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AT THE FOREFRONT OF HF/E

Gloria Calhoun. *Adaptable (Not Adaptive) Automation: Forefront of Human-Automation Teaming*. S. 269–277.

Objective: Identify a critical research gap for the human factors community that has implications for successful human-automation teaming. **Background:** There are a variety of approaches for applying automation in systems. Flexible application of automation such that its level and/or type changes during system operations has been shown to enhance human-automation system performance. **Method:** This mini-review describes flexible automation in which the level of automated support varies across tasks during system operation, rather than remaining fixed. Two types distinguish the locus of authority to change automation level: adaptable automation (the human operator assigns how automation is applied) has been found to aid human's situation awareness and provide more perceived control versus adaptive automation (the system assigns automation level) that may impose less workload and attentional demands by automatically adjusting levels in response to changes in one or more states of the human, task, environment, and so on. **Results:** In contrast to vast investments in adaptive automation approaches, limited research has been devoted to adaptable automation. Experiments directly comparing adaptable and adaptive automation are particularly scant. These few studies show that adaptable automation was not only preferred over adaptive automation, but it also resulted in improved task performance and, notably, less perceived workload. **Conclusion:** Systematic research examining adaptable automation is overdue, including hybrid approaches with adaptive automation. Specific recommendations for further research are provided. **Application:** Adaptable automation together with effective human-factored interface designs to establish working agreements are key to enabling human-automation teaming in future complex systems.

- **Keywords:** level of automation, human-automation interaction, working agreement, situation awareness, mode awareness

AVIATION AND AEROSPACE

Anja K. Faulhaber, Maik Friedrich, Tatjana Kapol. *Absence of Pilot Monitoring Affects Scanning Behavior of Pilot Flying: Implications for the Design of Single-Pilot Cockpits*. S. 278–290.

Objective: This study examines whether the pilot flying's (PF) scanning behavior is affected by the absence of the pilot monitoring (PM) and aims at deriving implications for the design of single-pilot cockpits for commercial aviation. **Background:** Due to technological progress, a crew reduction from two-crew to single-pilot operations (SPO) might be feasible. This requires a redesign of the cockpit to support the pilot adequately, especially during high workload phases such as approach and landing. In these phases, the continuous scanning of flight parameters is of particular importance. **Method:** Experienced pilots flew various approach and landing scenarios with or without the support of the PM in a fixed-base Airbus A320 simulator. A within-subject design was used and eye-tracking data were collected to analyze scanning behavior. **Results:** The results confirm that the absence of the PM affects the PF's scanning behavior. Participants spent significantly more time scanning secondary instruments at the expense of primary instruments when flying alone. Moreover, the frequency of transitions between the cockpit instruments and the external view increased while mean dwell durations on the external view decreased. **Conclusion:** The findings suggest that the PM supports the PF to achieve efficient scanning behavior. Information should be presented differently in commercial SPO to compensate for the PM's absence and to avoid visual overload. **Application:** This research will help inform the design of commercial SPO flight decks providing adequate support for the pilot particularly in terms of efficient scanning behavior.

- **Keywords:** single pilot, reduced crew, commercial aviation, eye tracking, simulator study

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Morteza Asgari, Hamid Reza Mokhtarinia, Mohammad Ali Sanjari, Sedighe Kahrizi, Gabel Charles Philip, Mohamad Parnianpour, Kinda Khalaf. *Trunk Dynamic Stability Assessment for Individuals With and Without Nonspecific Low Back Pain During Repetitive Movement*. S. 291–304.

Objective: This study aimed to employ nonlinear dynamic approaches to assess trunk dynamic stability with speed, symmetry, and load during repetitive flexion-extension (FE) movements for individuals with and without nonspecific low back pain (NSLBP). **Background:** Repetitive trunk FE movement is a typical work-related LBP risk factor contingent on speed, symmetry, and load. Improper settings/adjustments of these control parameters could undermine the dynamic stability of the trunk, hence leading to low back injuries. The underlying stability mechanisms and associated control impairments during such dynamic movements remain elusive. **Method:** Thirty-eight male volunteers (19 healthy, 19 NSLBP) enrolled in the current study. All participants performed repetitive trunk FE movements at high/low speeds, in symmetric/asymmetric directions, with/without a wearable loaded vest. Trunk instantaneous rotation angle was

computed for each trial to be assessed in terms of local and orbital stability, using maximum finite-time Lyapunov exponents (LyEs) and Floquet multipliers (FMs), respectively. **Results:** Both groups demonstrated equivalent competency in terms of trunk control and stability, suggesting functional adaptation strategies may be used by the NSLBP group. Wearing the loaded vest magnified the effects of trunk control impairment for the NSLBP group. The combined presence of high-speed and symmetrical FE movements was associated with least trunk local stability. **Conclusion:** Nonlinear dynamic techniques, particularly LyE, are potentially effective for assessing trunk dynamic stability dysfunction for individuals with NSLBP during various activities. **Application:** This work can be applied toward the development of quantitative personalized spinal evaluation tools with a wide range of potential occupational and clinical applications.

- **Keywords:** dynamic stability, nonspecific low back pain, repetitive trunk movements, Lyapunov exponent

Richard W. Marklin, Jr., Ashley M. Toll, Eric H. Bauman, John J. Simmins, John F. LaDisa, Jr., Robert Cooper. *Do Head-Mounted Augmented Reality Devices Affect Muscle Activity and Eye Strain of Utility Workers Who Do Procedural Work? Studies of Operators and Manhole Workers*. S. 305–323.

Objective: The objective was to determine the effect of two head-mounted display (HMD) augmented reality (AR) devices on muscle activity and eye strain of electric utility workers. The AR devices were the Microsoft HoloLens and RealWear HMT-1. **Background:** The HoloLens is an optical see-through device. The HMT-1 has a small display that is mounted to the side of one eye of the user. **Method:** Twelve power plant operators and 13 manhole workers conducted their normal procedural tasks on-site in three conditions: HoloLens, HMT-1, and "No AR" (regular method). Duration of test trials ranged up to 30 s for operators and up to 10 min for manhole workers. Mean and peak values of surface electromyographic (sEMG) signals from eight neck muscles were measured. A small eye camera measured blink rate of the right eye. **Results:** In general, there were no differences in sEMG activity between the AR and "No AR" conditions for both groups of workers. For the manhole workers, the HoloLens blink rate was 8 to 11 blinks per min lower than the HMT-1 in two tasks and 6.5 fewer than "No AR" in one task. Subjective assessment of the two AR devices did not vary in general. **Conclusion:** The decrease in blink rate with the HoloLens may expose utility manhole workers to risk of eye strain or dry-eye syndrome. **Application:** HMD AR devices should be tested thoroughly with respect to risk of eye strain before deployment by manhole workers for long-duration procedural work.

- **Keywords:** augmented reality, utility, muscle activity, eye strain, eye fatigue, blink rate

DISPLAYS AND CONTROLS

Lisa Graichen, Matthias Graichen, Josef F. Krems. *Effects of Gesture-Based Interaction on Driving Behavior: A Driving Simulator Study Using the Projection-Based Vehicle-in-the-Loop*. S. 324–342.

Objective: We observe the driving performance effects of gesture-based interaction (GBI) versus touch-based interaction (TBI) for in-vehicle information systems (IVISs). **Background:** As a contributing factor to a number of traffic accidents, driver distraction is a significant problem for traffic safety. More specifically, visual distraction has a strong

negative impact on driving performance and risk perception. Thus, the implementation of new interaction systems that use midair gestures to encourage glance-free interactions could reduce visual distraction among drivers. **Methods:** In this experiment, participants drove a projection-based Vehicle-in-the-Loop. The projection-based technology combines a visual simulation with kinesthetic, vestibular, and auditory feedback from a car on a test track. While driving, participants used GBI or TBI to perform IVIS tasks. To investigate driving behavior related to critical driving situations and car-following maneuvers, vehicle data based upon longitudinal and lateral driving were collected. **Results:** Participants reacted faster to critical driving situations when using GBI compared to TBI. For drivers using TBI, steering performance decreased and time headway to a preceding vehicle was higher. **Conclusion:**Gestures provide a safe alternative to in-vehicle interactions. Moreover, GBI has fewer effects on driver distraction than TBI. **Application:** Potential applications of this research include all in-vehicle interaction systems used by drivers.

- **Keywords:** in-vehicle information system, human-machine interaction, driver distraction

HUMAN-COMPUTER INTERACTION, COMPUTER SYSTEMS

Palvi Aggarwal, Frederic Moisan, Cleotilde Gonzalez, Varun Dutt. *Learning About the Effects of Alert Uncertainty in Attack and Defend Decisions via Cognitive Modelling*. S. 343–358.

Objective: We aim to learn about the cognitive mechanisms governing the decisions of attackers and defenders in cybersecurity involving intrusion detection systems (IDSs). **Background:** Prior research has experimentally studied the role of the presence and accuracy of IDS alerts on attacker's and defender's decisions using a game-theoretic approach. However, little is known about the cognitive mechanisms that govern these decisions. **Method:** To investigate the cognitive mechanisms governing the attacker's and defender's decisions in the presence of IDSs of different accuracies, instance-based learning (IBL) models were developed. One model (NIDS) disregarded the IDS alerts and one model (IDS) considered them in the instance structure. Both the IDS and NIDS models were trained in an existing dataset where IDSs were either absent or present and they possessed different accuracies. The calibrated IDS model was tested in a newly collected test dataset where IDSs were present 50% of the time and they possessed different accuracies. **Results:** Both the IDS and NIDS models were able to account for human decisions in the training dataset, where IDS was absent or present and it possessed different accuracies. However, the IDS model could accurately predict the decision-making in only one of the several IDS accuracy conditions in the test dataset. **Conclusions:** Cognitive models like IBL may provide some insights regarding the cognitive mechanisms governing the decisions of attackers and defenders in conditions not involving IDSs or IDSs of different accuracies. **Application:** IBL models may be helpful for penetration testing exercises in scenarios involving IDSs of different accuracies.

- **Keywords:** cybersecurity, behavioral game theory, instance-based learning theory, alerts

HUMAN-SYSTEMS INTEGRATION

Nir Douer, Joachim Meyer. *Judging One's Own or Another Person's Responsibility in Interactions With Automation*. S. 359–371.

Objective: We explore users' and observers' subjective assessments of human and automation capabilities and human causal responsibility for outcomes. **Background:** In intelligent systems and advanced automation, human responsibility for outcomes becomes equivocal, as do subjective perceptions of responsibility. In particular, actors who actively work with a system may perceive responsibility differently from observers. **Method:** In a laboratory experiment with pairs of participants, one participant (the "actor") performed a decision task, aided by an automated system, and the other (the "observer") passively observed the actor. We compared the perceptions of responsibility between the two roles when interacting with two systems with different capabilities. **Results:** Actors' behavior matched the theoretical predictions, and actors and observers assessed the system and human capabilities and the comparative human responsibility similarly. However, actors tended to relate adverse outcomes more to system characteristics than to their own limitations, whereas the observers insufficiently considered system capabilities when evaluating the actors' comparative responsibility. **Conclusion:** When intelligent systems greatly exceed human capabilities, users may correctly feel they contribute little to system performance. They may interfere more than necessary, impairing the overall performance. Outside observers, such as managers, may overweigh users' contribution to outcomes, holding users responsible for adverse outcomes when they rightly trusted the system. **Application:** Presenting users of intelligent systems and others with performance measures and the comparative human responsibility may help them calibrate subjective assessments of performance, reducing users' and outside observers' biases and attribution errors.

- **Keywords:** human-automation interaction, decision making, warning systems, warning compliance

MOTOR BEHAVIOR

Sébastien Mick, Arnaud Badets, Pierre-Yves Oudeyer, Daniel Cattaert, Aymar De Rugy. *Biological Plausibility of Arm Postures Influences the Controllability of Robotic Arm Teleoperation*. S. 372–384.

Objective: We investigated how participants controlling a humanoid robotic arm's 3D endpoint position by moving their own hand are influenced by the robot's postures. We hypothesized that control would be facilitated (impeded) by biologically plausible (implausible) postures of the robot. **Background:** Kinematic redundancy, whereby different arm postures achieve the same goal, is such that a robotic arm or prosthesis could theoretically be controlled with less signals than constitutive joints. However, congruency between a robot's motion and our own is known to interfere with movement production. Hence, we expect the human-likeness of a robotic arm's postures during endpoint teleoperation to influence controllability. **Method:** Twenty-two able-bodied participants performed a target-reaching task with a robotic arm whose endpoint's 3D position was controlled by moving their own hand. They completed a two-condition experiment corresponding to the robot displaying either biologically plausible or implausible postures. **Results:** Upon initial practice in the experiment's first part, endpoint trajectories were faster and shorter when the robot displayed human-like postures. However, these effects did not persist in the second part, where performance with implausible postures appeared to have benefited from initial practice with plausible ones. **Conclusion:** Humanoid robotic arm endpoint control is impaired by biologically implausible joint coordinations during initial familiarization but not afterwards, suggesting that the human-likeness of a robot's postures is more critical for control in this initial period. **Application:** These findings provide insight for the design of robotic arm teleoperation and prosthesis control schemes, in order to favor better familiarization and control from their users.

- **Keywords:** motor control, teleoperation, inverse kinematics, bio-inspired robotics, embodied cognition

NEUROERGONOMICS

Daniel M. Abdel-Malek, Ryan C. A. Foley, Fahima Wakeely, Jeffrey D. Graham, Nicholas J. La Delfa. *Exploring Localized Muscle Fatigue Responses at Current Upper-Extremity Ergonomics Threshold Limit Values*. S. 385–400.

Objective: The purpose of this study was to evaluate localized muscle fatigue responses at three upper-extremity ergonomics threshold limit value (TLV) duty cycles. **Background:** Recently, a TLV equation was published to help mitigate excessive development of localized muscle fatigue in repetitive upper limb tasks. This equation predicts acceptable levels of maximal voluntary contraction (% MVC) for a given duty cycle (DC). Experimental validation of this TLV curve has not yet been reported, which can help guide utilization by practitioners. **Method:** Eighteen participants performed intermittent isometric elbow flexion efforts, in three separate counter-balanced sessions, at workloads defined by the American Conference of Governmental Industrial Hygenists' (ACGIH) TLV equation: low DC (20% DC, 29.6% MVC), medium DC (40% DC, 19.7% MVC), and high DC (60% DC, 13.9% MVC). Targeted localized muscle fatigue (LMF) of the biceps brachii was tracked across numerous response variables, including decline in strength (MVC), electromyography (EMG) amplitude and mean power frequency (MnPF), and several psychophysical ratings. **Results:** At task completion, biceps MnPF and MVC (strength) were significantly different between each TLV workload, with the high DC condition eliciting the largest declines in MnPF and MVC. **Conclusion:** Findings demonstrate that working at different DCs along the ACGIH TLV curve may not be equivalent in preventing excessive LMF. Higher DC workloads elicited a greater LMF response across several response variables. **Application:** High DC work of the upper extremity should be avoided to mitigate excess LMF development. Current TLVs for repetitive upper-extremity work may overestimate acceptable relative contraction thresholds, particularly at higher duty cycles.

- **Keywords:** threshold limit values, localized muscle fatigue, physical work, ergonomics

SURFACE TRANSPORTATION

Dengbo He, Birsen Donmez. *The Influence of Visual-Manual Distractions on Anticipatory Driving*. S. 401–417.

Objective: The aim of this study is to investigate how anticipatory driving is influenced by distraction. **Background:** The anticipation of future events in traffic can allow potential gains in recognition and response times. Anticipatory actions (i.e., control actions in preparation for potential traffic changes) have been found to be more prevalent among experienced drivers in simulator studies when driving was the sole task. Despite the prevalence of visual-manual distractions and their negative effects on road safety, their influence on anticipatory driving has not yet been investigated beyond hazard anticipation. **Methods:** A simulator experiment was conducted with 16 experienced and 16 novice drivers. Half of the participants were provided with a self-paced visual-manual secondary task presented on a dashboard display. **Results:** More anticipatory actions were observed among experienced drivers; experienced drivers also

exhibited more efficient visual scanning behaviors as indicated by higher glance rates toward and percent times looking at cues that facilitate the anticipation of upcoming events. Regardless of experience, those with the secondary task displayed reduced anticipatory actions and paid less attention toward anticipatory cues. However, experienced drivers had lower odds of exhibiting long glances toward the secondary task compared to novices. Further, the inclusion of glance duration on anticipatory cues increased the accuracy of a model predicting anticipatory actions based on on-road glance durations. **Conclusion:** The results provide additional evidence to existing literature supporting the role of driving experience and distraction engagement in anticipatory driving. **Application:** These findings can guide the design of in-vehicle systems and guide training programs to support anticipatory driving.

- **Keywords :** driver distraction, anticipation, driving simulators, driver behavior, experience

Jing Chen, Edin Šabić, Scott Mishler, Cody Parker, Motonori Yamaguchi. *Effectiveness of Lateral Auditory Collision Warnings: Should Warnings Be Toward Danger or Toward Safety?* S. 418–435.

Objective: The present study investigated the design of spatially oriented auditory collision-warning signals to facilitate drivers' responses to potential collisions. **Background:** Prior studies on collision warnings have mostly focused on manual driving. It is necessary to examine the design of collision warnings for safe takeover actions in semi-autonomous driving. **Method:** In a video-based semi-autonomous driving scenario, participants responded to pedestrians walking across the road, with a warning tone presented in either the avoidance direction or the collision direction. The time interval between the warning tone and the potential collision was also manipulated. In Experiment 1, pedestrians always started walking from one side of the road to the other side. In Experiment 2, pedestrians appeared in the middle of the road and walked toward either side of the road. **Results:** In Experiment 1, drivers reacted to the pedestrian faster with collision-direction warnings than with avoidance-direction warnings. In Experiment 2, the difference between the two warning directions became nonsignificant. In both experiments, shorter time intervals to potential collisions resulted in faster reactions but did not influence the effect of warning direction. **Conclusion:** The collision-direction warnings were advantageous over the avoidance-direction warnings only when they occurred at the same lateral location as the pedestrian, indicating that this advantage was due to the capture of attention by the auditory warning signals. **Application:** The present results indicate that drivers would benefit most when warnings occur at the side of potential collision objects rather than the direction of a desirable action during semi-autonomous driving.

- **Keywords:** lateral collision warning, auditory warning, stimulus-response compatibility, semi-autonomous driving