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SPECIAL SECTION: MEASURING SAFETY AND PERFORMANCE IN HUMAN–AUTOMATION SYSTEMS: THEORIES, METRICS, AND PRACTICE

Special Issue Commentary

Jessica J. Marquez, Brian F. Gore. *Measuring Safety and Performance in Human–Automation Systems.* pp. 169–171.

In Humans and Automation, Sheridan (2002) defines human–automation systems as those machines that include automation and require human interaction. Researchers have investigated the benefits and unexpected challenges associated with human–automation systems for many years, growing our knowledge and understanding of the different aspects important to appropriately integrate human operators into these systems. However, the implementation of this research knowledge has been limited. In an effort to take advantage of the benefits of automation, it was integrated into existing work flows without fully appreciating how such a shift would change the work itself.

Kimberly Stowers, James Oglesby, Shirley Sonesh, Kevin Leyva, Chelsea Iwig, Eduardo Salas. *A Framework to Guide the Assessment of Human–Machine Systems*. pp. 172–188.

Objective: We have developed a framework for guiding measurement in human–machine systems. **Background:** The assessment of safety and performance in human–machine systems often relies on direct measurement, such as tracking reaction time and accidents. However, safety and performance emerge from the combination of several variables. The assessment of precursors to safety and performance are thus an important part of predicting and improving outcomes in human–machine systems. **Method:** As part of an in-depth literature analysis involving peer-reviewed, empirical articles, we located and classified variables important to human–machine systems, giving a snapshot of the state of science on human–machine system safety and performance. Using this information, we created a framework of safety and performance in human–machine systems. **Results:** This framework details several inputs and processes that collectively influence safety and performance. Inputs are divided according to human, machine, and environmental inputs. Processes are divided into attitudes, behaviors, and cognitive variables. Each class of inputs influences the processes and, subsequently, outcomes that

emerge in human–machine systems. **Conclusion:** This framework offers a useful starting point for understanding the current state of the science and measuring many of the complex variables relating to safety and performance in human-machine systems. **Application:** This framework can be applied to the design, development, and implementation of automated machines in spaceflight, military, and health care settings. We present a hypothetical example in our write-up of how it can be used to aid in project success.

Angelia Sebok, Christopher D. Wickens. *Implementing Lumberjacks and Black Swans Into Model-Based Tools to Support Human–Automation Interaction*. pp. 189–203.

Objective: The objectives were to (a) implement theoretical perspectives regarding human–automation interaction (HAI) into model-based tools to assist designers in developing systems that support effective performance and (b) conduct validations to assess the ability of the models to predict operator performance. **Background:** Two key concepts in HAI, the lumberjack analogy and black swan events, have been studied extensively. The lumberjack analogy describes the effects of imperfect automation on operator performance. In routine operations, an increased degree of automation supports performance, but in failure conditions, increased automation results in more significantly impaired performance. Black swans are the rare and unexpected failures of imperfect automation. **Method:** The lumberjack analogy and black swan concepts have been implemented into three model-based tools that predict operator performance in different systems. These tools include a flight management system, a remotely controlled robotic arm, and an environmental process control system. **Results:** Each modeling effort included a corresponding validation. In one validation, the software tool was used to compare three flight management system designs, which were ranked in the same order as predicted by subject matter experts. The second validation compared model-predicted operator complacency with empirical performance in the same conditions. The third validation compared model-predicted and empirically determined time to detect and repair faults in four automation conditions. **Conclusion:** The three model-based tools offer useful ways to predict operator performance in complex systems. **Application:** The three tools offer ways to predict the effects of different automation designs on operator performance.

Barry Strauch. *The Automation-by-Expertise-by-Training Interaction: Why Automation-Related Accidents Continue to Occur in Sociotechnical Systems*. pp. 204–228.

Objective: I introduce the automation-by-expertise-by-training interaction in automated systems and discuss its influence on operator performance. **Background:** Transportation accidents that, across a 30-year interval demonstrated identical automation-related operator errors, suggest a need to reexamine traditional views of automation. **Method:** I review accident investigation reports, regulator studies, and literature on human computer interaction, expertise, and training and discuss how failing to attend to the interaction of automation, expertise level, and training has enabled operators to commit identical automation-related errors. **Results:** Automated systems continue to provide capabilities exceeding operators' need for effective system operation and provide interfaces that can hinder, rather than enhance, operator automation-related situation awareness. Because of limitations in time and resources, training programs do not provide operators the expertise needed to effectively operate these automated systems, requiring them to obtain the expertise ad hoc during system operations. As a result, many do not acquire necessary automation-related system expertise. **Conclusion:** Integrating automation with expected operator expertise levels, and within training programs that provide operators the necessary automation expertise, can reduce opportunities for automation-related operator errors. **Application:** Research to address the automation-by-expertise-by-training interaction is needed. However, such research

must meet challenges inherent to examining realistic sociotechnical system automation features with representative samples of operators, perhaps by using observational and ethnographic research. Research in this domain should improve the integration of design and training and, it is hoped, enhance operator performance.

- **Keywords:** human error analysis, expert–novice differences, sociotechnical systems, accident analysis

Aaron W. Johnson, Kevin R. Duda, Thomas B. Sheridan, Charles M. Oman. *A Closed-Loop Model of Operator Visual Attention, Situation Awareness, and Performance Across Automation Mode Transitions*. pp. 229–241.

Objective: This article describes a closed-loop, integrated human–vehicle model designed to help understand the underlying cognitive processes that influenced changes in subject visual attention, mental workload, and situation awareness across control mode transitions in a simulated human-in-the-loop lunar landing experiment. **Background:** Control mode transitions from autopilot to manual flight may cause total attentional demands to exceed operator capacity. Attentional resources must be reallocated and reprioritized, which can increase the average uncertainty in the operator's estimates of low-priority system states. We define this increase in uncertainty as a reduction in situation awareness. **Method:** We present a model built upon the optimal control model for state estimation, the crossover model for manual control, and the SEEV (salience, effort, expectancy, value) model for visual attention. We modify the SEEV attention executive to direct visual attention based, in part, on the uncertainty in the operator's estimates of system states. **Results:** The model was validated using the simulated lunar landing experimental data, demonstrating an average difference in the percentage of attention ≤3.6% for all simulator instruments. The model's predictions of mental workload and situation awareness, measured by task performance and system state uncertainty, also mimicked the experimental data. **Conclusion:** Our model supports the hypothesis that visual attention is influenced by the uncertainty in system state estimates. **Application:** Conceptualizing situation awareness around the metric of system state uncertainty is a valuable way for system designers to understand and predict how reallocations in the operator's visual attention during control mode transitions can produce reallocations in situation awareness of certain states.

AUTOMATION, EXPERT SYSTEMS

Adam J. Reiner, Justin G. Hollands, Greg A. Jamieson. *Target Detection and Identification Performance Using an Automatic Target Detection System*. pp. 242–258.

Objective: We investigated the effects of automatic target detection (ATD) on the detection and identification performance of soldiers. **Background:** Prior studies have shown that highlighting targets can aid their detection. We provided soldiers with ATD that was more likely to detect one target identity than another, potentially acting as an implicit identification aid. **Method:** Twenty-eight soldiers detected and identified simulated human targets in an immersive virtual environment with and without ATD. Task difficulty was manipulated by varying scene illumination (day, night). The ATD identification bias was also manipulated (hostile bias, no bias, and friendly bias). We used signal detection measures to treat the identification results. **Results:** ATD presence improved detection performance, especially under high task difficulty (night illumination). Identification sensitivity was greater for cued than uncued targets. The identification decision criterion for cued targets varied with the ATD identification bias but showed a "sluggish beta" effect. **Conclusion:** ATD helps soldiers detect and identify targets. The effects of biased ATD on identification should be considered with respect to the operational context. **Application:** Less-than-perfectly-reliable ATD is a useful detection

aid for dismounted soldiers. Disclosure of known ATD identification bias to the operator may aid the identification process.

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Matthew S. Tenan, Michael E. LaFiandra, Samson V. Ortega. *The Effect of Soldier Marching, Rucksack Load, and Heart Rate on Marksmanship*. pp. 259–267.

Objective: The purpose was to determine if Soldier rucksack load, marching distance, and average heart rate (HR) during shooting affect the probability of hitting the target. **Background:** Infantry Soldiers routinely carry heavy rucksack loads and are expected to engage enemy targets should a threat arise. **Method:** Twelve male Soldiers performed two 11.8 km marches in forested terrain at 4.3 km/hour on separate days (randomized, counterbalanced design). The Rifleman load consisted of protective armor (26.1 kg); the Rucksack load included the Rifleman load plus a weighted rucksack (48.5 kg). Soldiers performed a live-fire shooting task (48 targets) prior to the march, in the middle of the march, and at the end of the march. HR was collected during the shooting task. Data were assessed with multilevel logistic regression controlling for the multiple observations on each subject and shooting target distance. Predicted probabilities for hitting the target were calculated. **Results:** There was a three-way interaction effect between rucksack load, average HR, and march (p = .02). Graphical assessment of predicted probabilities indicated that regardless of load, marching increases shooting performance. Increases in shooting HR after marching result in lower probability of hitting the target, and rucksack load has inconsistent effects on marksmanship. **Conclusion:** Early evidence suggests that rucksack load and marching may not uniformly decrease marksmanship but that an inverted-U phenomenon may govern changes in marksmanship. **Application:** The effects of load and marching on marksmanship are not linear; the abilities of Soldiers should be continuously monitored to understand their capabilities in a given scenario.

- **Keywords:** soldier, shooting, heart rate, inverted-U, military

HEALTH CARE/HEALTH SYSTEMS

Anna Hickling, Birgit Brecknell, Robert G. Loeb, Penelope Sanderson. *Using a Sequence of Earcons to Monitor Multiple Simulated Patients*. pp. 268–288.

Objective: The aim of this study was to determine whether a sequence of earcons can effectively convey the status of multiple processes, such as the status of multiple patients in a clinical setting. **Background:** Clinicians often monitor multiple patients. An auditory display that intermittently conveys the status of multiple patients may help. **Method:** Nonclinician participants listened to sequences of 500-ms earcons that each represented the heart rate (HR) and oxygen saturation (SpO_2) levels of a different simulated patient. In each sequence, one, two, or three patients had an abnormal level of HR and/or SpO_2. In Experiment 1, participants reported which of nine patients in a sequence were abnormal. In Experiment 2, participants identified the vital signs of one, two, or three abnormal patients in sequences of one, five, or nine patients, where the interstimulus interval (ISI) between earcons was 150 ms. Experiment 3 used the five-sequence condition of Experiment 2, but the ISI was either 150 ms or 800 ms. **Results:** Participants reported which patient(s) were abnormal with median 95% accuracy. Identification accuracy for vital signs decreased as the number of abnormal patients increased from one to three, $p < .001$, but accuracy was unaffected by number of patients in a sequence. Overall, identification accuracy was significantly higher with an ISI of 800 ms (89%) compared with an ISI of 150 ms (83%), $p < .001$. **Conclusion:** A multiple-patient display can be created by cycling through earcons that represent

individual patients. **Application:** The principles underlying the multiple-patient display can be extended to other vital signs, designs, and domains.

NEUROERGONOMICS

Gerhard Blasche, Sanja Pasalic, Verena-Maria Bauböck, Daniela Haluza, Rudolf Schoberberger. *Effects of Rest-Break Intention on Rest-Break Frequency and Work-Related Fatigue*. pp. 289–298.

Objectives: The present paper presents findings from two studies addressing the effects of the employee's intention to have rest breaks on rest-break frequency and the change of well-being during a workday. **Background:** Rest breaks are effective in avoiding an accumulation of fatigue during work. However, little is known about individual differences in rest-break behavior. **Method:** In Study 1, the association between rest-break intention and the daily number of rest breaks recorded over 4 consecutive workdays was determined by generalized linear model in a sample of employees (n = 111, 59% females). In Study 2, professional geriatric nurses (n = 95 females) who worked over two consecutive 12-hour day shifts recorded well-being (fatigue, distress, effort motivation) at the beginning and the end of their shifts. The effect of rest-break intention on the change of well-being was determined by multilevel modeling. **Results:** Rest-break intention was positively associated with the frequency of rest breaks (Study 1) and reduced the increase of fatigue and distress over the workday (Study 2). **Conclusion:** The results indicate that individual differences account for the number of breaks an employee takes and, as a consequence, for variations in the work-related fatigue and distress. **Application:** Strengthening rest-break intentions may help to increase rest-break behavior to avoid the buildup of fatigue and distress over a workday.

PHYSIOLOGICAL AND PSYCHOLOGICAL CONDITIONS ("INTERNAL ENVIRONMENT")

Nooshin Atashfeshan, Hamideh Razavi. *Determination of the Proper Rest Time for a Cyclic Mental Task Using ACT-R Architecture*. pp. 299–313.

Objective: Analysis of the effect of mental fatigue on a cognitive task and determination of the right start time for rest breaks in work environments. **Background:** Mental fatigue has been recognized as one of the most important factors influencing individual performance. Subjective and physiological measures are popular methods for analyzing fatigue, but they are restricted to physical experiments. Computational cognitive models are useful for predicting operator performance and can be used for analyzing fatigue in the design phase, particularly in industrial operations and inspections where cognitive tasks are frequent and the effects of mental fatigue are crucial. **Method:** A cyclic mental task is modeled by the ACT-R architecture, and the effect of mental fatigue on response time and error rate is studied. The task includes visual inspections in a production line or control workstation where an operator has to check products' conformity to specifications. Initially, simulated and experimental results are compared using correlation coefficients and paired t test statistics. After validation of the model, the effects are studied by human and simulated results, which are obtained by running 50-minute tests. **Results:** It is revealed that during the last 20 minutes of the tests, the response time increased by 20%, and during the last 12.5 minutes, the error rate increased by 7% on average. **Conclusion:** The proper start time for the rest period can be identified by setting a limit on the error rate or response time. **Application:** The proposed model can be applied early in production planning to decrease the negative effects of mental fatigue by predicting the operator performance. It can also be used for determining the rest breaks in the design phase without an operator in the loop.

SURFACE TRANSPORTATION

Matthias G. Arend, Thomas Franke. *The Role of Interaction Patterns with Hybrid Electric Vehicle Eco-Features for Drivers' Eco-Driving Performance*. pp. 314–327.

Objective: The objective of the present research was to understand drivers' interaction patterns with hybrid electric vehicles' (HEV) eco-features (electric propulsion, regenerative braking, neutral mode) and their relationship to fuel efficiency and driver characteristics (technical system knowledge, eco-driving motivation). **Background:** Eco-driving (driving behaviors performed to achieve higher fuel efficiency) has the potential to reduce CO_2 emissions caused by road vehicles. Eco-driving in HEVs is particularly challenging due to the systems' dynamic energy flows. As a result, drivers are likely to show diverse eco-driving behaviors, depending on factors like knowledge and motivation. The eco-features represent an interface for the control of the systems' energy flows. **Method:** A sample of 121 HEV drivers who had constantly logged their fuel consumption prior to the study participated in an online questionnaire. **Results:** Drivers' interaction patterns with the eco-features were related to fuel efficiency. A common factor was identified in an exploratory factor analysis, characterizing the intensity of actively dealing with electric energy, which was also related to fuel efficiency. Driver characteristics were not related to this factor, yet they were significant predictors of fuel efficiency. **Conclusion:** From the perspective of user–energy interaction, the relationship of the aggregated factor to fuel efficiency emphasizes the central role of drivers' perception of and interaction with energy conversions in determining HEV eco-driving success. **Application:** To arrive at an in-depth understanding of drivers' eco-driving behaviors that can guide interface design, authors of future research should be concerned with the psychological processes that underlie drivers' interaction patterns with eco-features.