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AT THE FOREFRONT OF HF/E

Kim-Phuong L. Vu, Robert Conrad Rorie, Lisa Fern, Robert Jay Shively. *Human Factors Contributions to the Development of Standards for Displays of Unmanned Aircraft Systems in Support of Detect-and-Avoid*. pp. 505–515.

Objective: The aim is to provide a high-level synthesis of human factors research that contributed to the development of detect-and-avoid display requirements for unmanned aircraft systems (UAS). **Background:** The integration of UAS into the U.S. National Airspace System is a priority under the Federal Aviation Administration's Modernization and Reform Act. For UAS to have routine access to the National Airspace System, UAS must have detect-and-avoid capabilities. One human factors challenge is to determine how to display information effectively to remote pilots for performing detect-and-avoid tasks. **Method:** A high-level review of research informing the display requirements for UAS detect-and-avoid is provided. In addition, description of the contributions of human factors researchers in the writing of the requirements is highlighted. **Results:** Findings from human-in-the-loop simulations are used to illustrate how evidence-based guidelines and requirements were established for the display of information to assist pilots in performing detect-and-avoid. Implications for human factors are discussed. **Conclusion:** Human factors researchers and engineers made many contributions to generate the data used to justify the detect-and-avoid display requirements. Human factors researchers must continue to be involved in the development of standards to ensure that requirements are evidence-based and take into account human operator performance and human factors principles and guidelines. **Application:** The research presented in this paper is relevant to the design of UAS, the writing of standards and requirements, and the work in human–systems integration.

- **Keywords:** aviation, UAS, safety, detect-and-avoid, standards

CRITIQUE AND REBUTTAL

Greg A. Jamieson, Gyrd Skraaning. *The Absence of Degree of Automation Trade-Offs in Complex Work Settings*. pp. 516–529.

Objective: The objective of this study was to test the predictions of the routine-failure trade-off (or lumberjack) model in a full-scope simulator study with expert operators performing realistic control tasks. **Background:** A meta-study of degree of automation (DOA) studies concluded that DOA predicts task performance under both routine and automation failure conditions, workload, and situation awareness. Empirical support for this conclusion appears to be weak for complex work situations. **Method:** A full-scope nuclear power plant simulator experiment was conducted in which licensed operating crews completed realistic procedure execution tasks. Dependent measures selected from the lumberjack model were collected and analyzed for systematic effects. **Results:** Situation awareness increased with increasing DOA, which contradicts the lumberjack model. Anticipated workload and failure task performance effects were not observed. **Conclusion:** The experimental results add further evidence challenging the applicability of the lumberjack model to complex work situations. **Application:** Practitioners should use caution when extending the predictions of the lumberjack model based on data from simple work situations to complex work situations. Researchers should invest more resources in testing the predictive power of the lumberjack model in complex work situations.

- **Keywords:** automation/expert systems, human–automation interaction, levels of automation, function allocation, supervisory control

Christopher D. Wickens, Linda Onnasch, Angelina Sebok, Dietrich Manzey. *Absence of DOA Effect but No Proper Test of the Lumberjack Effect: A Reply to Jamieson and Skraaning (2019)*. pp. 530–534.

Objective: The aim was to evaluate the relevance of the critique offered by Jamieson and Skraaning (2019) regarding the applicability of the lumberjack effect of human–automation interaction to complex real-world settings. **Background:** The lumberjack effect, based upon a meta-analysis, identifies the consequences of a higher degree of automation—to improve performance and reduce workload—when automation functions as intended, but to degrade performance more, as mediated by a loss of situation awareness (SA) when automation fails. Jamieson and Skraaning provide data from a process control scenario that they assert contradicts the effect. **Approach:** We analyzed key aspects of their simulation, measures, and results which we argue limit the strength of their conclusion that the lumberjack effect is not applicable to complex real-world systems. **Results:** Our analysis revealed limits in their inappropriate choice of automation, the lack of a routine performance measure, support for the lumberjack effect that was actually provided by subjective measures of the operators, an inappropriate assessment of SA, and a possible limitation of statistical power. **Conclusion:** We regard these limitations as reasons to temper the strong conclusions drawn by the authors, of no applicability of the lumberjack effect to complex environments. Their findings should be used as an impetus for conducting further research on human–automation interaction in these domains. **Applications:** The collective findings of both Jamieson and Skraaning and our study are applicable to system designers and users in deciding upon the appropriate level of automation to deploy.

- **Keywords:** human–automation interaction, level of automation, situation awareness, complex systems, failure response

Greg A. Jamieson, Gyrd Skraaning. *The Harder They Fall? A Response to Wickens et al. (2019) Regarding the Generalizability of Lumberjack Predictions to Complex Work Settings*. pp. 535–539.

Objective: This article is a response to Wickens et al.'s (2019) critique of Jamieson and Skraaning (2019). **Background:** Wickens et al. (2019) offer a five-point critique of Jamieson and Skraaning (2019) that they claim tempers the strength of our conclusions. **Approach:** We first correct a misrepresentation in the critique and then respond to each of the criticisms. **Results:** We preserve the strength of our skeptical conclusions about the applicability of the lumberjack model to complex work settings. **Applications:** We continue to caution system designers about the lack of evidence supporting the lumberjack model in the context of complex work systems.

- **Keywords:** human–automation interaction, level of automation, degree of automation, failure task performance, workload, situation awareness, scientific epistemology

AUTOMATION, EXPERT SYSTEMS

Anna Zirk, Rebecca Wiczorek, Dietrich Manzey. *Do We Really Need More Stages? Comparing the Effects of Likelihood Alarm Systems and Binary Alarm Systems*. pp. 540–552.

Objective: This research investigates the potential behavioral and performance benefits of a four-stage likelihood alarm system (4-LAS) contrasting a 3-LAS, a binary alarm system with a liberal threshold (lib-BAS), and a BAS with a conservative threshold (con-BAS). **Background:** Prior research has shown performance benefits of 3-LASs over conventional lib-BASs due to more distinct response strategies and better discriminating true from false alerts. This effect might be further enhanced using 4-LASs. However, the increase in stages could cause users to reduce cognitive complexity by responding in the same way to the two lower and the two higher stages, thus treating the 4-LAS like a con-BAS. **Method:** All systems were compared using a dual-task paradigm. Response strategies, number of joint human machine (JHM) false alarms (FAs), misses, and sensitivity were regarded. **Results:** Compared with the lib-BAS, JHM sensitivity only improved with the 4-LAS and the con-BAS. However, the number of JHM misses was lowest for the con-BAS compared with all other systems. **Conclusion:** JHM sensitivity improvements can be achieved by using a 4-LAS, as well as a con-BAS. However, only the latter one may also reduce the number of JHM misses, which is remarkable considering that BASs with conservative thresholds a priori commit more inbuilt misses than other systems. **Application:** Results suggest implementing conservative BASs in multi-task working environments to improve JHM sensitivity and reduce the number of JHM misses. When refraining from designing systems which are miss prone, 4-LASs represent a suitable compromise.

- **Keywords:** warning, threshold setting, decision-making, signal detection theory, automation

AVIATION AND AEROSPACE

Nicholas Wilson, Bijay Guragain, Ajay Verma, Lewis Archer, Kouhyar Tavakolian. *Blending Human and Machine: Feasibility of Measuring Fatigue Through the Aviation Headset*. pp. 553–564.

Objective: To determine viability of drowsiness detection, researchers study the feasibility of photoplethysmogram (PPG) data collection from the geography of the aviation headset, correlating to electrocardiogram (ECG) reference. **Background:**

Fatigue has been a probable cause, contributing factor, or a finding in 20% of transportation incidents and accidents studied between January 2001 and December 2012. This operational hazard is particularly troublesome within aviation and airline operations. **Method:** PPG and ECG data were collected synchronously from Federal Aviation Administration (FAA) commercially rated pilots during flight simulation in the window of circadian low (WOCL). Valid PPG and ECG data from 14 participants were analyzed, which yielded approximately 2 hr of data per participant for fatigue-related analysis. **Results:** The results of the study demonstrate clear trends toward decreased heart rate for both ECG and PPG and suggest progression of drowsiness between four separate periods (T1, T2, T3, and T4) selected during the study; however, the mean heart rate change from T1 to T4 was statistically significant. **Conclusion:** The results suggest that ECG and PPG data can be an important tool to observe conditions where drowsiness or fatigue may add risk to the operation. In addition, the data show high correlation between ECG and PPG data, further suggesting that a simpler PPG sensor, mounted within the geography of the aviation headset, may streamline the operationalization of important physiological data. **Application:** Incorporation of PPG sensors and associated signal processing methods into facilitating equipment, such as the aviation headset, may add a layer to operational safety.

- **Keywords:** aviation, heart rate, cardiac, fatigue, stress, pilot, headset

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Simon S. W. Li, Daniel H. K. Chow. *Comparison of Predictions Between an EMG-Assisted Approach and Two Optimization-Driven Approaches for Lumbar Spine Loading During Walking With Backpack Loads*. pp. 565–577.

Objective The efficacy of two optimization-driven biomechanical modeling approaches has been compared with an electromyography-assisted optimization (EMGAO) approach to predict lumbar spine loading while walking with backpack loads. **Background:** The EMGAO approach adopts more variables in the optimization process and is complex in data collection and processing, whereas optimization-driven approaches are simple and include the fewest possible variables. However, few studies have been conducted on the efficacy of using the optimization-driven approach to predict lumbar spine loading while walking with backpack loads. **Method:** Anthropometric information of 10 healthy male adults as well as their kinematic, kinetic, and electromyographic data acquired while they walked with various backpack loads (no-load, 5%, 10%, 15%, and 20% of body weight) served as inputs into the model for predicting lumbosacral joint compression forces. The efficacy of two optimization-driven models, namely double linear optimization with constraints on muscle intensity and single linear optimization without any constraints, was investigated by comparing the resulting force profile with that provided by a current EMGAO approach. **Results:** The double and single linear optimization approaches predicted mean deviations in peak force of −5.1%, and −19.2% as well as root-mean-square differences in force profile of 16.2%, and 25.4%, respectively. **Conclusion:** The double linear optimization approach was a relatively comparable estimator to the EMGAO approach in terms of its consistency, slight bias, and efficiency for predicting peak lumbosacral joint compression forces. **Application:** The double linear optimization approach is a useful biomechanical model for estimating peak lumbar compression forces while walking with backpack loads.

- **Keywords:** electromyography, optimization approach, backpack loads, lumbar spine loading, walking

COGNITION

Yoko Higuchi, Satoshi Inoue, Hiroto Hamada, Takatsune Kumada. *Artificial Optic Flow Guides Visual Attention in a Driving Scene*. pp. 578–588.

Objective: The objective of this study was to investigate whether an artificial optic flow created by dot motion guides attention in a driving scene. **Background:** To achieve safe driving, it is essential to understand the characteristics of human visual information processing as well as to provide appropriate support for drivers. Past research has demonstrated that expanding optic flow guides visual attention to the focus of expansion. Optic flow is an attractive candidate for use as a cue to direct drivers' attention toward the significant information. The question addressed concerns whether an artificial optic flow can successfully guide attention even in a traffic situation involving the optic flow that naturally occurs while driving. **Method:** We developed a visual search paradigm embedded in a video of a driving scene. Participants first observed an optic flow motion pattern superimposed on the video for brief period; next, when the optic flow and video ceased, they searched a static display for a target among multiple distractors. **Results:** The target detection was faster when a target's locus coincided with the implied focus of expansion from the preceding optic flow (vs. other loci). **Conclusion:** The artificial optic flow guides attention and facilitates searching objects at the focus of expansion even when the optic flow was superimposed on a driving scene. **Application:** Optic flow can be an effective cue for guiding drivers' attention in a traffic situation. This finding contributes to the understanding of visual attention in moving space and helps develop technology for traffic safety.

- **Keywords:** visual search, attentional processes, driver behavior

Mitchell L. Stephenson, Alec G. Ostrander, Hamid Norasi, Michael C. Dorneich. *Shoulder Muscular Fatigue From Static Posture Concurrently Reduces Cognitive Attentional Resources*. pp. 589–602.

Objective: The goal of this work is to determine whether muscular fatigue concurrently reduces cognitive attentional resources in technical tasks for healthy adults. **Background:** Muscular fatigue is common in the workplace but often dissociated with cognitive performance. A corpus of literature demonstrates a link between muscular fatigue and cognitive function, but few investigations demonstrate that the instigation of the former degrades the latter in a way that may affect technical task completion. For example, laparoscopic surgery increases muscular fatigue, which may risk attentional capacity reduction and undermine surgical outcomes. **Method:** A total of 26 healthy participants completed a dual-task cognitive assessment of attentional resources while concurrently statically fatiguing their shoulder musculature until volitional failure, in a similar loading pattern observed in laparoscopic procedures. Continuous and discrete monitoring task performance was recorded to reflect attentional resources. **Results:** Electromyography of the anterior deltoid and descending trapezius, as well as self-assessment surveys indicated fatigue occurrence; continuous tracking error, tracking velocity, and response time significantly increased with muscular fatigue. **Conclusion:** Muscular fatigue concurrently degrades cognitive attentional resources. **Application:** Complex tasks that rely on muscular and cognitive performance should consider interventions to reduce muscular fatigue to also preserve cognitive performance.

- **Keywords:** peripheral fatigue, cognitive performance, electromyography, laparoskopy

HUMAN-COMPUTER INTERACTION, COMPUTER SYSTEMS

Elise Labonté-LeMoyne, Marc-Antoine Jutras, Pierre-Majorique Léger, Sylvain Sénécal, Marc Fredette, Mickael Begon, Marie-Ève Mathieu. *Does Reducing Sedentarity With Standing Desks Hinder Cognitive Performance?* pp. 603–612.

Objective: The goal of this study was to determine if using a standing desk would affect the productivity of workers, based on the type of work they perform. **Background:** Standing desks are a promising new health intervention in the workplace, but users and employers often require more specific recommendations related to productivity, such as the type of work that is more suited for the standing desk. **Method:** Thirty-seven young and healthy adults performed eight cognitive tasks in a 2 × 2 × 2 within-subject design of the following independent variables: posture (sitting/standing), task difficulty (easy/hard), and input device (computer mouse/tactile screen) in a counterbalanced order. **Results:** Our results revealed that using a standing desk had no negative effect on performance or perception, but it did lead to increased brain activity in the alpha band for the parietal region ($\beta = 0.186$, $p = .001$). **Conclusion:** We conclude that users of standing desks can freely stand for any level of task difficulty for work that involves working memory. However, more research is needed to generalize these results to other types of cognitive abilities and prolonged use of standing desks. **Application:** Our results simplify recommendations for workers as they do not need to worry about the type of work they are performing when using a standing desk.

- **Keywords:** gait, posture, biomechanics, anthropometry, work physiology, attentional processes, cognition, dual task, time sharing, task switching, working memory, tactile/haptic displays, displays and controls, industrial/workplace ergonomics, macroergonomics and the environment

NEUROERGONOMICS

Yibo Zhu, Carolina Rodriguez-Paras, Joohyun Rhee, Ranjana K. Mehta. *Methodological Approaches and Recommendations for Functional Near-Infrared Spectroscopy Applications in HF/E Research*. pp. 613–642.

Objective: The objective of this study was to systematically document current methods and protocols employed when using functional near-infrared spectroscopy (fNIRS) techniques in human factors and ergonomics (HF/E) research and generate recommendations for conducting and reporting fNIRS findings in HF/E applications. **Method:** A total of 1,687 articles were identified through Ovid-MEDLINE, PubMed, Web of Science, and Scopus databases, of which 37 articles were included in the review based on review inclusion/exclusion criteria. **Results:** A majority of the HF/E fNIRS investigations were found in transportation, both ground and aviation, and in assessing cognitive (e.g., workload, working memory) over physical constructs. There were large variations pertaining to data cleaning, processing, and analysis approaches across the studies that warrant standardization of methodological approaches. The review identified major challenges in transparency and reporting of important fNIRS data collection and analyses specifications that diminishes study replicability, introduces potential biases, and increases likelihood of inaccurate results. As such, results reported in existing fNIRS studies need to be cautiously approached. **Conclusion:** To improve the quality of fNIRS investigations and/or to facilitate its adoption and integration in different HF/E applications, such as occupational ergonomics and rehabilitation, recommendations for fNIRS data collection, processing, analysis, and reporting are provided.

- **Keywords:** fNIRS, human factors, ergonomics, neuroergonomics

SENSORY AND PERCEPTUAL PROCESSES

Kylie Gomes, Scott Betza, Sara Lu Riggs. *Now You Feel It, Now You Don't: The Effect of Movement, Cue Complexity, and Body Location on Tactile Change Detection*. pp. 643–655.

Objective: To evaluate the effects that movement, cue complexity, and the location of tactile displays on the body have on tactile change detection. **Background:** Tactile displays have been demonstrated as a means to address data overload by offloading the visual and auditory modalities. However, change blindness—the failure to detect changes in a stimulus when changes coincide with another event or disruption in stimulus continuity—has been demonstrated to affect the tactile modality and may be exacerbated during movement. The complexity of tactile cues and locations of tactile displays on the body may also affect the detection of changes in tactile patterns. Limitations to tactile perception need to be examined. **Method:** Twenty-four participants performed a tactile change detection task while sitting, standing, and walking. Tactile cues varied in complexity and included low, medium, and high complexity cues presented to the arm or back. **Results:** Movement adversely affects tactile change detection as hit rates were the highest while sitting, followed by standing and walking. Cue complexity affected tactile change detection: Low complexity cues resulted in higher detection rates compared with medium and high complexity cues. The arms exhibited better change detection performance than the back. **Conclusion:** The design of tactile displays should consider the effect of movement. Cue complexity should be minimized and decisions about the location of a tactile display should take into account body movements to support tactile perception. **Application:** The findings can provide design guidelines to inform tactile display design for data-rich, complex domains.

- **Keywords:** tactile/haptic displays, change detection, sensory suppression, signal detection theory

SIMULATION AND VIRTUAL REALITY

Abdulaziz Alshaer, David O'Hare, Philippe Archambault, Mark Shirley, Holger Regenbrecht. *How to Observe Users' Movements in Virtual Environments: Viewpoint Control in a Power Wheelchair Simulator*. pp. 656–670.

Objective: We describe a networked, two-user virtual reality (VR) power wheelchair (PWC) simulator system in which an actor (client) and an observer (clinician) meet. We then present a study with 15 observers (expert clinicians) evaluating the effect of three principal forms of viewpoint control (egocentric-egomotion, egocentric-tethered, and client-centric) on the observer's assessment of driving tasks in a virtual environment (VE). **Background:** VR allows for the simulation and assessment of real-world tasks in a controlled, safe, and repeatable environment. Observing users' movement behavior in such a VE requires appropriate viewpoint control for the observer. The VR viewpoint user interface should allow an observer to make judgments equivalent or even superior to real-world situations. **Method:** A purpose-built VR PWC simulator was developed. In a series of PWC driving tasks, we measured the perceived ease of use and sense of presence of the observers and compared the virtual assessment with real-world "gold standard" scores, including confidence levels in judgments. **Results:** Findings suggest

that with more immersive techniques, such as egomotion and tethered egocentric viewpoints, judgments are both more accurate and more confident. The ability to walk and/or orbit around the view significantly affected the observers' sense of presence. **Conclusion:** Incorporating the observer into the VE, through egomotion, is an effective method for assessing users' behavior in VR with implications for the transferability of virtual experiences to the real world. **Application:** Our application domain serves as a representative example for tasks where the movement of users through a VE needs to be evaluated.

- **Keywords:** user observation, virtual reality, interaction techniques, immersion, driving simulator

SURFACE TRANSPORTATION

Areen Alsaid, John D. Lee, Morgan Price. *Moving Into the Loop: An Investigation of Drivers' Steering Behavior in Highly Automated Vehicles*. pp. 671–683.

Objective: This paper investigates driver engagement with vehicle automation and the transition to manual control in the context of a phenomenon that we have termed vicarious steering—drivers steering when the vehicle is under automated control. **Background:** Automated vehicles introduce many challenges, including disengagement from the driving task and out-of-the-loop performance decrement. We examine drivers' steering behavior when the automation is engaged, and steering input has no effect on the vehicle state. Such vicarious steering is a potential indicator of engagement for evaluating automated vehicles. **Method:** A total of 32 female and 32 male drivers between 25 and 55 years of age participated in this experiment. A 2 × 2 between-subject design combined control algorithms and instructed responsibility. The control algorithms (lane centering and adaptive) were intended to convey the capability of the automation. The adaptive algorithm drifted across the lane center when latent hazards were present. The instructed levels of responsibility (driver primarily responsible and automation primarily responsible) were intended to replicate the admonitions of owners' manuals. **Results:** The adaptive algorithm increased vicarious steering ($p < .001$), but instructed responsibility did not ($p = .67$), and there was no interaction between the algorithm and the responsibility ($p = .75$). Vicarious steering was associated with an increase in transitions to manual control and glances to the road but was negatively associated with driving performance immediately after the transition to manual control. **Conclusion:**Vicarious steering is a promising indicator of driver engagement when the vehicle is under automated control and automation algorithms can promote engagement.

- **Keywords:** automated vehicles, steering, vehicle control algorithms, trust, responsibility