

Human Factors – rok 2012, roč. 54

Číslo 3 (June 2012)

Special Section: Occupational Fall Prevention and Protection



OCCUPATIONAL FALL PREVENTION AND PROTECTION

Xiuwen Sue Dong, Xuanwen Wang, Christina Daw. *Fatal Falls Among Older Construction Workers*. S. 303-315.

Objective: This study examines recent trends and patterns in fall fatalities in the U.S. construction industry to determine whether fatal falls among older workers are different from younger workers in this industry. **Background:** Falls are the leading cause of fatalities in the U.S. construction industry. Given the increasingly aging workforce in construction, it is important to assess the risk of falls among older construction workers. **Methods:** Fatality data were obtained from the Census of Fatal Occupational Injuries for the years 1992 through 2008. Denominators for death rates were estimated from the Current Population Survey. Stratified and multivariate analyses were performed to examine whether there are differences in fatal falls between older workers (≥ 55 years) and younger workers (16-54 years). Fatal falls in nonconstruction industries were excluded from this study. **Results:** Older workers had higher rates of fatal falls than younger workers; results were significant in 11 of 14 construction occupations. Regression analysis indicated that older decedents had a higher likelihood that work-related death was caused by a fall, after controlling for major demographic and employment factors (odds ratio = 1.50, confidence interval [1.30, 1.72]). Falls from roofs accounted for one third of construction fatal falls, but falls from ladders caused a larger proportion of deadly falls in older decedents than in younger decedents. **Conclusion:** Older workers have a higher likelihood of dying from a fall. Roofs and ladders are particularly risky for older construction workers. **Application:** As the construction workforce ages, there is an urgent need to enhance fall prevention efforts, provide work accommodations, and match work capabilities to job duties.

- **Keywords:** aging workforce, construction, fall injury, fatality, older workers

Justin G. Young, Charles B. Woolley, James A. Ashton-Miller, Thomas J. Armstrong. *The Effect of Handhold Orientation, Size, and Wearing Gloves on Hand-Handhold Breakaway Strength*. S. 316-333.

Objective: The aim of this study was to quantify the effect of handhold orientation, size (diameter), and wearing a glove on the maximum breakaway strength between a hand and handhold. **Background:** Manual breakaway strength is known to be greatly reduced

for vertical compared with horizontal handholds, but oblique orientations have yet to be studied. **Method:** For this study, 12 young adults (6 female) attempted to hold on to fixed overhead cylindrical handholds with one hand in low-speed simulated falls as forces on the handhold were recorded in two experimental designs. Breakaway strength was measured for (a) three different-sized cylinders in four orientations while the participants were using the dominant hand and (b) a single-sized cylinder in four orientations while the participants were bare-handed or wearing a glove on the nondominant hand. **Results:** Handhold orientation ($p < .001$), handhold diameter ($p < .001$), and wearing gloves ($p < .001$) significantly affected breakaway strength. Breakaway strength increased 75% to 94% as the orientation of the handhold was moved from vertical to horizontal. Breakaway strength decreased 8% to 13% for large-diameter (51-mm) handholds as compared with smaller diameters (22 mm to 32 mm), depending on orientation. Gloves may increase or decrease the ability to hang on depending on interface friction; greater friction increased breakaway force. **Conclusion:** Handles oriented perpendicular to the pull direction and high-friction gloves provide the greatest breakaway strength. Smaller handhold diameters than predicted by grip strength afford greater capability in these orientations. **Application:** These insights can be used to design handholds that increase the ability to support one's body weight and reduce the effort needed to pull or lift heavy items.

- **Keywords:** grip strength, friction, biomechanics, handle design, falls, climbing, ladders, grasp

Peter Simeonov, Hongwei Hsiao, In-Ju Kim, John R. Powers, Tsui-Ying Kau. *Factors Affecting Extension Ladder Angular Positioning*. S. 334-345.

Objective: The study objectives were to identify factors affecting extension ladders' angular positioning and evaluate the effectiveness of two anthropometric positioning methods. **Background:** A leading cause for extension ladder fall incidents is a slide-out event, usually related to suboptimal ladder inclination. An improved ladder positioning method or procedure could reduce the risk of ladder stability failure and the related fall injury. **Method:** Participants in the study were 20 experienced and 20 inexperienced ladder users. A series of ladder positioning tests was performed in a laboratory environment with 4.88-m (16-ft) and 7.32-m (24-ft) ladders in extended and retracted positions. The setup methods included a no-instruction condition and two anthropometric approaches: the American National Standards Institute A14 and "fireman" methods. Performance measures included positioning angle and time. **Results:** The results indicated that ladder setup method and ladder effective length, defined by size and extended state, affected ladder positioning angle. On average, both anthropometric methods were effective in improving extension ladder positioning; however, they required 50% more time than did the no-instruction condition and had a 9.5% probability of setting the ladder at a less-than-70° angle. Shorter ladders were consistently positioned at shallower angles. **Conclusion:** Anthropometric methods may lead to safer ladder positioning than does no instruction when accurately and correctly performed. Workers tended to underperform as compared with their theoretical anthropometric estimates. Specific training or use of an assistive device may be needed to improve ladder users' performance. **Application:** The results provide practical insights for employers and workers to correctly set up extension ladders.

- **Keywords:** extension ladders, ladder safety, angular positioning, anthropometric methods

Hongwei Hsiao, Nina Turner, Richard Whisler, Joyce Zwiener. *Impact of Harness Fit on Suspension Tolerance*. S. 346-357.

Objective: This study investigated the effect of body size and shape and harness fit on suspension tolerance time. **Background:** Fall victims may develop suspension trauma, a

potentially fatal reduction of return blood flow from legs to the heart and brain, after a successfully arrested fall if they are not rescued quickly or the harness does not fit them well. **Method:** For this study, 20 men and 17 women with construction experience were suspended from the dorsal D-ring of a full-body fall-arrest harness. Their suspension tolerance time, physical characteristics, and harness fit levels were assessed. **Results:** Body characteristics (i.e., weight, stature, upper- and lower-torso depths) were associated with decreased suspension tolerance time ($r = -.36 \sim -.45, p \leq .03$). In addition, harness fit affected suspension tolerance time; workers with a torso angle of suspension greater than 35° , a thigh strap angle greater than 50° , or a poorly fitting harness size had shorter suspension tolerance time (mean differences = 14, 11, and 9.8 min, respectively, $p \leq .05$). **Conclusion:** Body size and harness fit were predictors of suspension tolerance time. Selecting well-fit harnesses and establishing a 9-min rescue plan are suggested to ensure that no more than 5% of workers would experience suspension trauma. **Applications:** The study provides a basis for harness designers, standards writers, and manufacturers to improve harness configurations and testing requirements for better worker protection against suspension trauma.

- **Keywords:** 3-D scan, body shape, harness fit, suspension, anthropometry, fall arrest, rescue

Christopher S. Pan, John R. Powers, Jared J. Hartsell, James R. Harris, Bryan M. Wimer, Renguang G. Dong, John Z. Wu. *Assessment of Fall-Arrest Systems for Scissor Lift Operators : Computer Modeling and Manikin Drop Testing. S. 358-372.*

Objective: The current study is intended to evaluate the stability of a scissor lift and the performance of various fall-arrest harnesses/lanyards during drop/fall-arrest conditions and to quantify the dynamic loading to the head/neck caused by fall-arrest forces. **Background:** No data exist that establish the efficacy of fall-arrest systems for use on scissor lifts or the injury potential from the fall incidents using a fall-arrest system. **Method:** The authors developed a multibody dynamic model of the scissor lift and a human lift operator model using ADAMS™ and LifeMOD™ Bio-mechanics Human Modeler. They evaluated lift stability for four fall-arrest system products and quantified biomechanical impacts on operators during drop/fall arrest, using manikin drop tests. Test conditions were constrained to flat surfaces to isolate the effect of manikin-lanyard interaction. **Results:** The fully extended scissor lift maintained structural and dynamic stability for all manikin drop test conditions. The maximum arrest forces from the harnesses/lanyards were all within the limits of ANSI Z359.1. The dynamic loading in the lower neck during the fall impact reached a level that is typically observed in automobile crash tests, indicating a potential injury risk for vulnerable participants. **Conclusion:** Fall-arrest systems may function as an effective mechanism for fall injury protection for operators of scissor lifts. However, operators may be subjected to significant biomechanical loadings on the lower neck during fall impact. **Application:** Results suggest that scissor lifts retain stability under test conditions approximating human falls from predefined distances but injury could occur to vulnerable body structures.

- **Keywords:** fall-arrest systems, fall from elevation, scissor lifts, computer modeling, manikin drop tests, head/neck injuries, fall hazard assessment

Sharon S. Chiou, Nina Turner, Joyce Zwiener, Darlene L. Weaver, William E. Haskell. *Effect of Boot Weight and Sole Flexibility on Gait and Physiological Responses of Firefighters in Stepping Over Obstacles. S. 373-386.*

Objective: The authors investigated the effect of boot weight and sole flexibility on spatiotemporal gait characteristics and physiological responses of firefighters in

negotiating obstacles. **Background:** Falls and overexertion are the leading causes of fire ground injuries and fatalities among firefighters. There have been few in-depth studies conducted to evaluate the risk factors of falls and overexertion associated with firefighter boots. **Method:** For the study, 13 female and 14 male firefighters, while wearing full turnout clothing and randomly assigned boots, walked for 5 min while stepping over obstacles. The independent variables included boot weight, sole flexibility, gender, and task duration. Spatiotemporal measures of foot trajectories and toe clearance were determined. Minute ventilation, oxygen consumption, carbon dioxide production, and heart rate were measured. **Results:** Increased boot weight was found to significantly reduce trailing toe clearance when crossing the 30-cm obstacle. Significant increases in lateral displacement of the foot were found near the end of the 5-min walk compared with the beginning of the task. Increased boot weight significantly increased oxygen consumption. There were significant decreases in oxygen consumption for more flexible soles. **Conclusion:** Firefighters were more likely to trip over obstacles when wearing heavier boots and after walking for a period of time. Boot weight affected metabolic variables (5% to 11% increases per 1-kg increase in boot weight), which were mitigated by sole flexibility (5% to 7% decrease for more flexible soles). **Application:** This study provides useful information for firefighters and boot manufacturers in boot selection and design for reducing falls and overexertion.

- **Keywords:** firefighter boots, obstacle negotiation, tripping, toe clearance, oxygen consumption

Harlan Amandus, Jennifer Bell, Hope Tiesman, Elyce Biddle. *The Epidemiology of Slips, Trips, and Falls in a Helicopter Manufacturing Plant*. S. 387-395.

Objective: The purpose of this evaluation was to evaluate the causes and costs of slips, trips, and falls (STFs) in a helicopter manufacturing plant. **Background:** STFs are a significant portion of the total industry injury burden. **Method:** For this study, 4,070 helicopter plant workers who were employed from January 1, 2004, through February 28, 2008, were enrolled. Company records on workers' compensation claims, occupational health first report of injury, and payroll records on hours worked were collected. Cause and source of all injuries, including STFs, were coded for analysis. **Results:** During the 4-year study period, there were 2,378 injuries and 226 STFs (46 falls [20%] to a lower level, 117 [52%] falls on the same level, 41 [18%] from loss of balance without a fall, and 22 [10%] from other events). Of the 226 STFs, 123 falls to the same level were caused by slippery substances (52), objects on floor (43), and surface hazards (28), and they cost \$1,543,946. Falls to lower levels primarily involved access to stands to and from aircraft and falling off large machines. **Conclusion:** More than half of the STF injury claims likely could have been prevented by housekeeping and maintenance, and this cost saving could reasonably offset a considerable portion of the cost of prevention. Training and stand modifications could be considered to prevent falls from elevation from stands, machines, and aircraft. **Application:** Recommendations for STF prevention are discussed.

- **Keywords:** causes and costs, helicopter plant, slips, trips, falls

ATTENTIONAL PROCESSES

Bruce Mehler, Bryan Reimer, Joseph F. Coughlin. *Sensitivity of Physiological Measures for Detecting Systematic Variations in Cognitive Demand From a Working Memory Task : An On-Road Study Across Three Age Groups*. S. 396-412.

Objective: To assess the sensitivity of two physiological measures for discriminating between levels of cognitive demand under driving conditions across different age groups. **Background:** Previous driving research presents a mixed picture concerning the sensitivity of physiological measures for differentiating tasks with presumed differences in mental workload. **Method:** A total of 108 relatively healthy drivers balanced by gender and across three age groups (20–29, 40–49, 60–69) engaged in three difficulty levels of an auditory presentation–verbal response working memory task. **Results:** Heart rate and skin conductance level (SCL) both increased in a statistically significant fashion with each incremental increase in cognitive demand, whereas driving performance measures did not provide incremental discrimination. SCL was lower in the 40s and 60s age groups; however, the pattern of incremental increase with higher demand was consistent for heart rate and SCL across all age groups. Although each measure was quite sensitive at the group level, considering both SCL and heart rate improved detection of periods of heightened cognitive demand at the individual level. **Conclusion:** The data provide clear evidence that two basic physiological measures can be utilized under field conditions to differentiate multiple levels of objectively defined changes in cognitive demand. Methodological considerations, including task engagement, may account for some of the inconsistencies in previous research. **Application:** These findings increase the confidence with which these measures may be applied to assess relative differences in mental workload when developing and optimizing human machine interface (HMI) designs and in exploring their potential role in advanced workload detection and augmented cognition systems.

- **Keywords:** mental workload, heart rate, skin conductance, working memory, verbal response, workload manager

AUTOMATION, EXPERT SYSTEMS

Chris Baber, Mark Butler. *Expertise in Crime Scene Examination : Comparing Search Strategies of Expert and Novice Crime Scene Examiners in Simulated Crime Scenes. S. 413-424.*

Objective: The strategies of novice and expert crime scene examiners were compared in searching crime scenes. **Background:** Previous studies have demonstrated that experts frame a scene through reconstructing the likely actions of a criminal and use contextual cues to develop hypotheses that guide subsequent search for evidence. **Method:** Novice (first-year undergraduate students of forensic sciences) and expert (experienced crime scene examiners) examined two “simulated” crime scenes. Performance was captured through a combination of concurrent verbal protocol and own-point recording, using head-mounted cameras. **Results:** Although both groups paid attention to the likely modus operandi of the perpetrator (in terms of possible actions taken), the novices paid more attention to individual objects, whereas the experts paid more attention to objects with “evidential value.” Novices explore the scene in terms of the objects that it contains, whereas experts consider the evidence analysis that can be performed as a consequence of the examination. **Conclusion:** The suggestion is that the novices are putting effort into detailing the scene in terms of its features, whereas the experts are putting effort into the likely actions that can be performed as a consequence of the examination. **Application:** The findings have helped in developing the expertise of novice crime scene examiners and approaches to training of expertise within this population.

- **Keywords:** crime scene examination, expertise, own-point recording, verbal protocol analysis

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Mary E. Sesto, Curtis B. Irwin, Karen B. Chen, Amrish O. Chourasia, Douglas A. Wiegmann. *Effect of Touch Screen Button Size and Spacing*

on Touch Characteristics of Users With and Without Disabilities. S. 425-436.

Objective: The aim of this study was to investigate the effect of button size and spacing on touch characteristics (forces, impulses, and dwell times) during a digit entry touch screen task. A secondary objective was to investigate the effect of disability on touch characteristics. **Background:** Touch screens are common in public settings and workplaces. Although research has examined the effect of button size and spacing on performance, the effect on touch characteristics is unknown. **Method:** A total of 52 participants ($n = 23$, fine motor control disability; $n = 14$, gross motor control disability; $n = 15$, no disability) completed a digit entry task. Button sizes varied from 10 mm to 30 mm, and button spacing was 1 mm or 3 mm. **Results:** Touch characteristics were significantly affected by button size. The exerted peak forces increased 17% between the largest and the smallest buttons, whereas impulses decreased 28%. Compared with the fine motor and nondisabled groups, the gross motor group had greater impulses (98% and 167%, respectively) and dwell times (60% and 129%, respectively). Peak forces were similar for all groups. **Conclusion:** Button size but not spacing influenced touch characteristics during a digit entry task. The gross motor group had significantly greater dwell times and impulses than did the fine motor and nondisabled groups. **Application:** Research on touch characteristics, in conjunction with that on user performance, can be used to guide human computer interface design strategies to improve accessibility of touch screen interfaces. Further research is needed to evaluate the effect of the exerted peak forces and impulses on user performance and fatigue.

- **Keywords:** touch green, force, impulse, disability

SENSORY AND PERCEPTUAL PROCESSES

Daniel H. Ashmead, D. Wesley Grantham, Erin S. Maloff, Benjamin Hornsby, Takabun Nakamura, Timothy J. Davis, Faith Pampel, Erin G. Rushing. *Auditory Perception of Motor Vehicle Travel Paths. S. 435-453.*

Objective: These experiments address concerns that motor vehicles in electric engine mode are so quiet that they pose a risk to pedestrians, especially those with visual impairments. **Background:** The "quiet car" issue has focused on hybrid and electric vehicles, although it also applies to internal combustion engine vehicles. Previous research has focused on detectability of vehicles, mostly in quiet settings. Instead, we focused on the functional ability to perceive vehicle motion paths. **Method:** Participants judged whether simulated vehicles were traveling straight or turning, with emphasis on the impact of background traffic sound. **Results:** In quiet, listeners made the straight-or-turn judgment soon enough in the vehicle's path to be useful for deciding whether to start crossing the street. This judgment is based largely on sound level cues rather than the spatial direction of the vehicle. With even moderate background traffic sound, the ability to tell straight from turn paths is severely compromised. The signal-to-noise ratio needed for the straight-or-turn judgment is much higher than that needed to detect a vehicle. **Conclusion:** Although a requirement for a minimum vehicle sound level might enhance detection of vehicles in quiet settings, it is unlikely that this requirement would contribute to pedestrian awareness of vehicle movements in typical traffic settings with many vehicles present. **Application:** The findings are relevant to deliberations by government agencies and automobile manufacturers about standards for minimum automobile sounds and, more generally, for solutions to pedestrians' needs for information about traffic, especially for pedestrians with sensory impairments.

- **Keywords:** pedestrian, traffic, quiet car, visual impairment

SURFACE TRANSPORTATION SYSTEMS

Bryan Reimer, Bruce Mehler, Ying Wang, Joseph F. Coughlin. *A Field Study on the Impact of Variations in Short-Term Memory Demands on Drivers' Visual Attention and Driving Performance Across Three Age Groups.* S. 454-468.

Objective: The aim of this study was to assess sensitivity of visual attention and driving performance for detecting changes in driver cognitive workload across different age groups. **Background:** The literature shows mixed results concerning the sensitivity of gaze concentration metrics to variations in cognitive demand. No studies appear showing how age affects gaze allocation during cognitive demand. **Method:** Recordings of drivers' gaze and driving performance by individuals in their 20s, 40s, and 60s were captured in actual driving conditions during three levels of cognitive demand. **Results:** Gaze concentration increased with task difficulty through the low and moderate levels of demand and then appeared to level out at the high demand level. At the moderate difficulty level, gaze concentration increased by 2.4 cm ($\approx 2^\circ$) from the reference period. The degree of gaze concentration with added cognitive demand is not related to age in the relatively healthy drivers studied. Driving performance measures did not show a consistent relationship with the objective demand level. **Conclusion:** Gaze concentration appears at low levels of cognitive demand prior to the appearance of marked decrements in driving control. There is no compelling evidence from this study that driving performance measures can be used to index differences in workload prior to capacity saturation. **Application:** Drivers' awareness of vehicle surroundings is incrementally affected by increases in cognitive demand. Developers of more advanced driver support systems should consider gaze concentration as a measure of driver cognitive workload. This recommendation is particularly relevant in light of the added benefits of gaze measurements for detecting visual demand.

- **Keywords:** mental workload, cognitive distraction, eye movements, visual tunneling, driving safety, situational awareness, voice interfaces, cellular telephone

TRAINING, EDUCATION, INSTRUCTIONAL SYSTEMS

D. C. Donderi, Keith K. Niall, Karyn Fish, Benjamin Goldstein. *Above-Real-Time Training (ARTT) Improves Transfer to a Simulated Flight Control Task.* S. 469-479.

Objective: The aim of this study was to measure the effects of above-real-time-training (ARTT) speed and screen resolution on a simulated flight control task. **Background:** ARTT has been shown to improve transfer to the criterion task in some military simulation experiments. We tested training speed and screen resolution in a project, sponsored by Defence Research and Development Canada, to develop components for prototype air mission simulators. **Method:** For this study, 54 participants used a single-screen PC-based flight simulation program to learn to chase and catch an F-18A fighter jet with another F-18A while controlling the chase aircraft with a throttle and side-stick controller. Screen resolution was varied between participants, and training speed was varied factorially across two sessions within participants. Pretest and posttest trials were at high resolution and criterion (900 knots) speed. **Results:** Posttest performance was best with high screen resolution training and when one ARTT training session was followed by a session of criterion speed training. **Conclusion:** ARTT followed by criterion training improves performance on a visual-motor coordination task. We think that ARTT influences known facilitators of transfer, including similarity to the criterion task and contextual interference. **Application:** Use high-screen resolution, start with ARTT, and finish with criterion speed training when preparing a mission simulation.

- **Keywords:** above-real-time training, transfer of training, attention, cognitive load, display resolution