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ACCIDENTS, HUMAN ERROR

Chantal Laroche, Christian Giguère, Véronique Vaillancourt, Claudia Marleau, Marie-, rance Cadieux, Karina Laprise-Girard, Emily Gula, Véronique Carroll, Manuelle Bibeau, Hugues Nélisse. *Effect of Hearing and Head Protection on the Localization of Tonal and Broadband Reverse Alarms*. pp. 1105–1120.

Objective: This study explored the effects of hearing protection devices (HPDs) and head protection on the ability of normal-hearing individuals to localize reverse alarms in background noise. **Background:** Among factors potentially contributing to accidents involving heavy vehicles, reverse alarms can be difficult to localize in space, leading to errors in identifying the source of danger. Previous studies have shown that traditional tonal alarms are more difficult to localize than broadband alarms. In addition, HPDs and safety helmets may further impair localization. **Method:** Standing in the middle of an array of eight loudspeakers, participants with and without HPDs (passive and level-dependent) had to identify the loudspeaker emitting a single cycle of the alarm while performing a task on a tablet computer. **Results:** The broadband alarm was easier to localize than the tonal alarm. Passive HPDs had a significant impact on sound localization (earmuffs generally more so than earplugs), particularly double hearing protection, and level-dependent HPDs did not fully restore sound localization abilities. The safety helmet had a much lesser impact on performance than HPDs. **Conclusion:** Where good sound localization abilities are essential in noisy workplaces, the broadband alarm should be used, double hearing protection should be avoided, and earplug-style passive or level-dependent devices may be a better choice than earmuff-style devices. Construction safety helmets, however, seem to have only a minimal effect on sound localization. **Application:** Results of this study will help stakeholders make decisions that are more informed in promoting safer workplaces.

AUTOMATION, EXPERT SYSTEMS

Monica Tatasciore, Vanessa K. Bowden, Troy A. W. Visser, Shayne Loft. *Should We Just Let the Machines Do It? The Benefit and Cost of Action Recommendation and Action Implementation Automation*. pp. 1121–1136.

Objective: To examine the effects of action recommendation and action implementation automation on performance, workload, situation awareness (SA), detection of automation failure, and return-to-manual performance in a submarine track management task. **Background:** Theory and meta-analytic evidence suggest that with increasing degrees of automation (DOA), operator performance improves and workload decreases, but SA and return-to-manual performance declines. **Method:** Participants monitored the location and heading of contacts in order to classify them, mark their closest point of approach (CPA), and dive when necessary. Participants were assigned either no automation, action recommendation automation, or action implementation automation. An automation failure occurred late in the task, whereby the automation provided incorrect classification advice or implemented incorrect classification actions. **Results:** Compared to no automation, action recommendation automation benefited automated task performance and lowered workload, but cost nonautomated task performance. Action implementation automation resulted in perfect automated task performance (by default) and lowered workload, with no costs to nonautomated task performance, SA, or return-to-manual performance compared to no automation. However, participants provided action implementation automation were less likely to detect the automation failure compared to those provided action recommendations, and made less accurate classifications immediately after the automation failure, compared to those provided no automation. **Conclusion:** Action implementation automation produced the anticipated benefits but also caused poorer automation failure detection. **Application:** While action implementation automation may be effective for some task contexts, system designers should be aware that operators may be less likely to detect automation failures and that performance may suffer until such failures are detected.

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Yi-Ning Wu, Adam Norton, Michael R. Zielinski, Pei-Chun Kao, Andrew Stanwicks, Patrick Pang, Charles H. Cring, Brian Flynn, Holly A. Yanco. *Characterizing the Effects of Explosive Ordnance Disposal Operations on the Human Body While Wearing Heavy Personal Protective Equipment*. pp. 1137–1153.

Objective: To provide a comprehensive characterization of explosive ordnance disposal (EOD) personal protective equipment (PPE) by evaluating its effects on the human body, specifically the poses, tasks, and conditions under which EOD operations are performed. **Background:** EOD PPE is designed to protect technicians from a blast. The required features of protection make EOD PPE heavy, bulky, poorly ventilated, and difficult to maneuver in. It is not clear how the EOD PPE wearer physiologically adapts to maintain physical and cognitive performance during EOD operations. **Method:** Fourteen participants performed EOD operations including mobility and inspection tasks with and without EOD PPE. Physiological measurement and kinematic data recording were used to record human physiological responses and performance. **Results:** All physiological measures were significantly higher during the mobility and the inspection tasks when EOD PPE was worn. Participants spent significantly more time to complete the mobility tasks, whereas mixed results were found in the inspection tasks. Higher back muscle activations were seen in participants who performed object manipulation while wearing

EOD PPE. **Conclusion:** EOD operations while wearing EOD PPE pose significant physical stress on the human body. The wearer's mobility is impacted by EOD PPE, resulting in decreased speed and higher muscle activations. **Application:** The testing and evaluation methodology in this study can be used to benchmark future EOD PPE designs. Identifying hazards posed by EOD PPE lays the groundwork for developing mitigation plans, such as exoskeletons, to reduce physical and cognitive stress caused by EOD PPE on the wearers without compromising their operational performance.

COGNITION

Ann J. Carrigan Amanda Charlton, Elliott Foucar, Mark W. Wiggins, Andrew Georgiou, Thomas J. Palmeri, Kim M. Curby. *The Role of Cue-Based Strategies in Skilled Diagnosis Among Pathologists*. pp. 1154–1167.

Objective: This research was designed to test whether behavioral indicators of pathology-related cue utilization were associated with performance on a diagnostic task. **Background:** Across many domains, including pathology, successful diagnosis depends on pattern recognition that is supported by associations in memory in the form of cues. Previous studies have focused on the specific information or knowledge on which medical image expertise relies. The target in this study is the more general ability to identify and interpret relevant information. **Method:** Data were collected from 54 histopathologists in both conference and online settings. The participants completed a pathology edition of the Expert Intensive Skills Evaluation 2.0 (EXPERTise 2.0) to establish behavioral indicators of context-related cue utilization. They also completed a separate diagnostic task designed to examine related diagnostic skills. **Results:** Behavioral indicators of higher or lower cue utilization were based on the participants' performance across five tasks. Accounting for the number of cases reported per year, higher cue utilization was associated with greater accuracy on the diagnostic task. A post hoc analysis suggested that higher cue utilization may be associated with a greater capacity to recognize low prevalence cases. **Conclusion:** This study provides support for the role of cue utilization in the development and maintenance of skilled diagnosis amongst pathologists. **Application:** Pathologist training needs to be structured to ensure that learners have the opportunity to form cue-based strategies and associations in memory, especially for less commonly seen diseases.

Dina Kanaan, Nadine Marie Moacdieh. *Eye Tracking to Evaluate the Effects of Interruptions and Workload in a Complex Task*. pp. 1168–1180.

Objective: To use eye tracking to understand the effects of interruptions in different workload conditions as part of a monitoring and change detection task. **Background:** Interruptions are detrimental to performance in complex, multitasking domains. There is a need for better display design techniques that help users overcome interruptions regardless of their workload level. This requires understanding a user's attentional state immediately after an interruption in order to determine what type of display adjustments are most suitable. **Method:** An emergency dispatching simulator was developed with a visual primary task and auditory interruptive task. Two levels of workload were induced by varying the number of emergency vehicles to monitor for changes and the rate of changes to monitor. Eye tracking, performance, and subjective measures (NASA-Task Load Index) were collected and analyzed for 41 participants. **Results:** As expected, high workload interacted with interruptions to further degrade primary task performance and alter participants' attention allocation immediately after the interruption. Participants in the high workload condition had more narrowed, slower scan patterns immediately after

the interruption as compared to before the interruption, as evidenced by lower scanpath length per second and mean saccade amplitude. However, this change was not observed in low workload. **Conclusion:** High workload modulates the effects of interruptions on performance and eye movements. Users in the high workload condition struggle to quickly scan the display in the seconds following an interruption. **Application:** The results can provide insight into the type of display adjustments needed right after an interruption in a high-workload environment.

Tobias Grundgeiger, Anna Hohm, Annabell Michalek, Timo Egenolf, Christian Markus, Oliver Happel. *The Validity of the SEEV Model as a Process Measure of Situation Awareness: The Example of a Simulated Endotracheal Intubation*. pp. 1181–1194.

Objective: In the context of anesthesiology, we investigated whether the salience effort expectancy value (SEEV) model fit is associated with situation awareness and perception scores. **Background:** The distribution of visual attention is important for situation awareness - that is, understanding what is going on—in safety-critical domains. Although the SEEV model has been suggested as a process situation awareness measure, the validity of the model as a predictor of situation awareness has not been tested. **Method:** In a medical simulation, 31 senior and 30 junior anesthesiologists wore a mobile eye tracker and induced general anesthesia into a simulated patient. When inserting a breathing tube into the mannequin's trachea (endotracheal intubation), the scenario included several clinically relevant events for situation awareness and general events in the environment. Both were assessed using direct awareness measures. **Results:** The overall SEEV model fit was good with no difference between junior and senior anesthesiologists. Overall, the situation awareness scores were low. As expected, the SEEV model fits showed significant positive correlations with situation awareness level 1 scores. **Conclusion:** The SEEV model seems to be suitable as a process situation awareness measure to predict and investigate the perception of changes in the environment (situation awareness level 1). The situation awareness scores indicated that anesthesiologists seem not to perceive the environment well during endotracheal intubation. **Application:** The SEEV model fit can be used to capture and assess situation awareness level 1. During endotracheal intubation, anesthesiologists should be supported by technology or staff to notice changes in the environment.

NEUROERGONOMICS

Remo M. A. Van der Heiden, J. Leon Kenemans, Stella F. Donker, Christian P. Janssen. *The Effect of Cognitive Load on Auditory Susceptibility During Automated Driving*. pp. 1195–1209.

Objective: We experimentally test the effect of cognitive load on auditory susceptibility during automated driving. **Background:** In automated vehicles, auditory alerts are frequently used to request human intervention. To ensure safe operation, human drivers need to be susceptible to auditory information. Previous work found reduced susceptibility during manual driving and in a lesser amount during automated driving. However, in practice, drivers also perform nondriving tasks during automated driving, of which the associated cognitive load may further reduce susceptibility to auditory information. We therefore study the effect of cognitive load during automated driving on auditory susceptibility. **Method:** Twenty-four participants were driven in a simulated automated car. Concurrently, they performed a task with two levels of cognitive load: repeat a noun or generate a verb that expresses the use of this noun. Every noun was followed by a probe stimulus to elicit a neurophysiological response: the frontal P3 (fP3), which is a known indicator for the level of auditory susceptibility. **Results:** The fP3 was

significantly lower during automated driving with cognitive load compared with without. The difficulty level of the cognitive task (repeat or generate) showed no effect. **Conclusion:** Engaging in other tasks during automated driving decreases auditory susceptibility as indicated by a reduced fP3. **Application:** Nondriving task can create additional cognitive load. Our study shows that performing such tasks during automated driving reduces the susceptibility for auditory alerts. This can inform designers of semi-automated vehicles (SAE levels 3 and 4), where human intervention might be needed.

SIMULATION AND VIRTUAL REALITY

Sonja Schneider, Philipp Maruhn, Nguyen-Thong Dang, Prashant Pala, Viola Cavallo, Klaus Bengler. *Pedestrian Crossing Decisions in Virtual Environments: Behavioral Validity in CAVEs and Head-Mounted Displays*. pp. 1210–1226.

Objective: To contribute to the validation of virtual reality (VR) as a tool for analyzing pedestrian behavior, we compared two types of high-fidelity pedestrian simulators to a test track. **Background:** While VR has become a popular tool in pedestrian research, it is uncertain to what extent simulator studies evoke the same behavior as nonvirtual environments. **Method:** An identical experimental procedure was replicated in a CAVE automatic virtual environment (CAVE), a head-mounted display (HMD), and on a test track. In each group, 30 participants were instructed to step forward whenever they felt the gap between two approaching vehicles was adequate for crossing. **Results:** Our analyses revealed distinct effects for the three environments. Overall acceptance was highest on the test track. In both simulators, crossings were initiated later, but a relationship between gap size and crossing initiation was apparent only in the CAVE. In contrast to the test track, vehicle speed significantly affected acceptance rates and safety margins in both simulators. **Conclusion:** For a common decision task, the results obtained in virtual environments deviate from those in a nonvirtual test bed. The consistency of differences indicates that restrictions apply when predicting real-world behavior based on VR studies. In particular, the higher susceptibility to speed effects warrants further investigation, since it implies that differences in perceptual processing alter experimental outcomes. **Application:** Our observations should inform the conclusions drawn from future research in pedestrian simulators, for example by accounting for a higher sensitivity to speed variations and a greater uncertainty associated with crossing decisions.

SURFACE TRANSPORTATION

Bradley W. Weaver, Patricia R. DeLucia. *A Systematic Review and Meta-Analysis of Takeover Performance During Conditionally Automated Driving*. pp. 1227–1260.

Objective: The aim of this paper was to synthesize the experimental research on factors that affect takeover performance during conditionally automated driving. **Background:**For conditionally automated driving, the automated driving system (ADS) can handle the entire dynamic driving task but only for limited domains. When the system reaches a limit, the driver is responsible for taking over vehicle control, which may be affected by how much time they are provided to take over, what they were doing prior to the takeover, or the type of information provided to them during the takeover. **Method:** Out of 8446 articles identified by a systematic literature search, 48 articles containing 51 experiments were included in the meta-analysis. Coded independent

variables were time budget, non-driving related task engagement and resource demands, and information support during the takeover. Coded dependent variables were takeover timing and quality measures. **Results:** Engaging in non-driving related tasks results in degraded takeover performance, particularly if it has overlapping resource demands with the driving task. Weak evidence suggests takeover performance is impaired with shorter time budgets. Current implementations of information support did not affect takeover performance. **Conclusion:** Future research and implementation should focus on providing the driver more time to take over while automation is active and should further explore information support. **Application:** The results of the current paper indicate the need for the development and deployment of vehicle-to-everything (V2X) services and driver monitoring.