.76	0.83	0.75
35-44	0.87	0.94	0.80	0.88	0.82	0.86
45-54	1.09	1.06	1.09	1.10	1.25	1.12
55-64	1.44	1.68	1.78	1.72	1.16	1.56
65 and over	3.79	4.02	4.33	3.26	3.11	3.70
Race						
White	0.92	0.92	0.93	0.93	0.92	0.92
Black	1.00	1.37	0.75	1.33	0.86	1.06
Hispanic origin						
Hispanic	1.26	1.37	1.48	1.37	1.14	1.32
White, non-Hispanic	0.93	0.86	0.86	0.86	0.93	0.89
Foreign-born						
Foreign-born	1.44	1.39	1.47	1.38	1.22	1.38
Native	0.90	0.91	0.87	0.88	0.93	0.90
Self-employed						
Self-employed	0.83	0.88	0.75	0.84	0.88	0.84
Wage-and-salary workers	1.05	1.03	1.07	1.04	1.02	1.04
Establishment size*						
1-10 employees	1.15	1.14	1.17	1.28	1.16	1.18
11-19 employees	0.84	0.79	0.90	0.61	1.10	0.85
20-49 employees	0.96	0.85	0.64	1.01	0.95	0.88
50-99 employees	0.49	0.52	1.21	0.80	0.86	0.78
100+ employees	0.51	0.61	0.61	0.72	0.69	0.63
Region						
South	1.12	1.19	1.29	1.05	1.14	1.16
West	0.86	0.72	0.67	0.83	0.68	0.75
Northeast	0.81	0.95	0.77	0.92	1.06	0.90
Midwest	1.15	1.01	1.04	1.23	1.07	1.10
Overall construction#	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Sources: 2003-2008 Census of Fatal Occupational Injuries, Current Population Survey, and Medical Expenditure Panel Survey.
** The MEPS data was used to estimate establishment size.*
 # Risk =1 for the overall construction industry used as the reference for comparisons

Table 1 reports the risk of fatal falls by selected characteristics. Construction workers aged 55 or older had the highest risk among all age groups. The risk of fatal falls for workers who were 65 years and older was almost 4 times higher than the construction industry on average. Younger workers who were under age 20 also had a higher risk of fatal falls. Hispanic workers, in particular those who were foreign-born, were also more likely to have fatal falls than their non-Hispanic and native counterparts. It is striking that the risk of fatal falls among small establishments with 10 or fewer employees was almost double than that for establishments with 100 or more employees. With regard to geographic differentials, the risk of fatal falls was higher in the South and Midwest when compared with all of construction nationwide.

When the rates of fatal falls were stratified by occupation, ironworkers, roofers, and welders ranked the highest in construction fatal falls (Table 2). The rate of fatal falls for ironworkers was as high as 11 times of that for all construction workers on average, while the risk for roofers was 7 times higher than construction as a whole.

In terms of types of falls, over 97% of fatal falls in construction were caused by falling to a lower level. Nearly one third of fatal falls in construction were caused by falls from roofs including roof edges, roofs unspecified, and skylights. Falls from ladders (17.0%) and from scaffold staging (16.6%) ranked the second and third type in construction, respectively.

Discussion

This study profiles fatal falls in construction from 1992 to 2008. The findings show that fatal falls are still the leading cause of death in construction, and that the proportion of fatal falls had increased when the economy was in the peak before its recent downturn. Risk of fatal falls varied among construction occupations and demographic groups. To reduce fatal falls, fall prevention strategies should target Hispanic workers, in particular those who are foreign-born; older workers who are age 55 or older, and young workers who are under 20 years old. New workers and workers who are employed in small construction establishments also need special attention and prevention efforts.

Table 2. Rate of work-related deaths from falls by selected occupations, 2003-2008

	2003	2004	2005	2006	2007	2003-2007
Selected occupations						
Ironworker	38.0	34.7	42.8	55.1	46.6	43.4
Roofer	21.6	32.2	17.6	30.3	28.0	26.0
Laborer	6.7	7.9	7.7	7.6	6.4	7.3
Welder	5.8	4.5	8.1	8.7	6.5	6.7
Painter	5.4	5.9	3.7	4.3	4.0	4.7
Brickmason	2.6	4.8	6.1	2.3	6.0	4.3
Carpenter	4.3	4.5	5.0	3.8	3.4	4.2
Drywall installer	3.4	4.9	3.0	4.3	2.2	3.6
Foreman	3.1	3.5	2.6	2.6	3.8	3.1
Electrician	2.9	3.9	1.5	2.3	2.2	2.5
All construction	**3.7**	**4.2**	**3.5**	**3.7**	**3.8**	**3.8**

Sources: 2003-2008 Census of Fatal Occupational Injuries and Current Population Survey.

Rate = per 100,000 full-time equivalent workers

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Outcomes of a Revised Apprentice Carpenter Fall Prevention Training Curriculum

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Falls from heights are a leading cause of morbidity and mortality among construction workers, especially inexperienced workers and those performing residential construction. We used a comprehensive needs assessment to identify gaps in apprentice carpenters' preparation to work at heights, used these results to guide a school-based fall prevention curriculum to fill these gaps, and measured the effects of the revised curriculum on knowledge, beliefs, and fall prevention behaviors.

Introduction

Falls are the leading cause of mortality and morbidity in the construction industry, which experiences more fatalities than any other industry. [BLS 2007b] Residential construction is at particularly high risk, with falls accounting for 42% of fatalities in this field [BLS 2007a]. Residential carpenters are covered by an OSHA fall prevention guideline, rather than by mandated regulations [OSHA 1999]. These carpenters also work in small crews at rapidly changing and geographically dispersed work sites, hampering interventions to reduce fall risks. We conducted a fall prevention training intervention study based within a carpenter apprenticeship training program.

Methods

The study population was union apprentice carpenters attending regularly scheduled training at the St. Louis Carpenters' Joint Apprenticeship Program (CJAP) in Missouri, USA between December 2005 and March 2009. CJAP is supported by the Carpenters' District Council of Greater St. Louis and Vicinity and the Home Builders Association of Greater St. Louis and Eastern Missouri.

Our study consisted of three phases: 1. Pre-intervention baseline measures and comprehensive needs assessment, 2. Curriculum re-design and delivery directed by the findings of the needs assessment, 3. Post-intervention measures to assess the effectiveness of the curriculum based intervention. All procedures were approved by the Institutional Review Board at Washington University.

In Phase I, we used results from focus groups and previous research to design a questionnaire measuring knowledge, attitudes, and self-reported fall prevention behaviors, and developed a work site audit tool to document observed fall hazards and fall prevention behaviors. We collected 1,027 questionnaires from apprentice carpenters and 197 work site audits from residential construction sites. Detailed findings of these pre-intervention measures have been reported in prior publications. [Kaskutas et al. 2009, 2010; Lipscomb et al. 2008]. Salient findings included a high rate of reported falls from height among apprentices in the previous year (16%). The most common type of fall was from a ladder (29%), though apprentices perceived ladder use as the lowest-risk task. Apprentices who reported a fall had fewer senior carpenters at their work sites, were 40% more likely to report unsafe co-worker behaviors, and were twice as likely to work in residential construction rather than commercial. Apprentices' knowledge of work safety standards varied widely. Work site audits showed many unsafe behaviors, including improperly erected ladders and unprotected openings and edges.

In Phase 2, we addressed the gaps in apprentice training identified in Phase I through changes in the apprenticeship training content, timing, and delivery. Curricular changes focused on tasks that were frequently performed by apprentices, that were frequently performed before receiving formal training, and that were commonly reported or observed as performed unsafely. These tasks included ladder use, work around floor openings, truss setting, and scaffold use. Use of the comprehensive gap analysis allowed U.S. to identify curricular changes that would match our overall goals of improving fall safety. Changes in training delivery emphasized more hands-on and participatory approaches consistent with adult learning principles, and greater integration of real-life stories into the training. Changes in the timing of safety training within the apprenticeship schedule were made so that training for specific tasks occurred prior to expected performance of the task at work. A detailed description of the revised fall prevention curriculum is given in an upcoming publication [Kaskutas et al. Journal of Safety Research, in press].

In Phase 3, we performed post-intervention questionnaires and work site audits to evaluate change since the baseline measures performed in Phase 1. The revised curriculum was begun in April of 2007; post-intervention measures were collected between September 2008 and March 2009. We did not identify individual carpenter apprentices in their questionnaire responses; the evaluation thus consisted of cross sectional data pre- and post-intervention. Comparisons between pre- and post-intervention questionnaire results were made using t-tests and chi-square tests. Linear regression was used to control results for potential differences in results due to age, contractor size, residential work experience, and the apprentice to journeyman ratio on different work sites.

Results

The post-intervention questionnaire was completed by 961 apprentices, with a response rate of 98%. Comparisons of pre-intervention to post-intervention scores in fall prevention knowledge, crew behaviors, confidence in ability to prevent a fall and perceived safety climate showed statistically significant improvements following the curriculum intervention (Table1).

Table 1. Pre- and Post-intervention Fall Safety Questionnaire Scale Scores

	Pre-intervention Mean (SD)	Post-intervention Mean (SD)	p-value (t-test)
Knowledge score	4.5 (1.4)	5.0 (1.6)	<0.01
Behavior score	12.7 (3.9)	15.0 (4.4)	<0.01
Confidence score	12.7 (2.0)	13.4 (1.8)	<0.01
Safety Climate score	14.5 (2.9)	15.5 (2.8)	<0.01

We found no difference in age and time worked in trade in the pre- and post-intervention apprentice populations. To control for temporal trends in carpenter work and employment during the survey periods (the post-intervention survey coincided with the beginning of the national downturn in new home construction) we ran separate linear regressions with the Knowledge, Behavior, and Safety Climate scales as outcomes. We found that the statistically significant improvements in post-intervention scores were maintained after adjusting for apprentice age, contractor size, residential construction experience in past year (yes/no), and apprentice: journeyman ratio. All factors were significant except age. The adjusted magnitude of the improvements was 2.4 points for Behavior scales, 0.93 points for Safety Climate scales, and 0.07 points for knowledge scales on post-intervention surveys. Improvements were similar across three categories of time in trade (< 1 year, 1-5 years and 5 or more years).

In addition to these changes in self-reported knowledge of fall safety guidelines, crew behavior, and safety climate, we found improvements in observed safety behaviors at work sites.

Comparison of pre- and post-intervention work-site fall safety audits showed improvement across all nine audit domains: safety climate and housekeeping, floor joists and subfloor, floor openings and edges, wall openings, truss setting, roof sheathing, ladders, scaffolds, and use of personal fall arrest systems. Overall compliance with observed fall safety rose from 59% of items to 75% ($p < .01$). Examples of changes in individual items from the 72-item audit are shown in Table 2.

Table 2. Percent compliance with fall safety items observed at work site audits

Individual Fall Safety Items	Pre-intervention n=197	Post-intervention n=200
Floor opening guarded	50	67
Controlled Access Zone adequately marked and monitored	2	28
Adequate guardrails	65	91
Window openings guarded	50	80
Truss chain removed safely	33	82
Step ladder not used while leaned against wall	51	76

The post-intervention period was also marked by a decrease in self-reported falls from height in the past year (16% to 13%) and a decrease in reports by the apprentices that they knew someone who had fallen from height in the past year (51% to 44%). These results were statistically significant in a chi-square analysis; we are currently modeling the results to adjust for the effects of other risk factors that changed between the two periods.

Discussion

We implemented a fall prevention training intervention that was guided by data from a comprehensive needs assessment. This curriculum intervention was followed by measureable improvements in knowledge, self-reported safety behaviors, and observed safety behaviors among residential carpentry work crews.

There are important limitations to this study, as the study design - a pre- post-intervention design without a concurrent control group – limits the strength of the conclusions that may be drawn from our findings. Other factors may account for the improvements in fall prevention behaviors we observed, including a change in the makeup of the workforce or nature of the work due to the downturn in new home construction that occurred during our study period. The observed improvements may also have occurred as a consequence of changes in the safety training activities and safety culture of construction contractors who employed our study group. Anecdotal evidence suggests that several contractors who were aware of our study made changes in safety policies and training during the study period. This can be viewed as a confounder in the analysis of our apprentice training school-based intervention; it can also be viewed as a result of the intervention.

Another limitation is the short follow-up period after the initiation of the curricular changes. Our post-intervention measures began little more than a year following the implementation of the new curriculum; many of the upper-term apprentices in this four-year training program had received little or none of the revised training at the time of evaluation. We are continuing annual follow-up to examine the longer-term results of these changes on the carpentry workforce. Finally, our study was designed to measure changes in knowledge, attitudes, and behaviors related to the training intervention, and was not powered to detect changes in mortality or morbidity related to falls.

Our study had several strengths, including the sampling of a large group of apprentices at different stages of training, and the high participation rates in surveys (98%) and work site audits (96%). Importantly, our study measured observed safety behaviors at almost 400 work sites in addition to self-reported behaviors. We benefited from a close collaboration between the apprenticeship program, the carpenters' union, and the home builders. The intensity of the evaluation was made possible by this organized environment. Though our evaluation would be very difficult to complete outside of a union-based apprenticeship, elements of our training program could readily be adapted for use in other settings.

Our intervention affected the training that apprentice carpenters received in the school-based portion of their apprenticeship, but not the training and mentoring they received on the job. Previous work by our team [Kaskutas et al. 2010; Lipscomb et al. 2008] suggests that inexperienced carpenters do not receive the type and amount of mentorship they would like from journeymen on their work crews. Future work is needed to improve the training and mentoring received by early-stage workers, who are at significantly higher risk of injury than more experienced carpenters.

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Today's Goal is Tomorrow's Safety: Harness Based Work at Height

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Once the third leading cause of work-related death across all industries, falls have surpassed workplace homicide to become the second leading cause after motor vehicle crashes. Last year alone, an estimated 717 workers died of injuries caused by falls from ladders, scaffolds, buildings, or other structures. This paper attempts to:1. Analyze falls as a continued leading cause of death and injury in the workplace, and 2. Explore a more results-oriented approach to protecting workers from falls at height.

Introduction

Once the third leading cause of work-related death across all industries, falls have surpassed workplace homicide to become the second leading cause after motor vehicle crashes. According to the U.S. Bureau of Labor Statistics, non-fatal injuries and illnesses involving falls in private industry totaled 255,750 in 1995. In another 735 instances that year, falls from height resulted in death. This adds up to 256,485 total incidents. Why do falls continue to be such a significant problem, and what can we do to reduce their frequency? Fall prevention and protection has been repeatedly addressed by OSHA, which has also suggested several methods to control fall hazards. These methods include the elimination or substitution of work, use of engineering controls, administrative controls, and the appropriate use of personal protective equipment (PPE).In addition, ANSI standards (Z359, A10) have continued to address fall protection, with a new emphasis on the employer's Managed Fall Protection Program.

Problems Associated with Falling

A search through the U.S. Department of Labor, Occupational Safety and Health Administration (USDOL/OSHA) website (http://www.osha.gov/pls/imis/accidentsearch.html) reveals that most of the fatal falls that occur in the workplace are the result of the decedent worker not utilizing any means of fall prevention or arrest. In a disturbing number of cases the worker is actually wearing a safety harness, and perhaps even a lanyard,but is not clipped in to anything. Unprotected falls from elevated work surfaces frequently result in the individual's impacting the ground, most often resulting in death.

A common concern noted in many fall accident investigations is that traditionally accepted fall protection methods are simply not feasible in certain situations. In an analysis of OSHA Recorded Fall Accidents in the Construction Industry [Huang and Hinze 2003] data from 2,955 OSHA-investigated fall accidents from January 1990 through October 2001 was examined. In this study it was noted that inadequate, inappropriate or a complete lack of PPE including fall protection equipment contributed to more than 30% of the falls. Of special interest is the fact that these statistics do not improve significantly after the 1996 revision of OSHAPPE regulations. Thus it can be surmised that equipment alone is not the answer to the continuing problem of falls in the workplace.

Even when fall protection is used, records show that injuries and even death can still occur. In one incident in 1991, an employee in Illinois slipped and fell into his fall arrest system while working (U.S. DOL/OSHA Inspection: 103278636, May 1992) [OSHA 1992]. His fall was caught by his fall arrest system and he was left suspended fifty vertical feet above the ground while waiting for the rescue response. The worker died from compression asphyxia while hanging in his harness and his death was directly attributed to the delay in rescue.

Harness Attachment

Numerous projects have undertaken to identify and explore the specific ways in which harness design can contribute to injuries sustained after an arrested fall. Harness use is arguably assumed to have originated in Europe, probably stemming from recreational use where falls (belayed using dynamic climbing rope) can often exceed 10′ and generate up to 12kN force. Harnesses are currently regulated in Europe by the PPE Directive and are required to meet CE standards, which permit both sternal and dorsal attachment points. Our corresponding code in the USA, ANSI Z359.1, also permits both front and rear attachment for various types of vertical work. In fact, in a comparative study of acceleration during a fall performed by Robert Lassiaat [Lassia 1991] the INSA in Lyon, France, and published in 1991it is indicated that the probability and type of injury sustained varies depending upon type of harness and location of attachment point.

To fully appreciate the effect of harness attachment points on the effects of a fall it is important to understand just how a worker is likely to fall. A quick study of OSHA's searchable database of accidents reveals that while some falls are the result of a surface dropping out from a worker (such as a failed scaffold or platform), most falls are the result of a slip or a trip. The former type of fall would result in a "feet-down" fall, while the effect of the latter would be a "head-down" or a tumbling type fall. Regardless of harness type, it is not feasible for a falling person to change their orientation of fall during descent.

The good news is that those workers who are wearing a harness and are properly attached to an adequate fall arrest system will most likely be caught before impacting the ground.

The bad news is that very fall arrest may result in injury.

According to Lassia's tests, the further an attachment lies from the center of gravity of the wearer, the greater the rotational forces and potential of whiplash during a catch. In other words, an attachment far from the center of gravity results in a much more violent catch.

Maurice Amphoux, in a presentation given in 1983, contends that a dorsal attachment, above the center of gravity, provides the best protection to the wearer in the event of a fall because it offers "better disposed suspension"; because the thrust of the chin on the chest limits forward flexion thereby protecting the spine;and because it protects the face from the lanyard when falling [Amphoux 1983].

One clear disadvantage to the dorsal attachment point is the complexity it adds for the user to connect,disconnect, or make adjustments to the system. In a majority of OSHA investigations where a fall resulted in a fatality, the decedent worker was not connected to a safety system – even though in many of the cases the worker was in fact wearing a harness and had a fall protection system available. Several factors are likely contributing. First, the incorporation of fall protection systems may decrease the efficiency of some work sites so the desire may be to work without it, or it may even increase the hazard (i.e., because of the longer lanyard, the lanyard ITSELF can become a tripping hazard). Second, the increased complexity of attaching and adjusting a dorsally attached system may either cause someone to "skip it" or use a system incorrectly. Finally, there may be an "out of sight out of mind" factor at work. When the lanyard is at the dorsal it tends to hang behind the wearer, and is out of the workers vision.

In a notable 2002 Australian Supreme Court case, a New South Wales worker who was rendered quadriplegic as the result of a fall was awarded over 6 million Australian dollars at least in part "because the hook was not properly connected to the (dorsal) D ring, even though the plaintiff understood that to have been the case." [Australian Supreme Court 2001].

Other concerns relating to the dorsal attachment are explored in a paper presented by Calgary, AB, rescue professional Mark Denvir, at the International Technical Rescue Symposium in 2004 [Denvir 2004]. Denvir performed research and field trials on the effects of various attachment positions during a fall, noting in his work that with the attachment at the front of the harness the body tends to rest in a reclined position while with a dorsal attachment the body will instead hang leaning forward when suspended. In his research paper Denvir notes that the arrest phase when experienced in this forward-leaning position "can be violent enough to produce damaging hyper extension and/or flexion of the neck. There is also a danger of being thrown into the structure causing damage to the unprotected face". Conversely, during a fall with a frontal attachment a worker has more control of his backup system, is more easily able to keep it relatively taut, and can even grab the lanyard with his hands in the event of a fall, thereby reducing potential for body rotation and whiplash. From the information in these studies it can be deduced that the preferred location of the attachment point will vary depending on whether the falling person is likely to fall a great distance, whether they will fall in a head-down vs. feet-down orientation, how important it is that they see/affirm their own connection to the system,whether they will be left suspended for any length of time, and whether they intend to self rescue. After a fall, even when fall protection is used, and even when an appropriate attachment point is selected, sometimes there is simply not an adequate emergency/rescue plan once fallen worker has been caught and is suspended by his safety equipment.

On a chilly, grey day in 2008 two experienced linemen perched atop a pole in Pennsylvania for two and a half hours waiting for rescue after their work platform failed. Unable to self-evacuate and separated from the ground by 130 vertical feet, one clung tightly to a tower arm while the other balanced precariously on a very thin power line. Unable to rescue themselves, the men needed help from an external source. The local fire department was called, but didn't have ladders long enough to reach the pair. They positioned a giant air mattress below the workers as a precaution, and then began reviewing their slim list of options. Eventually, a Coast Guard helicopter was summoned and, despite gusty winds and unstable weather, a winch-rescue technique was used to pluck the men from their shaky predicament after 150 harrowing minutes. Had they been left suspended, rather than able to use the pole for support while awaiting rescue, their demise would have been almost certain [Fox 29 News, Philadelphia 2008].

A 2002 literature study performed by Paul Seddon for the UK Health & Safety Executive [Seddon 2002] did an excellent job of locating and studying pre-existing literature dealing with the effects of motionless suspension in a harness. In his research, Seddon calls to attention such works as Peter Weber and Gerlinde Michels-Brendel's,Physiological limits of suspension in harnesses; Optimisation of intercepting devices - Biomechanical stress limits of humans - Appendix 5: Part III: Investigation of personal safety equipment to protect against falls by R Mattern and R Reibold for the Deutsche Montan Technologie (DMT) ; P Madsen et al. and published in Aviation, Space and Environmental Medicine; and The medical effects of being suspended in safety harnesses (1997), Bariod and Théry. The work of Bariod and Théry was originally undertaken with an eye to caving, but in fact the results are applicable to anyone working in the vertical realm and subject to the potential of being suspended in a harness. In their conclusion, the authors' caution that restriction of movement or loss of consciousness should be anticipated whenever a person falls into a safety harness, and they further emphasize that a relatively long period of time spent suspended and motionless can lead to death.

In summarizing this and the other papers reviewed in his research, Seddon concludes that the suspension phase of fall arrest needs to be more adequately addressed, with emphasis on corrective positioning and rescue.

Two years after the publication of Seddon's Harness suspension: review and evaluation of existing information, OSHA produced its own informational bulletin for workers in the vertical realm, titled: Suspension Trauma/Orthostatic Intolerance. This OSHA bulletin also addresses the urgency of releasing a fallen worker from suspension as quickly as possible.

Much work still needs to be done in the area of human physiological response to hanging in a harness, and additional research may especially be warranted into the more specific design elements of different harnesses.

Most studies to date have tested a limited number of harness styles so as to provide consistency in comparisons between responses of the human test subjects. Research results may vary yet further if the harness models tested were of the type specifically designed to suspend workers in a seated position, such as rope access or rescue harnesses.

Perhaps the most recent work done on the topic of suspension tolerance is a study just released by NIOSH [Turner et al. 2008]. The NIOSH study supports a sense of urgency in rescue, and offers additional perspectives on increasing orthostatic tolerance through the use of an extra accessory strap as a support beneath the knees. Interestingly, the NIOSH study showed insignificant differences between survivability times when using the dorsal attachment as compared with the sternal attachment.

Work at Height as a Professional Endeavor

In the Hinze study it was noted that misjudgment of the hazardous situation is the most frequent type of human error involving falls, accounting for about one third of all accidents. While judgment is a subjective criteria that is very difficult to quantify, it is possible that additional training and experience specific to fall safety would improve these statistics.

Professional Rope Access is a work method that combines trained technicians with a proven system of work and equipment to achieve complete system of work for safety at height or in areas of difficult access. The philosophy behind Rope Access is that employees receive extensive training (a minimum of 40 hours, as compared with the commonly accepted 8 or 10 hour minimums in typical fall protection) in proven yet versatile methods and techniques using purpose-built equipment. These employees then work under the employers Comprehensive Rope Access Plan, as called for by OSHA and defined by ANSI Z359.2, to achieve the goal.

Because Professional Rope Access is a complete system of work, users of this method worldwide have enjoyed an excellent safety record since record keeping began in 1989. According to a 2008 Rope Access Work and Safety Analysis [Robbins 2009] the average incident rate (IR) for all years between 1989 and 2008 combined is 3.38 incidents per 100,000 hours worked. It is impressive to note that this figure includes non-injury incidents (ie, “dangerous occurrences”) as well as injury incidents. Also notable is the fact that the actual annual IR has been decreasing since 2001, with an actual IR of 1.3/100,000 hours worked in 2008.

Rope Access offers the ability to perform a task with minimal environmental footprint and the ability to work without disrupting public access or other work nearby. Because it is quick to set up and dismantle, personnel are exposed to fall potential for a shorter period of time – reducing not only time and cost, but also hazard.

A rope access technician works from two ropes - a working rope and a back-up, safety rope - and is securely attached to both at all times. Each rope has a separate anchorage point so that in the unlikely event of a working rope failure the safety system prevents a fall. To minimize the hazard to pedestrians and coworkers,all tools less than 12 lbs are tether to the technician at all times. Heavier items are independently suspended.

A minimum of two technicians are required for any job so as to enable mutual surveillance - an extra safety feature. Rope Access practitioners may be “certified” by any one of several independent assessment organizations such as Society of Professional Rope Access Technicians (SPRAT), Industrial Rope Access Trade Association (IRATA), Australian Rope Access Association (ARAA), etc. Certified Technicians receive extensive training and independent assessment and are required to undergo periodic re-certification. Depending on the certification level, training may include any or all of the following: equipment use and maintenance, access by descent, access by ascent, horizontal traverse, deviations, and rescue procedures. A thorough equipment inspection and maintenance program is part of technician training and is part of the employers Rope Access Work Plan. Preparation of a Rope Access Work Plan is outlined in SPRAT's Safe Practices for Rope Access Work document.

Rope Access should not be confused with the more common (and less safety-driven) technique of "controlled descent". The term controlled descent is often used to describe generically any rope based system for accessing a site. Although the idea of controlled descent is the genesis of Professional Rope Access, this generic description does not take into account the kinds of extensive work planning, training, and capabilities encompassed by true rope access.

Summary

Empirical data suggests that the present regulatory approach to fall protection has not significantly reduced the number of fall incidents in either construction or general industry. The new ANSI Z359.2 calls for a Comprehensive Managed Fall Protection Plan, which is a good framework from which to build. Because the focus and emphasis on equipment criteria appears to be insufficient to reduce fall injuries, additional training and certification requirements should be placed on all who work at height.

In addition, because traditional fall protection methodologies are not always feasible, and because Rope Access is a proven method of work, the concept of Rope Access should be entertained at a more foundational level in the Fall Protection hierarchy. Further, Rope Access should be clearly separated from the concept of Controlled Descent and given preferential consideration over that work method.

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Fall Protection Issues in the Wind Power Industry

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The power generation industry has undergone dramatic changes in the last few years due to an increasing interest in and technical advancements associated with low carbon emission power generation alternatives such as wind energy. The increased activity in the wind energy sector, and the fact that many of the workers are new to this industry, raises potential safety considerations. Many of the structures that support wind turbines and blades are over 250 feet in height. Both the construction and maintenance of these facilities require skilled personnel working at significant heights. In order to determine the preparedness of the construction industry a case study of the Meadow Lake Wind Farm located in White County in north central Indiana was undertaken. The purpose of the study is to determine the current safety training culture, evaluate construction techniques as they relate to safety, and access the design of the wind turbines to minimize the risk of falls when working on wind power systems. Results of the case study show there is a significant effort to minimize risk of falls during construction of wind towers and turbines. Prevention through Design (PtD) elements include numerous strategically placed 5,000 pound anchorage points for worker tie off, safety systems for the ladders, work platform areas at tower connection points, and component design to reduce the requirement of workers to be exposed to fall hazards. However, many challenges remain for safely constructing and maintaining of wind power systems. Based on the initial assessment from Purdue researchers, the wind power generation farm at Meadow Lake has taken a positive step towards NIOSH's PtD initiative. It is yet to be determined if PtD innovations can continue to prevent falls from elevations as the next phase begins: the service and maintenance of wind turbines. For PtD to truly work power companies who hire workers to service and maintain wind turbines must continue to set high standards to keep fall related injuries and fatalities low in this industry.

Introduction

Power generation by capturing the wind's energy has been one of the fastest growing sources of renewable energy in the U.S. Wind farms are being added to the U.S. power grid at the fastest rate in U.S. history. There are currently numerous projects underway and planned for large wind farms throughout the U.S., and construction contractors and subcontractors are actively pursuing these projects in the recent economic downturn in other construction sectors. Since construction of a wind power farm is a relatively new area, many of the contractors and subcontractors pursing these construction projects have relatively little experience in the construction of these power systems. The lack of experience in this construction sector along with the tallheight of these systems creates significant fall hazards during various phases of construction. The U.S. currently has approximately 33,000 turbines generating 35,000 Megawatts (MW) of electricity. Wind turbines brought on-line in 2009 account for approximately 10,000 MW or 28.5 percent of the total capacity [AWEA 2010]. The rapid construction of wind farms in the U.S. has been a bright spot in the U.S. construction industry with other sectors of the construction industry suffering an economic downturn. Many contractors have retooled their construction workforce to support this rapid expansion and are actively bidding on wind farm construction projects. The construction of a wind farm requires a multitude of specialty contractors and skilled workforce to successfully complete a project. Potential contractors required for a project include:

- General contractors to manage subcontractors and oversee construction operations.

- Excavation contractors for construction site preparation and road building

- Crane and rigging companies for heavy lifts of towers and turbine components

- Steel erection companies for construction of towers and nacel (turbine unit housing) placement

- Electrical contractors for electrical transmission wiring and instrumentation systems.

The construction of a single wind turbine is typically a modular construction of components that include three major components:

- The base tower which is typically constructed in multiple sections on a concrete foundation

- The nacel that is attached to the top of the tower (a nacel is a component that contains the wind turbine electrical generator and other system components)

- The rotor assembly consisting of two to three blades.

The construction of a wind turbine is very similar to the construction of other industrial towers such as electrical transmission towers and communication towers (cellular, radio, and television towers). The extreme height of these towers also has significant fall hazards associated with the construction and maintenance operations. The Bureau of Labor Statistics' fatality and injury recording for the construction of these types of facilities falls under the "Heavy and Civil Engineering Construction" category with the subcategory of "Power and Communication Line and Related Structures Construction" (NAICS code 23713) [BLS 2009]. From 2003 to 2008 an average of 10.2 fatalities per year were attributed to falls from height for the construction of these facilities. The average number of fatalities per year over the same period was 402.5 for the entire industry. Falls from height for tower power and communication structures accounts for approximately 2.5 percent of the total number of construction fall fatalities.

One documented fall fatality in 1994 from a wind turbine construction provides insight into one of the many ways a worker could be killed by a fall hazard on these types of facilities. The report was documented under the NIOSH Fatality Assessment and Control Evaluation [NIOSH 1994]. The worker was descending on an interior ladder of a lower tower section that had been installed on the foundation. Ice from an upper tower section being place on the lower section fell on the worker knocking him off of the ladder. The worker was wearing a fall protection harness; however it was not attached to any fall arrest system. Wind turbines are becoming increasingly taller in order to maximize the amount of energy production. Wind turbine towers are now on average from 50 meters to 90 meters tall (164 feet to 295 feet) [Jervis 2009]. With the increasing height of these structures, the construction of these tall structures put workers at a significant risk for fall hazards in multiple phases of the construction and maintenance of the system. This paper details the analysis of a wind farm construction project in White County, Indiana.

Methods

The objective of this paper is to illustrate the potential hazards associated with the construction of wind power construction and current fall protection practices, based on the results of a case study of the Meadow Lake Wind Farm in White County, Indiana. When evaluating the safety hazards with wind tower construction, Purdue researchers were mindful of similar fall hazards when working at heights in the construction and maintenance of telephone cell towers. In 2009, Purdue researchers and students taking the Construction Engineering Technology class BCM 481 conducted a site visit to the Meadow Lake Wind Farm in White County, Indiana and did a site assessment of one of the wind turbines being constructed. Table 1. shows the general construction information for this project.

so that workers would be able to tie off for all construction processes at various locations. There should be no reason that a worker would be in a position in the construction process where there was not an anchorage point to tie off to. It was not determined if tie off locations were available for all possible worker locations that would be needed for the maintenance and repair of the structure. There was also a factory installed ladder system

Table 1. Meadow Lake Wind Farm Project (2009), White County Indiana

General Contractor	Bowen Engineering
Contract Amount	$74 million dollars
Tower Height	380-390 Feet
Blade Length	90 Feet (from hub to blade tip)
Nacel Unit Weight	12 tons (approximate)
Type of Turbine	Vestas V82 1.65MW Turbines
Number of Turbines for this Phase of Project	121
Total Power Output	200 MW Facility

A follow up meeting was conducted in March 2010, with the vice president and site supervisors from Bowen Construction in Indianapolis, Indiana where Purdue researchers and a student in Construction Engineering Technology program discussed the Prevention through Design (PtD) [NIOSH 2010] features of their wind farm in White County.

A work in progress: Later in 2010, Purdue researchers will be contacting group of contractors and subcontractors working in the wind power industry will be surveyed to determine the current safety training being employed on the construction site. Construction techniques to minimize the risks associated with working at heights will be evaluated based on survey results.

Results

Based on the site assessment and discussions with construction personnel, the researchers identified numerous safety procedures that were developed prior to the construction of the project in the design phase. A list of safety attributes are shown in Table 2. One of the more notable safety features includes numerous 5,000 anchorage points for tie off, Figure 1(a). The system was designed with fall arrest(Figure 1(b)). This safety feature is on all sections of the column structure. The ladder system not only aids in reducing fall hazards, but also provides support if workers are fatigued during climbing (climb assist).

Table 2. Design (PtD) for safety

1. Numerous 5,000 lb. anchorage points for tie-off
2. Ladder fall arrest system (factory installed)
3. Preinstalled factory mounted worker platforms with attached guardrails
4. Specially designed crane rigging attachments
5. Preassembly of numerous components (modular construction)
6. Construction sequencing design to reduce the requirement of workers to be exposed to fall hazards
7. Worker accessibility is carefully planned through out the entire wind turbine structure and nacel.

Finally, a significant amount of effort was put into reviewing the construction process and providing for unique construction apparatuses to reduce

(a)

Figure 1. (a) 5,000 lb Anchorage Points for Tie Off (b) Factory Installed Ladder System with Fall Arrest (from Bowen Engineering)

(b)

(a)

Figure 2. (a) Customized Crane Attachment for Hoisting Main Hub into Place (b)Exposed Worker during Tower Erection (from Bowen Engineering)

(b)

the hazards associated with construction. One such item was a customized crane attachment for hoisting the main hub into place (Figure 2(a)). The customized system allowed for more control over the hub placement when installing the hub and fan blades. This increased control reduces the hazards during the very difficult placement process.

Based on the field survey by the Purdue researchers and students it was determined that the wind turbine structures were very modular in construction design, thus making PtD features that can easily be built into system and repeated in future construction. In addition, the case study also provided information on construction practices used to minimize the risk for working at heights.

Summary

The Meadow Lake Wind Farm project is a good example of how an elevated structure can be designed and constructed to reduce the likelihood of workers being injured or killed in a fall related incident. The "Prevention through Design" process is much easier to implement in a wind farm project than other industrial projects due to the factory-assembled modular construction.

Even through the fall hazard was greatly reduced, workers on the project were still exposed to potential hazards such as struck-by, caught-in-between, and overhead load as shown in Figure 2(b). While it is clear that PtD elements were used in the design and construction of wind turbines in White County, Indiana, it is unclear whether PtD will transcend fall prevention when workers are servicing and maintaining wind turbines.

Like telephone cell tower construction and maintenance, this is an area where the construction industry needs to be vigilant and maintain active surveillance to prevent falls from elevations among wind turbine workers.

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Stairway Handrail Graspability and Fall Mitigation: Research and its Application in Standards, Codes, Construction and Litigation

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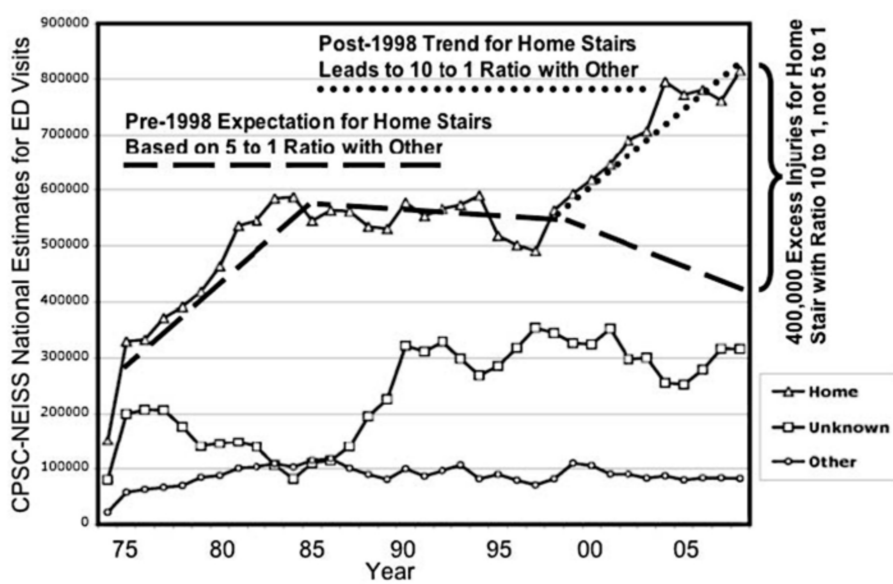
Although not as extensive nor as well applied as ergonomics studies of tool handle design for graspability, there has been significant research and technology transfer effort over the last few decades on stairway handrail shape, size, position, usability, effectiveness and related standards plus codes—all intended to address the roles played by handrails in stairway usability generally and fall mitigation in particular. Handrail studies described by Maki et al. [2006] and Dusenberry et al. [2009] are prominent and, in the latter case, controversial. The experience of making sense of this body of research in technology transfer efforts focused on standards and building codes, particularly in the US, holds lessons for the larger effort to address large and growing problems with stairway usability and safety, especially in homes. Deficient handrails are implicated, along with a few other key factors (changing user demographics, step geometry dimensions plus their uniformity, construction quality, and code enforcement), in the relatively rapid growth of stair-related injuries in recent years. Responsibility for this situation is widely shared. If, as appears the case, the construction industry has been insufficiently responsive to ample public notice—for example in model code and standards development, there might be a growing role for stairway fall-related litigation.

Introduction

The current USA toll of stair-related injuries, about 90 percent of which occur in homes, is about 2 million medically treated injuries annually with medical care costs alone (comprising about 10 percent of comprehensive, societal costs) totaling about one million US dollars per hour (based on the author's updating of estimates by Lawrence et al. [1999]). Figure 1 shows the recent increase in stairway-related injuries based on US Consumer Product Safety Commission (CPSC) National Electronic Injury Information System (NEISS) national estimates. Notably these national estimates for homes and non-home (other) settings—while tracking each other approximately for over two decades with a five-to-one ratio, recently reached a ten-to-one ratio. US home stairways are now the site of about 90 percent of the estimated US stair-related injuries where the location is known. The recent trend is troubling but not surprising; some long-used standards for home design, construction and regulation continue to be inappropriately lower than those applied elsewhere.

Figure 1. U.S. emergency department (ED) visits for stairway-related injuries 1974-2008

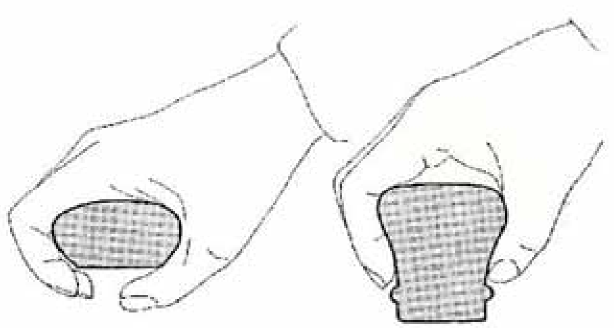


One example of the double, lower standard for home stairways is the widespread use, especially for new homes in the US, of what is called the Type 2 handrail—generally the classification for a handrail that a user cannot grasp with a power grip with fingers encircling and wrapping underneath the handrail as with a Type 1 handrail; these classifications are in the International Building

Code and International Residential Code used widely in the US.

Figure 2 shows the most commonly used Type 2 profile, the "6010" designation used in the stairway industry. Also shown is the superior power grip facilitated by a less costly, more-functional Type 1 handrail—indeed a handrail that has the same upper section as does the "6010" profile. Based on research evidence (reviewed by Maki et al. [2006], and by Fenney and Webber [1994], plus the recent paper by Dusenberry et al. [2009]—as interpreted by this author based on long experience with handrail research, the Type 2 handrail should not be permitted for any stairway because the poor grasp will not facilitate arresting a stair-related fall [Pauls 2009].

Figure 2. Power grip with Type 1 handrail versus pinch grip with Type 2 handrail



Approach taken

Objectives

Improved general usability and fall-mitigation efficacy of stairway handrails are the overarching objectives. Accomplishing this through good-quality research and technology transfer are sub-objectives. A key question is how well these sub-objectives are actually being achieved—and if not, why not.

Method

The presentation provides an overview from the perspective of one person, the author, who has conducted, funded, criticized and applied research related to stairway handrails over a three-decade period in Canada and the USA. Such application has been most prominent in standards and model code development processes in the US and Canada as well as in fall-related forensics work there. The former activity involves decades of participation in codes and standards development via the submission of proposals and comments, testimony, and (in some cases) casting votes in open forums or written ballots. In the author's case, he has additional perspectives of a professional in ergonomics and public health, in many cases formally representing the public health community generally and the American Public Health Association specifically (in an unpaid capacity). The latter, forensics activity (performed for attorneys) involves careful examination of documents, legal and otherwise; meticulous site inspection and documentation; and effective delivery of professional opinions via affidavits, reports, depositions and trial testimony.) This responds to the ICFPP's focus on "practical application of prevention and intervention tools and methods" with specific attention to how well—and with what degree of sophistication—standards and codes for building construction are using handrail graspability research.

Results and Discussion

It appears that handrail industry and homebuilder marketing concerns (including attempts to maintain certain apparent traditional characteristics of stairways) have prevailed over science in relation to stairway handrail usability and safety. In at least one case, this has led to flaws in the peer-reviewed scientific literature, specifically in the publications of certain studies performed by Dusenberry et al. [1996, 1999, 2009] funded by the Stairway Manufacturers Association (SMA), that attempted to justify the performance of Type 2 handrails as at least that of the Type 1 handrails. Generally, the traditional building code practice of having a double, lower standard of building code design requirements for dwellings contributed to what appears to be a lower standard for the research which, up to now, has only been applied to stairways serving one- and two-family dwelling units.

When the SMA attempted to broaden the

application (or scoping) of Type 2 handrails to all other stairways it encountered stiff opposition from representatives of the accessibility/ usability community (via a key staff person with the US Access Board) and an ergonomist (the author of this paper). The result of the public hearing of the International Code Council (ICC) was that SMA's proposal was defeated. Also, SMA was told that it needed to first get the US national committee on accessibility and usability of buildings and facilities (the ANSI A117 Committee—operating under an ICC secretariat) to assess the technical evidence and decide on the suitability of the Type 2 handrails for the ICC/ANSI A117.1 standard. Between approximately 2007 and 2009 this national committee deliberated on the SMA proposal at great length and without a consensus one way or another. The committee, early on, urged the SMA proponent to have the research purportedly supporting the proposal submitted to and accepted by a peer-reviewed journal with credibility in the ergonomics field. This was done and, eventually the work was accepted by the journal, Applied Ergonomics in 2008. With a copy of the authors' submission to this journal distributed to the committee, the discussion intensified. Anticipating that peer review would lead to some revisions in the paper, the committee was unable to decide on approval or disapproval until January 2009 just after the paper was released by publishers of Applied Ergonomics in finally revised preprint form. However, there appeared to be none of the revisions the critics of the research expected would be demanded in the peer review process.

In January 2009, in its final vote on the SMA proposal to incorporate Type 2 handrails into ICC/ ANSI A117.1, it was noted (by this author as a longstanding member of the A117 committee) that there were serious methodological and reporting flaws in the paper. Chief among these was the fact that the testing protocols—in addition to using an unrealistic test set up (with subjects seated and hold their arms outstretched horizontally as one of several test handrail profiles was slowly pulled from their grasp—used the worst of the codes/standards-accepted Type 1 handrails (a 51 mm, 2-inch diameter circular profile) along with several Type 2 handrail profiles—all of which were missing the ridges near the base of the profile (as illustrated in Figure 2). Yet the Applied Ergonomics paper, in its "Conclusions" section," never revealed the tests were performed with profiles markedly different from those for which very detailed code requirements had been prepared in the 1990s and which included the ridges. Even worse, the paper's authors claimed in the penultimate section, "Handrail provisions in building codes," that, "Data and analyses presented herein have been considered by the International Code Council (ICC) in the United States during its deliberations, leading to its reversal of prior restrictions and adoption of the 'Type II' handrail for residential applications." ICC adoption actually preceded peer-reviewed journal publication of the critical study details—including the fact that the tested handrails were markedly different from those actually marketed and installed. Moreover, no building code, including ICC's has permitted Type 2 handrails for applications other than one- and two-family dwelling unit stairways (which only the ICC permits).

In addition to flaws described above, there were other flaws with the Dusenberry et al. [2009] paper in Applied Ergonomics. These included a literature review that appears cursory; misreporting of results comparing Type 2 profiles with all those generally permitted by codes in the US, Canada, and UK, that facilitate power grips (with fingers able to curl underneath the profile); and absence of standard statistical tests. Comments on these defects have been submitted to the journal but have not yet been published.

Conclusions

Relative to the International Conference on Fall Prevention and Protection (ICFPP), the dissemination of research findings and discussion of challenges facing advocates for fall prevention and mitigation/ protection differ greatly in home and non-home settings, including occupational settings—with the latter being a major focus of the Conference host, the CDC National Institute for Occupational Safety and Health (NIOSH). Home stairways are largely designed and constructed as decorative features; workplace stairways are more based on ergonomics. Thus attempts to have research findings applied to these settings differ, e.g., the approaches to, and efficacy of, standards and regulations are different. Among strategies that should be addressed are the various approaches used by CDC, including in its National Center on Injury Prevention and Control, to address home stairway-related fall injuries. Falls are not merely a problem faced by older people; home stairway design is best dealt with using principles of universal design. Indeed, the dramatic growth in home stairway-related injuries shown in Figure 1 is not explained by a larger proportion of older persons being hurt on stairways. The growth is similar for both under 65 age groups and 65-plus age groups.

One of several reasons is the continuing acceptance, among code writers, adopting authorities and enforcement agencies of inappropriate lower standards for homes. Type 2 handrails—and their dubious justification by flawed studies—are a case in point. Other factors include the continued acceptance in most model building codes of significantly worse step geometry for home stairs, both in terms of nominal dimensions and their variability. These defects have public health consequences including increased risk of injuries and reduced usability; however there are highly effective diagnostic or inspection tests that are quick and easy to do [Johnson and Pauls 2010]. We should be employing all the measures available to reduce the toll of falls, especially on home stairways, including better handrails.

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Identification of Flooring Having Sustainable Wet Slip Resistance

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The widely-accepted principle of safety by design, as well as U.S. laws and building codes, require that flooring be slip-resistant over its life cycle — not just at the time of installation. Safety criteria based solely on static coefficient of friction, often used in the U.S. for assessing safety, are too often misleading where flooring gets wet or otherwise lubricated in use. Over 150 safety criteria have been adopted in Germany and Australia for specific situations — swimming pool decks, commercial kitchens,rest rooms, etc. These are based on a laboratory test device, the variable-angler amp, that is not readily portable. The pendulum tester is a portable ASTM method,has been used successfully since at least 1971 for assessing pedestrian traction potential, and is a national standard for pedestrian traction in 44 nations on four continents. Abrasion of a flooring sample, tested with the pendulum before and after,is being used to assess "Sustainable Slip Resistance." Some architects and property owners are now combining this pendulum-based test with situation-specific safety criteria to specify and verify safe flooring.

Introduction

The purpose of this paper is to provide an overview of a particular testing method and selection criteria for use in choosing and sourcing slip-resistant flooring that maintains good tribological characteristics over its life cycle. The test method is known as Sustainable Slip Resistance (SSR), and together with situation-specific safety criteria is becoming an established methodology in certain international venues. In safety engineering it is widely accepted that "safety by design" is the most reliable method of preventing accidents; people should not be expected reliably to use safety equipment (e.g. slip-resistant footwear) or exercise special caution ("Slippery [or wet] floor" warnings). If flooring is in an area where it can get wet or otherwise lubricated (airborne deep-fryer fat, automobile grease, etc.), it needs to be slip-resistant under such conditions.

Although it is sometimes assumed that flooring slip resistance never changes with time, experience of building and cruise ship owners shows that this is not true. Wear from shoes plus abrasive soil on a busy floor, or certain inappropriate maintenance practices, can in some cases reduce the wet slip resistance in a matter of weeks — or even an hour. Post-construction cleanup using an abrasive pad has in a number of instances destroyed the slip resistance before the building or outdoor swimming pool has even opened. One well-publicized example was at the Watershed Centre in Kilkenny near Waterford, Ireland. The tile installed had good barefoot slip resistance, but this was destroyed by post-construction cleanup with an abrasive pad before the pool opened. In the four months after the new pool opened in December 2008, there were 28 reported slips and falls while various remediation methods were tried. The pool subsequently was closed until April 27, 2009 [Kilkenny Alive 2009] after being remediated successfully by chemical treatment. Numerous lawsuits are in progress. The Americans with Disabilities Act (ADA) requires that flooring accessible to disabled persons be slip resistant— not just when the building is constructed, but throughout its lifetime. Typical building codes in the USA require that "Every existing building, structure, premises or portion thereof shall be maintained inconformity with the code regulations and Department approvals in effect at the time of such construction and occupancy ... Every existing building, structure, or portion thereof shall be maintained in a safe condition and good repair … all physical elements of every existing building, structure or portion thereof shall be maintained… by restorative means, in a condition as close as reasonably feasible to their originally required and approved state." [City of Los Angeles 2008]

If a building owner can be confident that his or her new flooring will sustain its slip resistance for a period of years this can protect a considerable investment in the flooring and prevent business interruptions as well as protect the safety of the pedestrian. The stakes are even higher for hotels and cruise ships, which are occupied virtually nonstop with guests who will not tolerate the noise involved in changing out hard flooring.

Sustainable Slip Resistance (SSR) testing was developed by Strautins [2007, 2008] in Australia for McDonald's Restaurants to identify flooring that is not highly susceptible to loss of its slip resistance from wear or some types of inappropriate maintenance. This test and appropriate selection criteria can help avoid investment in inappropriate flooring as well as prevent costly, life-altering accidents and increased healthcare costs. This paper explains the method and how it can be used to improve flooring safety in the USA.

Test Methods and Safety Criteria

Germany and Australia have for over 10 years had detailed flooring slip resistance standards based on some 150 specific situations — e.g. external walkways, swimming pool decks, swimming pool stairs, commercial kitchens, hospital operating rooms, etc. [Sotter 2000; CTIOA 2001a] Many architects elsewhere in Europe have informally adopted them. The slip resistance ratings are based on humans walking an oily or wet flooring sample in standard footwear and/or bare feet on a laboratory variable-angle ramp the repeatability of which was extensively documented [Jung and Schenk 1988]. However, the test results apply only to flooring before vit is installed. In some cases initially good wet slip resistance is gone after the building has been open for only a few weeks. The ramp test can't be used to assess safety of the flooring on site under the ambient conditions.

The United Kingdom has since 1971 had well-established slip resistance standards based on a portable test method, the pendulum. This test was developed for pedestrian traction by the U.S. National Bureau of Standards in the 1940s and further refined in the UK [Giles et al. 1964]. It was validated for pedestrian traction in 1971, together with its safety standards, in the UK over a period of 25 years by 3500 real-world public walking area tests and site accident records [Greater London Council 1971, 1985]. The test is an ASTM standard (E 303), slightly modified for pedestrian traction.

In the USA, architects and designers generally look for a wet static coefficient of friction of 0.60 or higher by ASTM method C 1028 to assess potential safety for wet areas of level floors. This can give deceptive results,applying "safe" ratings to some flooring samples that are in fact very slippery when wet [Powers et al. 2007]. The method is now acknowledged by ASTM [2005], Ceramic Tile Institute of America [2001b], and Tile Council of North America [Astrachan 2007] to be inadequate for assessing safety.

The ASTM C 1028 method does not represent the most current state of knowledge about testing methods, but this is not widely known by American architects and property owners. An objective in this section is to correct this situation and suggest a more useful test and safety standards (safety assessment) for due diligence based on the pendulum. The pendulum is now a standard test method for pedestrian slip resistance in 44 nations(European Committee for Standardization EN 13036-4, 2003 names many of them) [CEN 2003] on four continents and has been endorsed by Ceramic Tile Institute of America since 2001 [CTIOA 2001b].

The SSR test procedure consists of an initial wet pendulum test; abrasion, wet, for up to several thousand cycles with a standard (100 x 100 mm 3M green Scotchbrite) abrasive pad under a standard load of 1 kg at 50 cycles/min; and another wet pendulum test after abrasion. Both hard and soft rubber pendulum sliders (or "test feet") might be used if the area is walked on in both hard-bottom footwear and bare feet or soft-soled footwear. The abrasion is conducted either manually or mechanically using a Gardco 12VFI linear washability and wear tester.

Typically, about 85 percent of the loss in slip resistance after 5000 cycles has already occurred after 500 cycles [Strautins 2008]. Depending on the flooring buyer's situation, the flooring might be considered to have Sustainable Slip Resistance for a level floor if (for example) the wet Pendulum Test Value (PTV) is 35 or higher after abrasion for 500 cycles. The 500-cycle result in the laboratory has been found by in situ pendulum tests to be roughly equivalent to 6-12 months of wear in customer areas at a busy McDonald's Restaurant. The 500-cycle specification was adopted by McDonald's in Australia in October 2006. Other major property owners such as Aldi, Toyota, Westfield and a major cruise ship company have adopted similar specifications.

In the USA, flooring with SSR is available in ceramic tile, natural stone, and resilient products. Abrasive containing coatings, some transparent, are also available that have SSR.

In some cases, analogous to the variable-angle ramp test-related standards mentioned above, the SSR safety standards are situation-specific [Natspec 2009; Bowman 2010] rather than "one size fits all." Thus a minimum pre-abrasion wet PTV of 35 might be required for hotel or hospital bathroom floors; a minimum of 45(hard rubber slider) for stair nosings that get wet in use; and 54 (hard slider) for commercial kitchens and steep outdoor ramps. If the flooring is to be sealed after installation, the laboratory tests should be conducted with the correct sealer applied. Cleanability tests with expected contaminants (local mud, coffee, red wine, ketchup,etc.) by owners and/or other duty holders are also advisable before final selection of flooring. The methods of cleaning [Tari, Brassington et al. 2009] should be planned. (A dirty mop with dirty water might not be adequate for non-slip flooring, but abrasive pads can destroy wet slip resistance quickly.)

Experience has shown that what is specified and ordered is not always what is delivered, and it is prudent for property owners to verify that flooring meets their slip resistance specification both before installation and at turnover of the property for occupancy. Monitoring of slip resistance every 3–12 months after that can further protect pedestrian, owner, and other duty holders.

Conclusions

Sustainable Slip Resistance as a test method and formal or informal standard provides advantages over formalized and standardized test methods currently in place, in that it addresses a most important component of product utility: the ability of the test method to assess potential product wet slip resistance over its life cycle. The ability of the surface to maintain its slip resistance over time and with wear is a significant aspect of product use, and the informal adoption of this standard as part of due diligence potentially establishes conformance with the state of the art in surface slip resistance determination.

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