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AUTOMATION, EXPERT SYSTEMS

John D. Lee, Shu-Yuan Liu, Joshua Domeyer, Azadeh DinparastDjadid. *Assessing Drivers' Trust of Automated Vehicle Driving Styles With a Two-Part Mixed Model of Intervention Tendency and Magnitude*. pp. 197–209.

Objective: This study examines how driving styles of fully automated vehicles affect drivers' trust using a statistical technique—the two-part mixed model—that considers the frequency and magnitude of drivers' interventions. **Background:** Adoption of fully automated vehicles depends on how people accept and trust them, and the vehicle's driving style might have an important influence. **Method:** A driving simulator experiment exposed participants to a fully automated vehicle with three driving styles (aggressive, moderate, and conservative) across four intersection types (with and without a stop sign and with and without crossing path traffic). Drivers indicated their dissatisfaction with the automation by depressing the brake or accelerator pedals. A two-part mixed model examined how automation style, intersection type, and the distance between the automation's driving style and the person's driving style affected the frequency and magnitude of their pedal depression. **Results:** The conservative automated driving style increased the frequency and magnitude of accelerator pedal inputs; conversely, the aggressive style increased the frequency and magnitude of brake pedal inputs. The two-part mixed model showed a similar pattern for the factors influencing driver response, but the distance between driving styles affected how often the brake pedal was pressed, but it had little effect on how much it was pressed. **Conclusion:** Eliciting brake and accelerator pedal responses provides a temporally precise indicator of drivers' trust of automated driving styles, and the two-part model considers both the discrete and continuous characteristics of this indicator. **Application:** We offer a measure and method for assessing driving styles.

- ▪ **Keywords:** automated vehicles, vehicle control algorithms, acceptance, driving style, two-part model

Miguel Martínez-García, Yu Zhang, Timothy Gordon. *Memory Pattern Identification for Feedback Tracking Control in Human–Machine Systems.* **pp. 210–226.**

Objective: The aim of this paper was to identify the characteristics of memory patterns with respect to a visual input, perceived by the human operator during a manual control task, which consisted in following a moving target on a display with a cursor. **Background:** Manual control tasks involve nondeclarative memory. The memory encodings of different motor skills have been referred to as procedural memories. The procedural memories have a pattern, which this paper sought to identify for the particular case of a one-dimensional tracking task. Specifically, data recorded from human subjects controlling dynamic systems with different fractional order were investigated. **Method:** A finite impulse response (FIR) controller was fitted to the data, and pattern analysis of the fitted parameters was performed. Then, the FIR model was further reduced to a lower order controller; from the simplified model, the stability analysis of the human–machine system in closed-loop was conducted. **Results:** It is shown that the FIR model can be used to identify and represent patterns in human procedural memories during manual control tasks. The obtained procedural memory pattern presents a time scale of about 650 ms before decay. Furthermore, the fitted controller is stable for systems with fractional order less than or equal to 1. **Conclusion:** For systems of different fractional order, the proposed control scheme—based on an FIR model—can effectively characterize the linear properties of manual control in humans. **Application:** This research supports a biofidelic approach to human manual control modeling over feedback visual perceptions. Relevant applications of this research are the following: the development of shared-control systems, where a virtual human model assists the human during a control task, and human operator state monitoring.

- **Keywords:** human–machine interaction, information processing, memory, autonomous agents, adaptive automation, fractional-order systems

AVIATION AND AEROSPACE

Fabian Möller, Uwe Hoffmann, Marc Dalecki, Tobias Dräger, Michael Doppelmayr, Fabian Steinberg. *Physical Exercise Intensity During Submersion Selectively Affects Executive Functions.* **pp. 227–239.**

Objective: The intact cognitive processing capacity in highly demanding and dynamically changing situations (e.g., in extreme environmental conditions) is of central relevance for personal safety. This study therefore investigated whether underwater physical exercise (PE) affected cognitive performance by comparing these effects during underwater fin-swimming as opposed to inactivity under normal environmental conditions. **Background:** Although acute bouts of PE can modulate cognitive performance under highly controlled and standardized laboratory conditions, no previous study has determined whether PE acutely modulates cognitive performance in non-laboratory testing conditions involving extreme environments (e.g., underwater). **Method:** A total of 27 healthy volunteers (16 males and 11 females; 28.9 ± 7.4 years of age) participated in two experiments involving either moderate or high PE intensity. A PRE/POST crossover design was employed among participants while performing cognitive tests in a counterbalanced order (i.e., before and after 20 min of PE in submersion [WET] and once before and after inactivity [DRY] while in the laboratory). Cognitive performance was measured as a combination of executive functions through the Eriksen Flanker (inhibition) and Two-Back (working memory) Tasks using an underwater tablet computer. **Results:** ANOVAs revealed enhanced reaction times only in the Flanker test after moderate PE for the WET condition. No other effects were detected. **Conclusion:** These findings indicate that

cognitive performance is exercise-intensity-dependent with enhanced effects during moderate PE, even in extreme environments (i.e., underwater). **Application:** These results should be relevant in recreational and occupational contexts involving underwater activity and may also apply to microgravity (e.g., during extra-vehicular activities). **Description:** This study compared the acute effects of physical exercise (PE) on cognitive performance in an underwater environment while participants fin-swam with SCUBA (self-contained underwater breathing apparatus) gear. Findings revealed that 20 min of moderate PE positively affected cognitive performance (i.e., inhibitory control ability). However, no changes were observed after high-intensity exercise.

- **Keywords:** SCUBA, diving, microgravity, space safety, executive functions, cognition

Jingyu Zhang, Xiaotian E, Feng Du, Jiazhong Yang, Shayne Loft. *The Difficulty to Break a Relational Complexity Network Can Predict Air Traffic Controllers' Mental Workload and Performance in Conflict Resolution*. pp. 240–253.

Objective: To test the network disentangling model for explaining air traffic controllers' (ATCos) conflict resolution performance. The network rigidity index (NRI), and the steps to break the relational complexity network following a central-available-node-first rule, was hypothesized to explain the overall task demand, whereas marginal-effort-decrease rule was expected to explain the actual operational outcome. **Background:** Understanding the conflict resolution process of ATCos is important for aviation safety and efficiency. However, linear models are insufficient. We proposed a new model that ATCos behavior can be largely considered as a process to break the relational complexity network, in which nodes represent the aircraft while links represent the cognitive complexity to understand the aircraft dyad relationship. **Method:** Twenty-one professional ATCos completed 27 conflict resolution scenarios that varied in the NRI and other control variables. Multilevel regression analyses were performed to understand the influence of the NRI on the number of interventions, mental workload, and unresolved rate. A cross-validation was performed to evaluate the predictive power of the model. **Results:** NRI influenced ATCos intervention number in a curvilinear manner, which further leads to ATCo's mental workload. The deviance between the number of interventions and the NRI was strongly linked with unresolved rate. Cross-validation suggests that the models predictions are robust. **Conclusion:** The network disentangling model provides a useful theory-driven way to explain controllers' conflict resolution workload and other important performance outcomes such as intervention probability. **Application:** The proposed model can potentially be used for workload management, sector design, and intelligent decision support tool development.

- **Keywords:** relational complexity network, workload, air traffic controllers, conflict resolution, network disentangling, error, operation

COGNITION

Manzura Zholdassova, Almira Kustubayeva, Gerald Matthews. *The ANT Executive Control Index: No Evidence for Temporal Decrement*. pp. 254–273.

Objective: This study tested whether indices of executive control, alertness, and orienting measured with Attention Network Test (ANT) are vulnerable to temporal decrement in performance. **Background:** Developing the resource theory of sustained attention requires identifying neurocognitive processes vulnerable to decrement.

Executive control processes may be prone to impairment in fatigue states. Such processes are also highlighted in alternative theories. Determining the role of executive control in vigilance can both advance theory and contribute to practical countermeasures for decrement in human factors contexts. **Method:** In Study 1, 80 participants performed the standard ANT for an extended duration of about 55 to 60 min. Study 2 (160 participants) introduced manipulations of trial blocking and stimulus degradation intended to increase resource depletion. Reaction time and accuracy measures were analyzed. Subjective stress and workload were assessed in both studies. **Results:** In both studies, the ANT induced levels of subjective workload and task disengagement consistent with previous sustained attention studies. No systematic decrement in any performance measure was observed. **Conclusion:** Executive control assessed by the ANT is not highly vulnerable to temporal decrement, even when task demands are elevated. Future work should differentiate executive control processes; proactive control may be more implicated in sustained attention decrement than in reactive control. **Application:** Designing systems and interfaces to reduce executive control demands may be generally beneficial but will not directly mitigate temporal performance decrement. Enhancing design guidelines and neuroergonomic methods for monitoring operator attention requires further work to identify key neurocognitive processes for decrement.

- **Keywords:** vigilance, Attention Network Test, executive control, resource theory, cognitive load

HUMAN-SYSTEMS INTEGRATION

Ben Elix, Neelam Naikar. *Designing for Adaptation in Workers' Individual Behaviors and Collective Structures With Cognitive Work Analysis: Case Study of the Diagram of Work Organization Possibilities*. **pp. 274–295.**

Objective: We demonstrate that the diagram of work organization possibilities, a recent addition to cognitive work analysis, can be used to develop designs that promote adaptation in the workplace. **Background:** Workers in sociotechnical systems adapt not just their individual behaviors but also their collective structures in dealing with instability, uncertainty, and unpredictability in their tasks. However, conventional design approaches are limited in supporting adaptations in both workers' behaviors and structures, especially during unforeseen situations. The work organization possibilities diagram has the potential to meet these requirements, but its value for design has not been established. **Method:** We present a case study of a future system for maritime surveillance that provides an analytical demonstration of the utility of the diagram for design and empirical validation of the impact, uniqueness, and feasibility of this approach in an industrial setting. **Results:** This application results in a team design that is integrated with the career and training progression pathway of the crew in a way that maximizes the system's behavioral and structural possibilities for adaptation. Further, the approach has impact on practice, makes a distinct contribution to design relative to other techniques, and is implemented feasibly in an industrial setting. **Conclusion:** The work organization possibilities diagram can contribute to the development of an integrated system design that supports actors' possibilities for behavioral and structural adaptation in a unified fashion. **Application:** This research provides a basis for designing interfaces, teams, training, and automation that preserve a system's inherent capacity for adaptation.

- **Keywords**: sociotechnical system, team design, training design, system design, human–system integration

SIMULATION AND VIRTUAL REALITY

Christopher Widdowson, Israel Becerra, Cameron Merrill, Ranxiao Frances Wang, Steven LaValle. *Assessing Postural Instability and Cybersickness Through Linear and Angular Displacement*. pp. 296–311.

Objective: To examine the hypothesis that constant speed is more comfortable than variable speed profiles and may minimize cybersickness. **Background:** Current best practices for virtual reality (VR) content creation suggest keeping any form of acceleration as short and infrequent as possible to mitigate cybersickness. **Methods:** In Experiment 1, participants experienced repetitions of simulated linear motion, and in Experiment 2, they experienced repetitions of a circular motion. Three speed profiles were tested in each experiment. Each trial lasted 2 min while standing. Cybersickness was measured using the Simulator Sickness Questionnaire (SSQ) and operationally defined in terms of total severity scores. Postural stability was measured using a Wii Balance Board and operationally defined in terms of center of pressure (COP) path length. Postural measures were decomposed into anterior-posterior and medial-lateral axes and subjected to detrended fluctuation analysis. **Results:** For both experiments, no significant differences were observed between the three speed profiles in terms of cybersickness or postural stability, and none of the baseline postural measures could predict SSQ scores for the speed profile conditions. An axis effect was observed in both experiments such that normalized COP movement was significantly greater along the anterior-posterior axis than the medial-lateral axis. **Conclusion:** Results showed no convincing evidence to support the common belief that constant speed is more comfortable than variable speed profiles for scenarios typical of VR applications. **Application:** The present findings offer guidelines for the design of locomotion techniques involving traversal in VR environments.

- ▪ **Keywords:** simulator sickness, motion sickness, virtual environments, immersive environments, gait, posture

SURFACE TRANSPORTATION

Edin Šabić, Jing Chen, Justin A. MacDonald. *Toward a Better Understanding of In-Vehicle Auditory Warnings and Background Noise*. pp. 312–335.

Objective: The effectiveness of three types of in-vehicle warnings was assessed in a driving simulator across different noise conditions. **Background:** Although there has been much research comparing different types of warnings in auditory displays and interfaces, many of these investigations have been conducted in quiet laboratory environments with little to no consideration of background noise. Furthermore, the suitability of some auditory warning types, such as spearcons, as car warnings has not been investigated. **Method:** Two experiments were conducted to assess the effectiveness of three auditory warnings (spearcons, text-to-speech, auditory icons) with different types of background noise while participants performed a simulated driving task. **Results:** Our results showed that both the nature of the background noise and the type of auditory warning influenced warning recognition accuracy and reaction time. Spearcons outperformed text-to-speech warnings in relatively quiet environments, such as in the baseline noise condition where no music or talk-radio was played. However, spearcons were not better than text-to-speech warnings with other background noises. Similarly, the effectiveness of auditory icons as warnings fluctuated across background noise, but, overall, auditory icons were the least efficient of the three warning types. **Conclusion:** Our results supported that background noise can have an idiosyncratic

effect on a warning's effectiveness and illuminated the need for future research into ameliorating the effects of background noise. **Application:** This research can be applied to better present warnings based on the anticipated auditory environment in which they will be communicated.

- **Keywords:** warning systems, auditory displays, noise/acoustics, audition, vehicle design

Xingwei Wu, Linda Ng Boyle. *Auditory Messages for Intersection Movement Assist (IMA) Systems: Effects of Speech- and Nonspeech-Based Cue*s. pp. 336–347.

Objective: The objective of this study was to assess the effects of different warning messages for an Intersection Movement Assist (IMA) based on drivers' ability to avoid a potential safety hazard. **Background:** An IMA system can detect hazards and warn drivers when it is unsafe to enter an intersection. The effects of different warning information conveyed by these systems are still unknown. **Method:** A driving simulator study with 80 participants was conducted with a red light running (RLR) scenario using a 5 (warnings) x 2 (training) between-subject design. IMA warnings included the messages "Danger," "Brake now," "Vehicle on your left," a beep, and no IMA warning. Training was provided to half of the participants. Analysis of variance and logistic regression models were used to examine differences in drivers' avoidance behavior. **Results:** The analyses showed that all tested warning messages can significantly enhance drivers' avoidance performance. Significant differences were observed in crash occurrence, avoidance behavior (i.e., reaction time and speed change), and eye movements (i.e., fixation pattern and time to first fixation). The effects of training also differed given the warning message provided. **Conclusion:** The "Brake now" message performed best in reducing crash involvement and prompted better avoidance performance. The "Danger" and "Vehicle on your left" messages improved drivers' hazard detection ability. The training showed a potential to enhance the effectiveness of nonspeech warning messages. **Application:** The findings of this study can help designers and engineers better design IMA warning messages for RLR scenarios.

- **Keywords:** collision warning, auditory warning message, intersection movement assist, driving behavior

SYSTEM DESIGN AND ANALYSIS (GENERAL)

Donghyun Beck, Jaemoon Jung, Woojin Park. *Evaluating the Effects of In-Vehicle Side-View Display Layout Design on Physical Demands of Driving.* pp. 348–363.

Objective: A driving simulator study was conducted to comparatively evaluate the effects of three camera monitor system (CMS) display layouts and the traditional side-view mirror arrangement on the physical demands of driving. **Background:** Despite the possible benefits of CMS displays in reducing the physical demands of driving, little empirical evidence is available to substantiate these benefits. The effects of CMS display layout designs are not well understood. **Method:** The three CMS display layouts varied in the locations of the side-view displays: (A) inside the car near the conventional side-view mirrors, (B) on the dashboard at each side of the steering wheel, and (C) on the center fascia with the displays joined side by side. Twenty-two participants performed a safety-critical lane changing task with each design alternative. The dependent measures were the following: spread of eye movement, spread of head movement, and perceived physical demand. **Results:** Compared with the traditional mirror system, all three CMS display layouts showed a reduction in physical demands, albeit differing in the

types/magnitudes of physical demand reduction. **Conclusion:** Well-designed CMS display layouts could significantly reduce the physical demands of driving. The physical demands were reduced by placing the CMS displays close to the position of the driver's normal line-of-sight when looking at the road ahead and locating each CMS display on each side of the driver, that is, at locations compatible with the driver's expectation. **Application:** Physical demand reductions by CMS displays would especially benefit drivers frequently checking the side-view mirrors with large eye/head movements and physically weak/impaired drivers.