ASSE Foundation Research

Transitioning Sloped Surfaces

The effects of roofing work on balance and falls

By Lloyd "Chip" Wade and Jerry Davis

THE CONSTRUCTION INDUSTRY has been estimated to account for nearly 20 percent of the U.S. gross domestic product from 1998 to 2002, representing the principal manufacturing industry in the country [BEA(a)]. Annual reports of gross output show industry growth from $730 to $899 billion per year during this same timeframe [BEA(b)].

Although the construction industry is among the most profitable of all manufacturing industries, it has historically been recognized as one of the most costly with respect to worker safety and health. In 2002, Bureau of Labor Statistics (BLS) reported that 5,524 fatalities occurred in 2002—with 1,121 of these occurring in the construction industry (NAICS 236). It was also reported that 12.2 workers per 100,000 in the construction industry were fatally injured in 2002, representing the third-highest fatality rate, behind only agriculture and mining (Figure 1). Although the overall number of workplace fatalities has been declining slightly over the past decade (Figure 2), the construction industry continues to account for approximately 20 to 25 percent of annual occupational fatalities.

Falls from elevation are a major contributor to these statistics—and unlike the overall decline in fatalities, workplace falls continue to increase each year. Based on BLS statistics for 2002, falls from elevations are the second-leading cause of fatalities in industry today, second only to transportation fatalities (Figure 3). During 2002, deaths due to falls from elevation accounted for 13 percent of all work-related fatalities, with a reported 718 fatalities for the year.

Historically in the U.S., deaths due to falls from elevation account for approximately 10 percent of all fatalities annually, with an average of 540 per year. Falls from elevations can occur in most industries, and can involve a wide range of tasks and a myriad of work settings—from the ironworker connecting steel columns hundreds of feet in the air to the roofer on a pitched roof approximately 10 to 30 feet above the ground.

An epidemiological study documented by the National Traumatic Occupational Fatalities (NTOF) surveillance system analyzed 15 years of data (1980 to 1994) to identify work settings in which fatal falls were likely to occur as well as the risk factors that contributed to those falls (NIOSH). During that period, 8,102 workers were reported to have died as a result of falls from elevations. The construction industry accounted for 4,044—or nearly 50 percent—of those fatalities. Within the construction industry subgroup—NAICS 236—NTOF identified general contracting and roofing as the work settings with the highest risk factors for a fall from elevation.

Supporting the NTOF finding that approximately 50 percent of all construction fatalities involve falls from elevation, the preliminary statistics reported by BLS for 2002 indicate that the construction industry accounted for nearly 50 percent of all fatal falls from elevation during that year. General construction laborers and roofers accounted for 72 and 61 fatal falls, respectively—or 24 and 57 percent of fatal injuries in each trade (BLS).

Clearly, roofers are at a greater risk for a fatal fall compared to other types of construction laborers. According to BLS data, falls from elevations in 2002 declined 11 percent from 2001 levels. However, fatal falls from elevations in the construction industry increased 13 percent over levels for 2000. Additionally, falls from elevations, to lower levels, from roofs and ladders, and from scaffolding all surpassed levels for 2000 (Figure 4), resulting in estimated direct and indirect costs of $146 billion in 2002—the highest reported since the fatality census began in 1992.

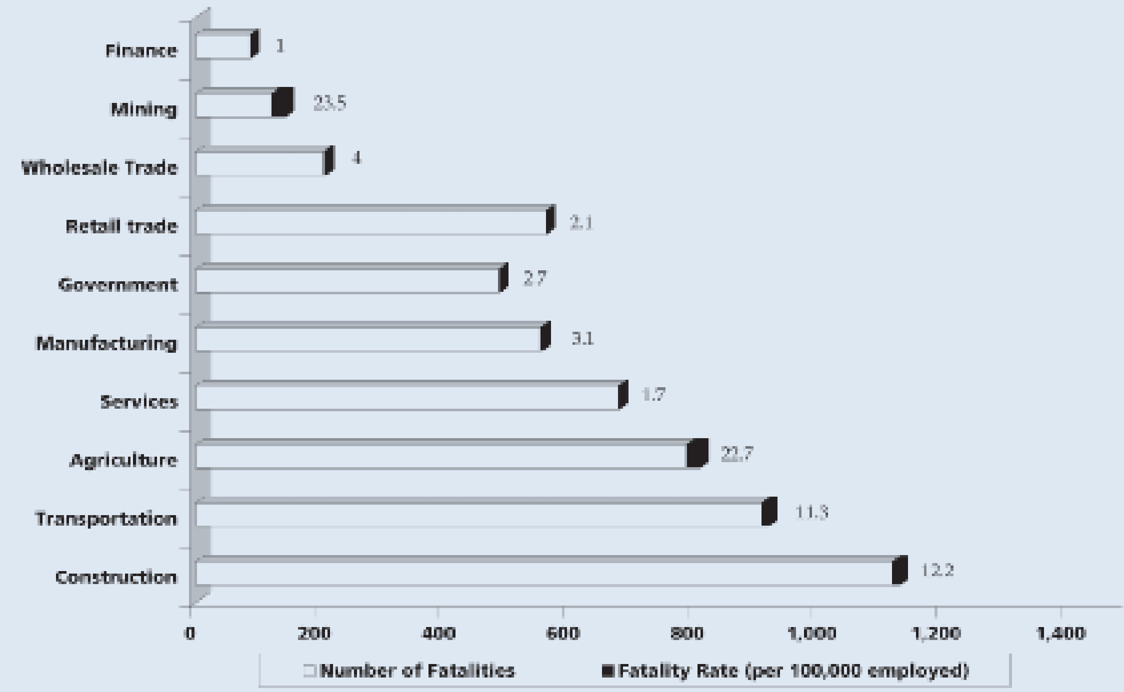
These various statistics reflect a hazard that current safety initiatives, work methods and/or fall protection practices have not completely addressed. Given the large number of construction-related falls from elevations, roofs, ladders and scaffolding, as well as the high associated monetary costs, researchers have begun to investigate physiological, psychological and/or biomechanical factors that may contribute to workplace falls. It is expected that these preliminary investigations may lead to improved fall protection systems and/or safety initiatives to be implemented on residential construction sites.

Lloyd "Chip" Wade, Ph.D., CPE, *is a post-doctoral research associate in the Dept. of Bioengineering at the University of Pittsburgh, where he conducts research focused on human postural control and ergonomics. He holds a Ph.D. in Biomechanics from Auburn University.*

Jerry Davis, Ph.D., CSP, CPE, *is a research assistant professor in Auburn University's Dept. of Industrial and Systems Engineering. He specializes in the areas of work measurement and occupational safety. Davis holds a Ph.D. in Industrial Systems and Engineering from Auburn University. He is a professional member of ASSE's Alabama Chapter and is a member of the Society's Academics and Engineering practice specialties.*

Figure 1

Number & Rates of Occupational Fatalities by Industry Division, 2002



Abstract: *Fatal and nonfatal falls from elevation continue to be a significant issue for today's workforce. Recent literature has indicated that exposure to an inclined (pitched) surface, such as a roofing environment, has a detrimental effect on postural control. This study investigated the influence of exposure to inclined surfaces on flat surface postural control at varying durations of exposure. Results found that as exposure (time) to a sloped surface increased, individual stability was negatively affected. These results suggest that as workers are exposed to an inclination over a period of time, they would be susceptible to decrements in balance as they navigate in a typical roofing environment.*

Residential Roofing Research

Research has linked a greater amount of postural instability to an increased risk of falling. The mechanism of a fall can be described as follows: postural instability (slip, trip), attempt at equilibrium recovery and, if one is unable to recover, a fall with the possibility of eventual injuries (Leclercq 95). Individual factors relating to falls are not well known for workers, unlike those for the elderly, which have been well-documented (Skinner, et al 208; Maki, et al 1; Brandt and Dieterich 3; Gauchard, et al 1330). Research has suggested that both intrinsic (neurosensory inputs) and extrinsic (environmental) factors, individually or in combination, play a role in the fall process of the elderly and that these factors may also play a role in the occupational fall process (Gauchard, et al 1330).

The control of postural stability during standing and walking has been the subject of considerable research over the past two decades. Humans maintain an upright standing posture through the integration of information from the visual, vestibular and

Figure 2

Fatal Work Injuries, 1992 to 2002

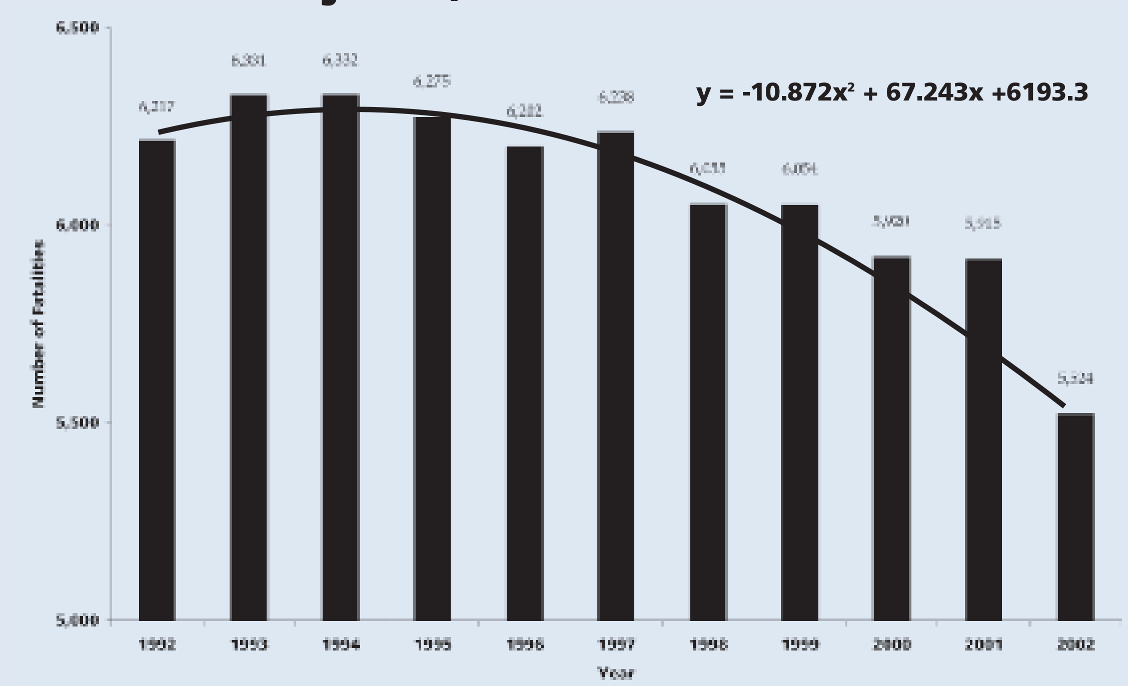
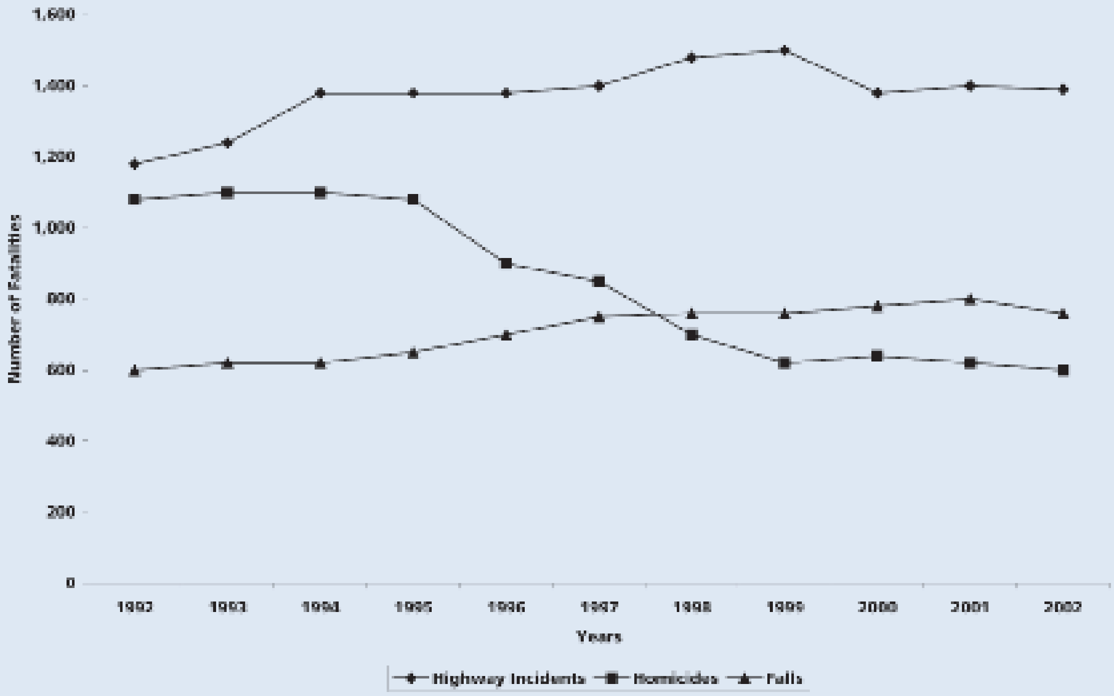


Figure 3

Three Most Frequent Work-Related Fatal Events, 1992 to 2002



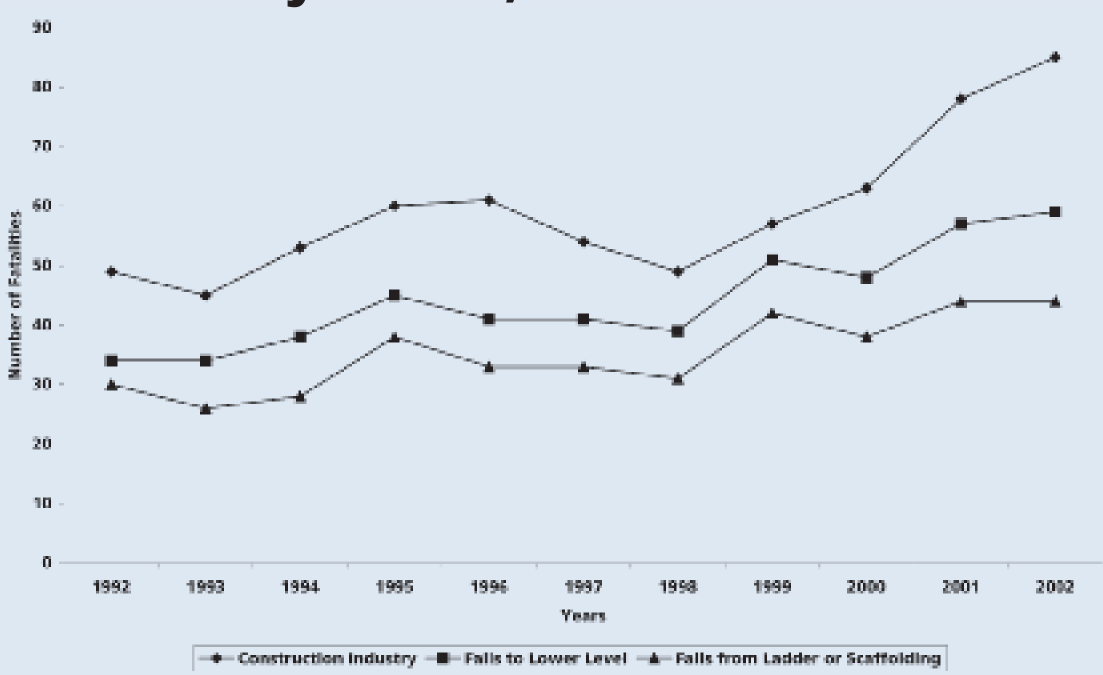
proprioceptive systems ("Postural Control" sidebar, pg. 48). While the three systems provide different types of information, the high degree of integration of the central nervous system makes it difficult to predict the effects of removal or degradation of any one of these systems (Horak, et al 167).

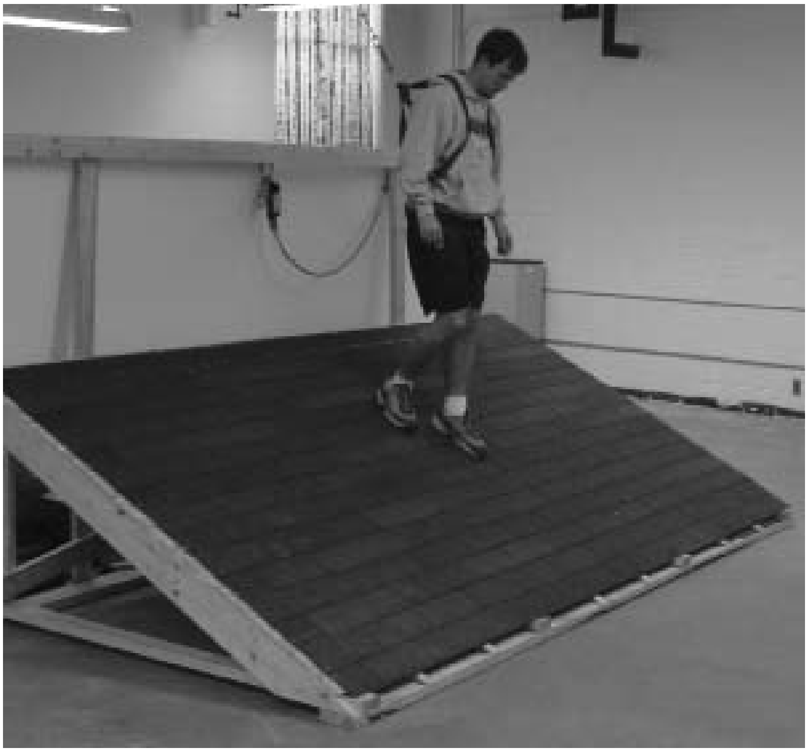
In roofing, workers may experience several work surface conditions (metallic, wood, roofing paper, shingles, tiles, metal), work settings (inclination, ladders, scaffolds) and functional job activities (tool use, ascending/descending ladders, materials handling) during a given day. All of these conditions, either individually or in combination, have been reported to be present during a fall incident (Cattledge, et al 655). One study reported that 55 percent of all construction industry falls reported in West Virginia during 1991 were related to a ladder or scaffold, and that most of these falls occurred while the individual was ascending or descending a ladder (Cattledge, et al 655).

Data collected by NTOF and BLS, in conjunction with Cattledge, et al's findings, suggest that navigation of a ladder or scaffolding places a person at a higher risk than normal for a potential fall. This could be explained by the lack of multiple point contact dur-

Figure 4

Fatal Falls by Roofers, 1992 to 2002





Subject walking on laboratory sloped surface.

ing navigation of such equipment. In an ideal situation, a worker would have three- to four-point contact with a ladder or scaffolding (e.g., two feet and/or two hands). During manual materials handling or typical work-related tasks, however, a worker may only have one to two points of contact (e.g., one foot and/or one hand). Less-than-ideal circumstances may put a worker at an even higher risk of potential fall and injury.

For example, consider a worker who finishes a task on a pitched roof, then must navigate a ladder to descend from elevation. These changing surface conditions (inclined to flat) require substantial postural adaptations. One's ability to control these adaptations may lead to a decrement in postural stability, resulting in a fall. Studies of the influence of standing on sloped surfaces as it relates to balance have reported that an increase in surface inclination had a significant detrimental effect on standing balance while on that surface (Emerich, et al 104; Hsiao and Simeonov 537; Simeonov, et al 136; Sun, et al 677).

Sun, et al (677) reported that an increased risk of falling was caused by the increased surface friction demands when an individual stands on an inclination. Additionally, Emerich, et al (104) indicated that balance was significantly affected by exposure to varying degrees of inclination. However, research has yet to investigate and quantify the existence (if any) of a relationship between exposure to sloped surfaces and (immediate) follow-on postural stability on flat (level) surfaces. While previous literature identifies the exposure to a ladder or scaffolding as a risk factor for falls from a roof, research has yet to quantify the changes in balance as a result of the transition from a sloped surface to a flat surface (e.g., roof to ladder, or roof to scaffolding).

Facts about the main influences or initiating factors leading to fall incidents are needed for the development of fall prevention interventions. However, from biomechanical, physical and psychological perspectives, it appears that most occupational falls—including falls from roofs—can be regarded as a result of a decrement in balance. Although current literature on falls from roofs provides data regarding injury frequency and situation, definitive information on the risk factors involved is lacking.

Roofing work is frequently performed on inclined surfaces. These surfaces are associated with increased risk of mechanical perturbations during task performance due to large shear forces at the shoe/floor interface (Simeonov, et al 136). As the angle of inclination increases, the shear force along the surface has an increasing gravitational component (Sun, et al 677); furthermore, there is a linear increase of the coefficient of friction at the shoe/floor interface with an increased angle of inclination (Redfern and McVay 511). Redfern and McVay (511) reported that slips are more likely to occur in downhill walking due to the increased frictional demands at heel strike when compared to the same stage of incline walking. Long periods of elevated shear forces may be an important contributing factor to falls from an inclined surface.

While the cited research has advanced the understanding of construction-related hazards, the present study was conducted to examine a worker's ability to adapt to continuously changing support surfaces that might be encountered in a roofing environment. The primary purpose was to assess the effect of exposure to an inclined roof on a subject's flat surface balance. A secondary purpose was to investigate whether a decrement in balance was found following exposure and, if so, to assess whether this decrement continued to increase with extended exposure durations.

Postural Control System Definitions

Postural control depends on the integration of information from the visual, vestibular and somatosensory (proprioceptive) sensory systems. These three sensory systems perform different operations that affect postural control in various situations

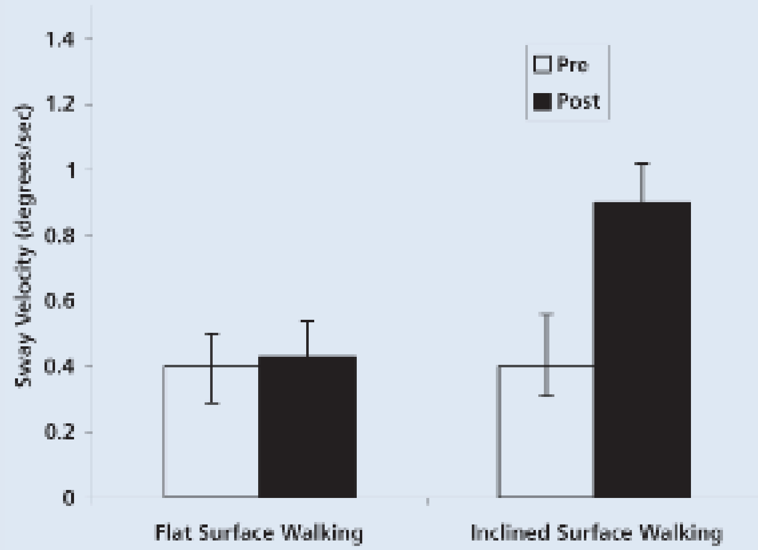
Visual System: Provides information to the central nervous system (CNS) regarding the orientation of the neck and head in relation to the external surroundings. In particular, motion detected by the retina can either be used to determine self-motion or movement of the environment.

Vestibular System: Does not provide information regarding position relative to external objects, but instead measures gravitational, linear and angular acceleration of the head. The vestibular organ represents an inertial measuring device, which allows one to sense, in the absence of external sensory cues (vision, proprioception), self-motion with respect to the six degrees of freedom (three rotational and three translational) in space.

Somatosensory (Proprioceptive) System: Provides information to the CNS on the position of the joints and body segments relative to one another and relative to the support surface. The two essential parts of proprioception: 1) the body's ability to vary contractile forces of the muscles in immediate response to external forces; and 2) the sense that informs the CNS of the position of the limb(s) at any given point in time (kinesthetic awareness).

Figure 5

Effect of Exposure to a Pitched Roof Setting on Balance: Eyes Open



Current Studies: Method

Twenty residential male roofers between the ages of 19 and 45 (M=27.9 years, SD=6.9 years) participated in the studies. All subjects completed a preliminary medical questionnaire and provided informed consent in accordance with the university's Institutional Review Board policy. Although no subjects were excluded from the study, exclusion criteria included 1) inability to walk unassisted; 2) lower limb injuries within the last year; 3) history of vestibular disorders; 4) lower extremity surgery; 5) eye disorders or surgery; and 6) self-reported drug use.

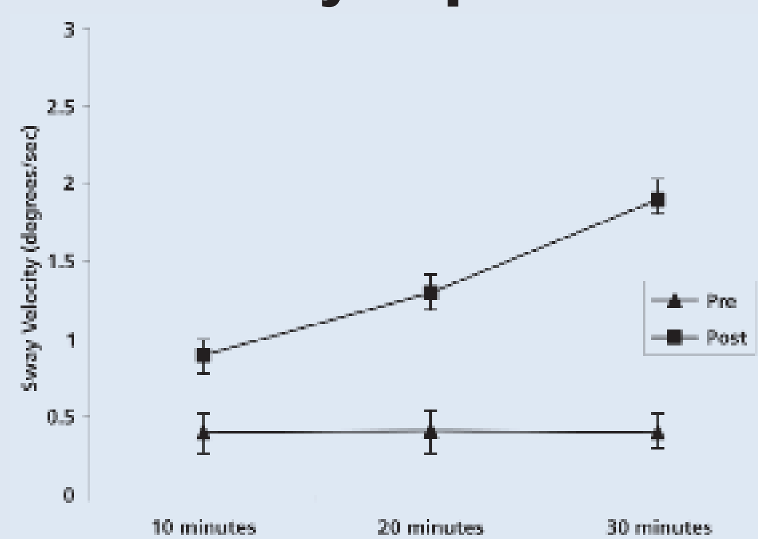
The study used a NeuroCom® Balance Master System™ and the modified clinical test of sensory interaction on balance (mCTSIB) protocol. The Balance Master System has multiple testing protocols designed to examine various balance measures. The mCTSIB protocol quantifies dual support (weight evenly distributed on both feet, standing quietly) sway velocity with the subject standing on a firm surface with his/her eyes open. The trials (10 seconds in duration) of the mCTSIB protocol were selected to reflect the variety of visual and support surface conditions encountered by workers in the course of their daily activities.

A pitched roof segment measuring 12x8 feet at a 6/12 (26-degree) pitch was built in a laboratory setting (Photo 1). This segment was constructed according to local building regulations. Subjects were fitted into a fall arrest system that prevented rapid descents of more than two feet. The fall harness was attached to a self-retracting lifeline that was anchored to a steel girder above the testing site. The fall harness exceeds the standard for fall protection equipment set forth in ANSI Z359.1-1992 (R-1999) and was worn by all subjects during testing conditions.

The procedure for the initial testing session consisted of the roofers being tested on the basic Balance Master System, followed by walking for 10 minutes at a self-selected pace and on a self-selected path along a flat surface area equal to that of the constructed pitched roof segment. Upon completion of the walking trial, the roofer was again tested on the Balance Master System. The subject was afforded 24 hours of rest, followed by another session in which he was tested on the basic Balance Master System, exposed to the pitched roof segment walking for 10 minutes at a self-selected pace and on a self-selected path, followed by the final Balance Master System session.

Figure 6

Effect of Exposure to a Pitched Roof Setting on Balance: Eyes Open



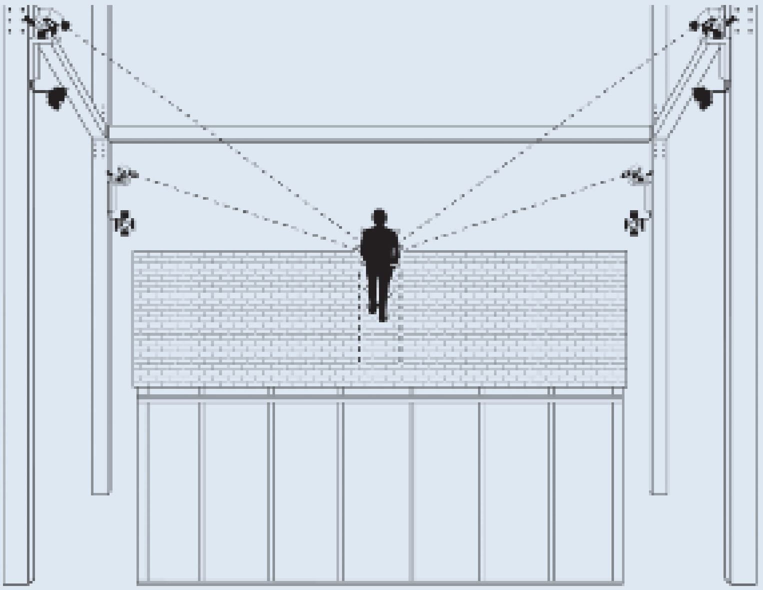
Results

Statistical analysis of the pitched roof segment-walking task demonstrated a significant task main effect during the mCTSIB testing protocol (Figure 5), with the main effect indicating a statistically significant difference between walking tasks. However, analysis of the flat surface walking task revealed no significant differences in balance measures. These results indicate that a significant decrement occurred on an individual's balance following 10 minutes of exposure to a pitched roof segment. With these findings in mind, a second investigation was conducted to determine whether increased exposure time on a sloped roof segment would continue to affect an individual's balance.

The next investigation followed the original protocol, with the only difference being that of exposure times. Subjects were exposed to the inclined surface for 10, 20 and 30 minutes on three subsequent days, with at least 24 hours of rest between. Again, statistical analysis revealed a significant main effect over time for the pitched roof segment-walking task, with a significant interaction between time exposures

Figure 7

Artist Rendering of Experimental Pitched Roof Setting



(Figure 6). Once again, analysis of the flat surface walking task revealed no significant differences. These findings suggest that as exposure time to a pitched roof segment increased, there continued to be a significant decrease in an individual's balance.

Discussion

These findings provide practical information to those involved in the construction of structures with a pitched roof design. They imply that an individual is less stable directly after performing a roofing task on a pitched roof setting. The results further suggest that individuals should be afforded ample time to recover before moving into heavy lifting tasks or activities which would place them at a higher risk of injury from falls. Accordingly, future research should investigate how long a decrement in postural stability on flat surfaces exists after working on an inclined surface.

While much attention has focused on behaviors while in contact with a pitched roof, previous research has not examined the effect of the inclination on balance once the subject has exited the roof setting. This study demonstrates that an individual's balance decreases following exposure to the inclined surface when s/he walks on a flat surface immediately following exposure to the inclined surface. This finding is extremely important when considering the typical activities performed in a roof work setting. Employees must navigate a ladder/scaffolding to ascend/descend to the working environment. Ladders and scaffolding typically have flat surface rungs or walkways. As the worker is exposed to the inclination over a period of time, s/he may be susceptible to decrements in balance as s/he returns to navigating the ladder or scaffolding following the inclined exposure.

By determining the changes in balance performance during the transition from an incline surface (roof) to that of a flat surface (ladder, scaffolding), safety measures and engineering controls can be developed and implemented to reduce the risk of falls during this period. With this in mind, studies are being conducted to investigate whole body movements while on a pitched roof setting to determine behavioral and biomechanical changes due to exposure to roofing environments (Figure 7).

Conclusion

Although current work practices help reduce the severity of injuries due to falling, statistics suggest that current measures are not enough to prevent falling incidents. Research is needed to identify ways to improve existing work practices, and to develop new approaches, methods and systems for fall prevention and protection. Studying the role and the effect of the various factors that may lead to disruption in the control of balance of workers at elevation may provide a scientific basis for new fall-prevention strategies. ■

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