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Accidents, Safety, and Human Error

Julia Werneke, Andro Kleen, and Mark Vollrath. *Perfect Timing: Urgency, Not Driving Situations, Influence the Best Timing to Activate Warnings.* S. 249-259.

Objective: The aim of the study was to investigate the influence of different driving scenarios (urban, rural, highway) on the timing required by drivers from a two-stage warning system, based on car-to-car communication. **Background:** Car-to-car communication systems are designed to inform drivers of potential hazards at an early stage, before they are visible to them. Here, questions arise as to how drivers acknowledge early warnings and when they should be informed (first stage) and warned (second stage). Hence, optimum timing for presenting the information was tested. **Method:** A psychophysical method was used to establish the optimum timing in three driving scenarios at different speed limits (urban: 50 km/h, rural: 100 km/h, highway: 130 km/h). A total of 24 participants (11 female, 13 male; *M* = 29.1 years, *SD* = 11.6 years) participated in the study. **Results:** The results showed that the optimum timing did not differ among the three scenarios. The first and second stages should ultimately be presented at different timings at each speed limit (first stage: 26.5 s, second stage: 12.1 s before a potential hazard). **Conclusion:** The results showed that well-selected timing for activating information and warning is crucial for the acceptance of these systems. Appropriate timing for presenting the information and warning can be derived for these systems. **Application:** The findings will be integrated in further development of assistance systems based on car-to-x technology within the Car2X-Safety project of the Niedersächsisches Forschungszentrum Fahrzeugtechnik in Germany. This study was also supported by Chalmers University of Technology in Sweden.

- **Keywords:** collision warning timing, car-to-car communication, driver assistance, driving scenario, traffic jam, method of adjustment

Matthew R. Yanko and Thomas M. Spalek. *Driving With the Wandering Mind: The Effect That Mind-Wandering Has on Driving Performance.* S. 260-269.

Objective: The principal objective of the present work was to examine the effects of mind state (mind-wandering vs. on-task) on driving performance in a high-fidelity driving simulator. **Background:** Mind-wandering is thought to interfere with goal-directed thought. It is likely, then, that when driving, mind-wandering might lead to impairments in critical aspects of driving performance. In two experiments, we assess the extent to which mind-wandering interferes with responsiveness to sudden events, mean velocity,

and headway distance. **Method:** Using a car-following procedure in a high-fidelity driving simulator, participants were probed at random times to indicate whether they were on-task at that moment or mind-wandering. The dependent measures were analyzed based on the participant's response to the probe. **Results:** Compared to when on-task, when mind-wandering participants showed longer response times to sudden events, drove at a higher velocity, and maintained a shorter headway distance. **Conclusion:** Collectively, these findings indicate that mind-wandering affects a broad range of driving responses and may therefore lead to higher crash risk. **Application:** The results suggest that situations that are likely associated with mind-wandering (e.g., route familiarity) can impair driving performance.

- **Keywords:** driving performance, mind-wandering, attention, distraction, high-fidelity driving simulator

Aerospace Systems

Nadine Bienefeld and Gudela Grote. *Shared Leadership in Multiteam Systems: How Cockpit and Cabin Crews Lead Each Other to Safety.* S. 270-286.

Objective: In this study, we aimed to examine the effect of shared leadership within and across teams in multiteam systems (MTS) on team goal attainment and MTS success. **Background:** Due to different and sometimes competing goals in MTS, leadership is required within and across teams. Shared leadership, the effectiveness of which has been proven in single teams, may be an effective strategy to cope with these challenges. **Method:** We observed leadership in 84 cockpit and cabin crews that collaborated in the form of six-member MTS aircrews (N = 504) during standardized simulations of an in-flight emergency. Leadership was coded by three trained observers using a structured observation system. Team goal attainment was assessed by two subject matter experts using a checklist-based rating tool. MTS goal attainment was measured objectively on the basis of the outcome of the simulated flights. **Results:** In successful MTS aircrews, formal leaders and team members displayed significantly more leadership behaviors, shared leadership by pursers and flight attendants predicted team goal attainment, and pursers' shared leadership across team boundaries predicted cross-team goal attainment. In cockpit crews, leadership was not shared and captains' vertical leadership predicted team goal attainment regardless of MTS success. **Conclusion:** The results indicate that in general, shared leadership positively relates to team goal attainment and MTS success, whereby boundary spanners' dual leadership role is key. **Application:** Leadership training in MTS should address shared rather than merely vertical forms of leadership, and component teams in MTS should be trained together with emphasis on boundary spanners' dual leadership role. Furthermore, team members should be empowered to engage in leadership processes when required.

- **Keywords:** aircrew behavior, aviation safety, high-risk teams, leadership, multiteam systems, shared leadership, team performance, team work

Cognitive Processes

Andrew Neal, Sam Hannah, Penelope Sanderson, Scott Bolland, Martijn Mooij, and Sean Murphy. *Development and Validation of a Multilevel Model for Predicting Workload Under Routine and Nonroutine Conditions in an Air Traffic Management Center.* S. 287-305.

Objective: The aim of this study was to develop a model capable of predicting variability in the mental workload experienced by frontline operators under routine and nonroutine conditions. **Background:** Excess workload is a risk that needs to be managed in safety-critical industries. Predictive models are needed to manage this risk effectively yet are difficult to develop. Much of the difficulty stems from the fact that workload prediction is a multilevel problem. **Method:** A multilevel workload model was developed in Study 1 with data collected from an en route air traffic management center. Dynamic density metrics were used to predict variability in workload within and between work units while controlling for variability among raters. The model was cross-validated in Studies 2 and 3 with the use of a high-fidelity simulator. **Results:** Reported workload generally remained within the bounds of the 90% prediction interval in Studies 2 and 3. Workload crossed the upper bound of the prediction interval only under nonroutine conditions. Qualitative analyses suggest that nonroutine events caused workload to cross the upper bound of the prediction interval because the controllers could not manage their workload strategically. **Conclusion:** The model performed well under both routine and nonroutine conditions and over different patterns of workload variation. **Application:** Workload prediction models can be used to support both strategic and tactical workload management. Strategic uses include the analysis of historical and projected workflows and the assessment of staffing needs. Tactical uses include the dynamic reallocation of resources to meet changes in demand.

- **Keywords:** mental workload, air traffic control, multilevel modeling

Ari Antonovsky, Clare Pollock, and Leon Straker. *Identification of the Human Factors Contributing to Maintenance Failures in a Petroleum Operation.* S. 306-321.

Objective: This research aimed to identify the most frequently occurring human factors contributing to maintenance-related failures within a petroleum industry organization. Commonality between failures will assist in understanding reliability in maintenance processes, thereby preventing accidents in high-hazard domains. **Background:** Methods exist for understanding the human factors contributing to accidents. Their application in a maintenance context mainly has been advanced in aviation and nuclear power. Maintenance in the petroleum industry provides a different context for investigating the role that human factors play in influencing outcomes. It is therefore worth investigating the contributing human factors to improve our understanding of both human factors in reliability and the factors specific to this domain. **Method:** Detailed analyses were conducted of maintenance-related failures (N = 38) in a petroleum company using structured interviews with maintenance technicians. The interview structure was based on the Human Factor Investigation Tool (HFIT), which in turn was based on Rasmussen's model of human malfunction. **Results:** A mean of 9.5 factors per incident was identified across the cases investigated. The three most frequent human factors contributing to the maintenance failures were found to be assumption (79% of cases), design and maintenance (71%), and communication (66%). **Conclusion:** HFIT proved to be a useful instrument for identifying the pattern of human factors that recurred most frequently in maintenance-related failures. **Application:** The high frequency of failures attributed to assumptions and communication demonstrated the importance of problem-solving abilities and organizational communication in a domain where maintenance personnel have a high degree of autonomy and a wide geographical distribution.

- **Keywords:** assumption, organizational communication, equipment design, HFIT, reliability

William S. Helton, Gregory J. Funke, and Benjamin A. Knott. *Measuring Workload in Collaborative Contexts: Trait Versus State Perspectives.* S. 322-332.

Objective: In the present study, we explored the state versus trait aspects of measures of task and team workload in a disaster simulation. **Background:** There is often a need to assess workload in both individual and collaborative settings. Researchers in this field often use the NASA Task Load Index (NASA-TLX) as a global measure of workload by aggregating the NASA-TLX's component items. Using this practice, one may overlook the distinction between traits and states. **Method:** Fifteen dyadic teams (11 inexperienced, 4 experienced) completed five sessions of a tsunami disaster simulator. After every session, individuals completed a modified version of the NASA-TLX that included team workload measures. We then examined the workload items by using a between-subjects and within-subjects perspective. **Results:** Between-subjects and within-subjects correlations among the items indicated the workload items are more independent within subjects (as states) than between subjects (as traits). Correlations between the workload items and simulation performance were also different at the trait and state levels. **Conclusion:** Workload may behave differently at trait (between-subjects) and state (within-subjects) levels. **Application:** Researchers interested in workload measurement as a state should take a within-subjects perspective in their analyses.

- **Keywords:** collaboration, disasters, serious games, states, task workload, traits

J. Alberto Espinosa and Mark A. Clark. Team Knowledge Representation: A Network Perspective. S. 333-348.

Objective: We propose a network perspective of team knowledge that offers both conceptual and methodological advantages, expanding explanatory value through representation and measurement of component structure and content. **Background:** Team knowledge has typically been conceptualized and measured with relatively simple aggregates, without fully accounting for differing knowledge configurations among team members. Teams with similar aggregate values of team knowledge may have very different team dynamics depending on how knowledge isolates, cliques, and densities are distributed across the team; which members are the most knowledgeable; who shares knowledge with whom; and how knowledge clusters are distributed. **Method:** We illustrate our proposed network approach through a sample of 57 teams, including how to compute, analyze, and visually represent team knowledge. **Results:** Team knowledge network structures (isolation, centrality) are associated with outcomes of, respectively, task coordination, strategy coordination, and the proportion of team knowledge cliques, all after controlling for shared team knowledge. **Conclusion:** Network analysis helps to represent, measure, and understand the relationship of team knowledge to outcomes of interest to team researchers, members, and managers. Our approach complements existing team knowledge measures. **Application:** Researchers and managers can apply network concepts and measures to help understand where team knowledge is held within a team and how this relational structure may influence team coordination, cohesion, and performance.

- **Keywords:** team knowledge, shared knowledge, shared cognition, network analysis

Communication Systems

Holly A. H. Handley. A Network Model for Human Interoperability. S. 349-360.

Objective: The objective is to demonstrate how the Human View architecture can be used to define and evaluate the *human* interoperability capabilities of a net-centric system. Human interoperability strives to understand the types of system relationships that affect collaboration across networked environments. **Background:** The Human View was developed as an additional system architectural viewpoint to focus on the human component of a system by capturing data on human roles, tasks, constraints, interactions, and metrics. This framework can be used to collect and organize social system parameters to facilitate the way that humans interact across organizational boundaries. **Method:** By mapping the Human View elements to organizational relationships defined in the domain of network theory, a network model of the Human View can be developed. This representation can then be aligned with a Layers of Interoperability model for collaborative systems. The model extends traditional technical interoperability to include organizational aspects important for human interoperability. The resulting composite model can be used to evaluate the human interoperability capability of network-enabled systems. **Results:** An interagency response to a crisis situation is an example where increased levels of human interoperability can affect the effectiveness of the organizational interactions. The existing Human View products representing the interagency capabilities were evaluated using the network model to demonstrate how the social system variables can be identified and evaluated to improve the system design. **Conclusion:** By understanding and incorporating human interoperability requirements, the resulting system design can more effectively support collaborative tasks across technological environments to facilitate timely responses to events.

- **Keywords:** human systems, system architectures, human viewpoint, organizational design, collaboration, interoperability, net-centric environment

Computer Systems

Adam Euerby and Catherine M. Burns. Improving Social Connection Through a Communities-of-Practice-Inspired Cognitive Work Analysis Approach.. S. 361-383.

Objective: Increasingly, people work in socially networked environments. With growing adoption of enterprise social network technologies, supporting effective social community is becoming an important factor in organizational success. **Background:** Relatively few human factors methods have been applied to social connection in communities. Although team methods provide a contribution, they do not suit design for communities. Wenger's community of practice concept, combined with cognitive work analysis, provided one way of designing for community. **Method:** We used a cognitive work analysis approach modified with principles for supporting communities of practice to generate a new website design. Over several months, the community using the site was studied to examine their degree of social connectedness and communication levels. **Results:** Social network analysis and communications analysis, conducted at three different intervals, showed increases in connections between people and between people and organizations, as well as increased communication following the launch of the new design. **Conclusion:** In this work, we suggest that human factors approaches can be effective in social environments, when applied considering social community principles. **Application:** This work has implications for the development of new human factors methods as well as the design of interfaces for sociotechnical systems that have community building requirements.

- **Keywords:** community, cognitive work analysis, communities of practice, social networking, social network analysis, website, design

Displays and Controls

Lisa Steiner, Robin Burgess-Limerick, and William Porter. Directional Control-Response Compatibility Relationships Assessed by Physical Simulation of an Underground Bolting Machine. S. 384-391.

Objective: The authors examine the pattern of direction errors made during the manipulation of a physical simulation of an underground coal mine bolting machine to assess the directional control-response compatibility relationships associated with the device and to compare these results to data obtained from a virtual simulation of a generic device. **Background:** Directional errors during the manual control of underground coal roof bolting equipment are associated with serious injuries. Directional control-response relationships have previously been examined using a virtual simulation of a generic device; however, the applicability of these results to a specific physical device may be questioned. **Method:** Forty-eight participants randomly assigned to different directional control-response relationships manipulated horizontal or vertical control levers to move a simulated bolter arm in three directions (elevation, slew, and sump) as well as to cause a light to become illuminated and raise or lower a stabilizing jack. Directional errors were recorded during the completion of 240 trials by each participant. **Results:** Directional error rates are increased when the control and response are in opposite directions or if the direction of the control and response are perpendicular. The pattern of direction error rates was consistent with experiments obtained from a generic device in a virtual environment. **Conclusion:** Error rates are increased by incompatible directional control-response relationships. **Application:** Ensuring that the design of equipment controls maintains compatible directional control-response relationships has potential to reduce the errors made in high-risk situations, such as underground coal mining.

- **Keywords:** control errors, machinery, safety

Psychomotor Processes

William S. Helton, James Head, and Benno A. Blaschke. Cornering Law: The Difficulty of Negotiating Corners With an Unmanned Ground Vehicle. . S. 392-402.

Objective: We investigated skill development and workload of pilots driving teleoperated unmanned ground vehicles (UGVs) through different apertures and viewpoints using the cornering law. **Background:** Due to technological and cost restraints, humans are still needed for tasks involving UGVs. Operators of teleoperated UGVs are likely to have less situation awareness and thus are more prone to getting stuck or damaged when negotiating apertures. To our knowledge, the operation of physical UGVs through corners has not been examined. Therefore, a better understanding of cornering a teleoperated UGVs is imperative. **Method:** In Experiment 1, 20 novice participants repeatedly teleoperated a physical UGV using a third-person overhead view through apertures that varied in width. In Experiment 2, 18 additional novice participants completed a similar task but used a first-person view. **Results:** Participants' performance increased (i.e., faster cornering times and less collisions) over sessions. The cornering law successfully modeled the effect of different aperture widths on participant performance for both viewing perspectives. **Conclusion:** In this study, we successfully modeled human performance of teleoperated UGVs using the cornering law. Analogous to Fitts' and

steering law, we were able to successfully model and predict cornering performance based on a derived index of cornering difficulty. **Application:** The cornering law could be used to aid in the development of prototype user interfaces and also to examine the effects of different teleoperation views (first person vs. third person).

- **Keywords: cornering,** Fitts' law, motor control, remote navigation, unmanned ground vehicles

Simulation and Virtual Reality

John Taverniers and Pieter De Boeck. *Force-on-Force Handgun Practice: An Intra-Individual Exploration of Stress Effects, Biomarker Regulation, and Behavioral Changes.* S. 403-413.

Objective: The aim of this study was to explore human factors aspects of reality-based "force-on-force" (FoF) handgun practice through a within-subjects field experiment that assessed subjective stress measurements, biomarker regulation, performance outcomes, and behavioral adaptations. **Background:** FoF handgun practice is a recent training asset for armed officers whereby dynamic opponents may act, react, and even retaliate with specially designed marker ammunition. Predesigned scenarios enable trainees to practice in a simulated real-life environment. **Method:** A sample of experienced military personnel (N = 20) ran a handgun workshop in two conditions: FoF practice and traditional cardboard-target practice. Intra-individual assessments included anticipated distress, subjective stress, salivary alpha-amylase (sAA), shooting accuracy, and directly observable training seriousness. **Results:** Compared with the standard cardboard practice condition, FoF exposure caused significant increases in anticipatory distress, subjective stress, and sAA secretion. Furthermore, participants' first encounter with FoF practice (vs. cardboard practice) substantially degraded their shooting performance and had a significant positive impact on the earnestness with which they approached their mission during the workshop. **Conclusion:** FoF practice is an effective training tool for armed officers because it simulates a realistic work environment by increasing task-specific stress such that it affects important outcomes of professional performance and leads to desirable behavioral changes during training. **Application:** Potential applications of this research include the introduction of biomarker assessments in human factors research and the design, based on reality-based practice, of effective training procedures for high-reliability professionals.

- **Keywords:** alpha-amylase, behavioral change, biomarker, marker ammunition, reality-based practice, stress, training

Surface Transportation Systems

Jibo He, Jason S. McCarley, and Arthur F. Kramer. *Lane Keeping Under Cognitive Load: Performance Changes and Mechanisms.* S. 414-426.

Objective: A pair of simulated driving experiments studied the effects of cognitive load on drivers' lane-keeping performance. **Background:** Cognitive load while driving often reduces the variability of lane position. However, there is no agreement as to whether this effect should be interpreted as a performance loss, consistent with other effects of distraction on driving, or as an anomalous performance gain. **Method:** Participants in a high-fidelity driving simulator performed a lane-keeping task in lateral wind, with instructions to keep a steady lane position. Under high load conditions, participants performed a concurrent working memory task with auditory stimuli. Cross-spectral analysis measured the relationship between wind force and steering inputs.

Results: Cognitive load reduced the variability of lane position and increased the coupling between steering wheel position and crosswind strength. **Conclusion:** Although cognitive load disrupts driver performance in a variety of ways, it produces a performance gain in lane keeping. This effect appears to reflect drivers' efforts to protect lateral control against the risk of distraction, at the apparent neglect of other elements of driving performance. **Application:** Results may inform educational efforts to help drivers understand the risks of distraction and the inadequacies of compensatory driving strategies.

- **Keywords:** cognitive load, lane keeping, vehicle control, multitasking, driver distraction