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BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Heather Johnston, Colleen Dewis, John Kozey. *Comparison Considerations Toward Investigating the Factors of Load and Age Group on the Maximum Reach Envelope*. pp. 785–799.

Objective: The objectives were to compare cylindrical and spherical coordinate representations of the maximum reach envelope (MRE) and apply these to a comparison of age and load on the MRE. **Background:** The MRE is a useful measurement in the design of workstations and quantifying functional capability of the upper body. As a dynamic measure, there are human factors that impact the size, shape, and boundaries of the MRE. **Method:** Three-dimensional reach measures were recorded using a computerized potentiometric system for anthropometric measures (CPSAM) on two adult groups (aged 18–25 years and 35–70 years). Reach trials were performed holding .0, .5, and 1 kg. **Results:** Three-dimensional Cartesian coordinates were transformed into cylindrical (r, θ, Z) and spherical (r, θ, φ) coordinates. Median reach distance vectors were calculated for 54 panels within the MRE as created by incremented banding of the respective coordinate systems. Reach distance and reach area were compared between the two groups and the loaded conditions using a spherical coordinate system. Both younger adults and unloaded condition produced greater reach distances and reach areas. **Conclusions:** Where a cylindrical coordinate system may reflect absolute reference for design, a normalized spherical coordinate system may better reflect functional range of motion and better compare individual and group differences. Age and load are both factors that impact the MRE. **Application:** These findings present measurement considerations for use in human reach investigation and design.

Etienne Goubault, Romain Martinez, Najoua Assila, Élodie Monga-Dubreuil, Jennifer Dowling-Medley, Fabien Dal Maso, Mickael Begon. *Effect of Expertise on Shoulder and Upper Limb Kinematics, Electromyography, and Estimated Muscle Forces During a Lifting Task*. pp. 800–819

Objective: To highlight the working strategies used by expert manual handlers compared with novice manual handlers, based on recordings of shoulder and upper limb

kinematics, electromyography (EMG), and estimated muscle forces during a lifting task. **Background:** Novice workers involved in assembly, manual handling, and personal assistance tasks are at a higher risk of upper limb musculoskeletal disorders (MSDs). However, few studies have investigated the effect of expertise on upper limb exposure during workplace tasks. **Method:** Sixteen experts in manual handling and sixteen novices were equipped with 10 electromyographic electrodes to record shoulder muscle activity during a manual handling task consisting of lifting a box (8 or 12 kg), instrumented with three six-axis force sensors, from hip to eye level. Three-dimensional trunk and upper limb kinematics, hand-to-box contact forces, and EMG were recorded. Then, joint contributions, activation levels, and muscle forces were calculated and compared between groups. **Results:** Sternoclavicular–acromioclavicular joint contributions were higher in experts at the beginning of the movement, and in novices at the end, whereas the opposite was observed for the glenohumeral joint. EMG activation levels were 37% higher for novices but predicted muscle forces were higher in experts. **Conclusion:** This study highlights significant differences between experts and novices in shoulder kinematics, EMG, and muscle forces; hence, providing effective work guidelines to ensure the development of a safe handling strategy is important. **Application:** Shoulder kinematics, EMG, and muscle forces could be used as ergonomic tools to identify inappropriate techniques that could increase the prevalence of shoulder injuries.

COGNITION

Pongsatorn Saiklang, Rungthip Puntumetakul, James Selfe, Gillian Yeowell. *An Evaluation of an Innovative Exercise to Relieve Chronic Low Back Pain in Sedentary Workers*. pp. 820–834.

Objective: The purpose of the study was to examine the effectiveness of a novel supported dynamic lumbar extension with the abdominal drawing-in maneuver (ADIM) technique on stature change, deep abdominal muscle activity, trunk muscle fatigue, and pain intensity during prolonged sitting in chronic low back pain (CLBP) participants. **Background:** Prolonged sitting can cause trunk muscle fatigue from continuous contraction of deep trunk muscles in seated postures. Deficiency of activity of deep muscles can reduce muscular support of the spine, causing stress on spinal structures, which could result in pain. **Method:** Thirty participants with CLBP were randomly allocated: (a) control—sitting without exercise, and (b) intervention—supported dynamic lumbar extension with the ADIM technique. **Results:** Compared to the intervention condition, the control condition demonstrated significantly greater deterioration in stature change, increased levels of deep trunk muscle fatigue, and an increase in pain during prolonged sitting. **Conclusion:** The supported dynamic lumbar extension with the ADIM technique appears to provide a protective effect on detrimental stature change and deep trunk muscle fatigue. In addition, it prevented an increase in pain intensity during prolonged sitting in people with CLBP. **Application:** Sedentary behavior harms health, particularly affecting the lower back. Clinicians can use the intervention to induce dynamic lumbar movement, and this exercise can maintain deep trunk muscle activity during prolonged sitting, thereby helping to prevent low back pain (LBP) problems.

HEALTH CARE/HEALTH SYSTEMS

Matthew L. Bolton, Judy R. Edworthy, Andrew D. Boyd. *Masking Between Reserved Alarm Sounds of the IEC 60601-1-8 International Medical Alarm Standard: A Systematic, Formal Analysis*. pp. 835–851

Objective: In this work, we systematically evaluated the reserved alarm sounds of the IEC 60601-1-8 international medical alarm standard to determine when and how they can be totally and partially masked. **Background:** IEC 60601-1-8 gives engineers instruction for creating human-perceivable auditory medical alarms. This includes reserved alarm sounds: common types of alarms where each is a tonal melody. Even when this standard is honored, practitioners still fail to hear alarms, causing practitioner nonresponse and, thus, potential patient harm. Simultaneous masking, a condition where one or more alarms is imperceptible in the presence of other concurrently sounding alarms due to limitations of the human sensory system, is partially responsible for this. **Methods:** In this research, we use automated proof techniques to determine if masking can occur in a modeled configuration of medical alarms. This allows us to determine when and how reserved alarm sound can mask other reserved alarms and to explore parameters to address discovered problems. **Results:** We report the minimum number of other alarm sounds it takes to both totally and partially mask each of the high-, medium-, and low-priority alarm sounds from the standard. **Conclusions:** Significant masking problems were found for both the total and partial masking of high-, medium-, and low-priority reserved alarm sounds. **Application:** We show that discovered problems can be mitigated by setting alarm volumes to standard values based on priority level and by randomizing the timing of alarm tones.

HUMAN-COMPUTER INTERACTION, COMPUTER SYSTEMS

Hyungil Kim, Joseph L. Gabbard. *Assessing Distraction Potential of Augmented Reality Head-Up Displays for Vehicle Drivers*. pp. 852–865.

Objective: To develop a framework for quantifying the visual and cognitive distraction potential of augmented reality (AR) head-up displays (HUDs). **Background:** AR HUDs promise to be less distractive than traditional in-vehicle displays because they project information onto the driver's forward-looking view of the road. However, AR graphics may direct the driver's attention away from critical road elements. Moreover, current in-vehicle device assessment methods, which are based on eyes-off-road time measures, cannot capture this unique challenge. **Method:** This article proposes a new method for the assessment of AR HUDs by measuring driver gaze behavior, situation awareness, confidence, and workload. An experimental user study (n = 24) was conducted in a driving simulator to apply the proposed method for the assessment of two AR pedestrian collision warning (PCW) design alternatives. **Results:** Only one of the two tested AR interfaces improved driver awareness of pedestrians without visually and cognitively distracting drivers from other road elements that were not augmented by the display but still critical for safe driving. **Conclusion:** Our initial human-subject experiment demonstrated the potential of the proposed method in quantifying both positive and negative consequences of AR HUDs on driver cognitive processes. More importantly, the study suggests that AR interfaces can be informative or distractive depending on the perceptual forms of graphical elements presented on the displays. **Application:** The proposed methods can be applied by designers of in-vehicle AR HUD interfaces and be leveraged by designers of AR user interfaces in general.

HUMAN-SYSTEMS INTEGRATION

Claudia Ziegler Acemyan, Philip Kortum, Michael D. Byrne, Dan S. Wallach. *Summative Usability Assessments of STAR-Vote: A Cryptographically Secure e2e Voting System That Has Been Empirically Proven to Be Easy to Use*. pp. 866–889

Background: From the project's inception, STAR-Vote was intended to be one of the first usable, end-to-end (e2e) voting systems with sophisticated security. To realize STAR-Vote, computer security experts, statistical auditors, human factors (HF)/human-computer interaction (HCI) researchers, and election officials collaborated throughout the project and relied upon a user-centered, iterative design and development process, which included human factors research and usability testing, to make certain the system would be both usable and secure. **Objective:** While best practices in HF/HCI methods for design were used and all apparent usability problems were identified and fixed, summative system usability assessments were conducted toward the end of the user-centered design process to determine whether STAR-Vote is in fact easy to use. **Method and Results:** After collecting efficiency, effectiveness, and satisfaction measurements per ISO 9241-11's system usability criteria, an analysis of the data revealed that there is evidence for STAR-Vote being the most usable, cryptographically secure voting system to date when compared with the previously tested e2e systems: Helios, Prêt à Voter, and Scantegrity. **Conclusion and Application:** STAR-Vote being one of the first e2e voting systems that is both highly usable and secure is a significant accomplishment, because tamper-resistant voting systems can be used in U.S. elections to ensure the integrity of the electoral process, while still ensuring that voter intent is accurately reflected in the cast ballots. Moreover, this research empirically shows that a complex, secure system can still be usable—meaning that implemented security is not an excuse for poor usability.

SURFACE TRANSPORTATION

James Unverricht, Yusuke Yamani, Jing Chen, William J. Horrey. *Minding the Gap: Effects of an Attention Maintenance Training Program on Driver Calibration*. pp. 890–903.

Objective: The present study examines the effect of an existing driver training program, FOrward Concentration and Attention Learning (FOCAL) on young drivers' calibration, drivers' ability to estimate the length of their in-vehicle glances while driving, using two different measures, normalized difference scores and Brier Scores. **Background:** Young drivers are poor at maintaining attention to the forward roadway while driving a vehicle. Additionally, drivers may overestimate their attention maintenance abilities. Driver training programs such as FOCAL may train target skills such as attention maintenance but also might serve as a promising way to reduce errors in drivers' calibration of their self-perceived attention maintenance behaviors in comparison to their actual performance. **Method:** Thirty-six participants completed either FOCAL or a Placebo training program, immediately followed by driving simulator evaluations of their attention maintenance performance. In the evaluation drive, participants navigated four driving simulator scenarios during which their eyes were tracked. In each scenario, participants performed a map task on a tablet simulating an in-vehicle infotainment system. **Results:** FOCAL-trained drivers maintained their attention to the forward roadway more and reported better calibration using the normalized difference measure than Placebo-trained drivers. However, the Brier scores did not distinguish the two groups on their calibration **Conclusion:** The study implies that FOCAL has the potential to improve not only attention maintenance skills but also calibration of the skills for young drivers.

Application: Driver training programs may be designed to train not only targeted higher cognitive skills but also driver calibration - both critical for driving safety in young drivers.

TEAMS AND GROUPS

Thomas O'Neill, Nathan McNeese, Amy Barron, Beau Schelble. *Human-Autonomy Teaming: A Review and Analysis of the Empirical Literature*. pp. 904–938.

Objective: We define human-autonomy teaming and offer a synthesis of the existing empirical research on the topic. Specifically, we identify the research environments, dependent variables, themes representing the key findings, and critical future research directions. **Background:** Whereas a burgeoning literature on high-performance teamwork identifies the factors critical to success, much less is known about how human-autonomy teams (HATs) achieve success. Human-autonomy teamwork involves humans working interdependently toward a common goal along with autonomous agents. Autonomous agents involve a degree of self-government and self-directed behavior (agency), and autonomous agents take on a unique role or set of tasks and work interdependently with human team members to achieve a shared objective. **Method:** We searched the literature on human-autonomy teaming. To meet our criteria for inclusion, the paper needed to involve empirical research and meet our definition of human-autonomy teaming. We found 76 articles that met our criteria for inclusion. **Results:** We report on research environments and we find that the key independent variables involve autonomous agent characteristics, team composition, task characteristics, human individual differences, training, and communication. We identify themes for each of these and discuss the future research needs. **Conclusion:** There are areas where research findings are clear and consistent, but there are many opportunities for future research. Particularly important will be research that identifies mechanisms linking team input to team output variables.