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COGNITION

Jussi P. P. Jokinen, Tuomo Kujala, Antti Oulasvirta. *Multitasking in Driving as Optimal Adaptation Under Uncertainty*. pp. 1324–1341.

Objective: The objective was to better understand how people adapt multitasking behavior when circumstances in driving change and how safe versus unsafe behaviors emerge. **Background:** Multitasking strategies in driving adapt to changes in the task environment, but the cognitive mechanisms of this adaptation are not well known. Missing is a unifying account to explain the joint contribution of task constraints, goals, cognitive capabilities, and beliefs about the driving environment. **Method:** We model the driver's decision to deploy visual attention as a stochastic sequential decision-making problem and propose hierarchical reinforcement learning as a computationally tractable solution to it. The supervisory level deploys attention based on per-task value estimates, which incorporate beliefs about risk. Model simulations are compared against human data collected in a driving simulator. **Results:** Human data show adaptation to the attentional demands of ongoing tasks, as measured in lane deviation and in-car gaze deployment. The predictions of our model fit the human data on these metrics. **Conclusion:** Multitasking strategies can be understood as optimal adaptation under uncertainty, wherein the driver adapts to cognitive constraints and the task environment's uncertainties, aiming to maximize the expected long-term utility. Safe and unsafe behaviors emerge as the driver has to arbitrate between conflicting goals and manage uncertainty about them. **Application:** Simulations can inform studies of conditions that are likely to give rise to unsafe driving behavior.

- **Keywords:** driving, multitasking, task interleaving, computational rationality, reinforcement learning

Kunihiro Hasegawa, Motohiro Kimura, Yuji Takeda. *Pedal Misapplication: Interruption Effects and Age-Related Differences*. pp. 1342–1351.

Objective: This study aimed to investigate whether pedal misapplication occurs more frequently when a pedal task is interrupted for a longer period of time. **Background:** Misapplication of a vehicle's brake and accelerator pedals can cause severe traffic accidents, especially for older drivers. The present study provides empirical support for the hypothesis that pedal misapplication occurs more frequently when drivers are interrupted for longer periods of time and is demonstrated more prominently in older drivers. **Methods:** Forty younger participants and 40 older participants were asked to perform a pedal choice response task (stepping on either a brake or accelerator pedal) that had been preceded by an interruption task (i.e., touch number task). **Results:** Pedal misapplications occurred more frequently when the pedal choice response task was preceded by the touch number task for a longer interval (about 120 s) than for a shorter interval (about 30 s). Furthermore, the time-related increase in pedal misapplications was greater for older participants. **Conclusion:** Pedal misapplication increases when the pedal task is interrupted for a longer time period, especially for older adults. **Application:** The findings contribute to our understanding of when and where pedal misapplications tend to occur.

- **Keywords:** accidents, human error, age, driver behavior, distraction, risk assessment

COMMUNICATION

Brigid M. Gillespie, Joseph Gillespie, Rhonda J. Boorman, Karin Granqvist, Johan Stranne, Annette Erichsen-Andersson. *The Impact of Robotic-Assisted Surgery on Team Performance: A Systematic Mixed Studies Review*. pp. 1352–1379.

Objective: The aim of this study is to describe the impact of robotic-assisted surgery on team performance in the operating room. **Background:** The introduction of surgical robots has improved the technical performance of surgical procedures but has also contributed to unexpected interactions in surgical teams, leading to new types of errors. **Method:** A systematic literature search of Cumulative Index to Nursing and Allied Health Literature, PubMed, ProQuest, Cochrane, Web of Science, PsycINFO, and Scopus databases using key words and MeSH terms was conducted. Screening identified studies employing qualitative and quantitative methods published between January 2000 and September 2019. Two reviewers independently appraised the methodological quality of the articles using the Mixed Methods Appraisal Tool (2018). Discussions were held among authors to examine quality scores of the studies and emergent themes, and agreement was reached through consensus. Themes were derived using inductive content analysis. **Results:** Combined searches identified 1,065 citations. Of these, 19 articles, 16 quantitative and 3 qualitative, were included. Robotic-assisted surgeries included urology, gynecology, cardiac, and general procedures involving surgeons, anesthetists, nurses, and technicians. Three themes emerged: Negotiating the altered physical environs and adapting team communications to manage task and technology; managing the robotic system to optimize workflow efficiency; and technical proficiency depends on experience, team familiarity, and case complexity. **Conclusion:** Inclusion of a robot as a team member adds further complexity to the work of surgery. **Application:** These review findings will inform training programs specifically designed to optimize teamwork, workflow efficiency, and learning needs.

- **Keywords:** nontechnical skills, ergonomics, operating room, workflow, patient safety

HUMAN-ROBOT INTERACTION

Jeroen Roozendaal, Emma Johansson, Joost de Winter, David Abbink, Sebastiaan Petermeijer. *Haptic Lane-Keeping Assistance for Truck Driving: A Test Track Study*. pp. 1380–1395.

Objective: This study aims to compare the effectiveness and subjective acceptance of three designs for haptic lane-keeping assistance in truck driving. **Background:** Haptic lane-keeping assistance provides steering torques toward a reference trajectory, either continuously or only when exceeding a bandwidth. These approaches have been previously investigated in driving simulators, but it is unclear how these generalize toward real-life truck driving. **Method:** Three haptic lane-keeping algorithms to assist truck drivers were evaluated on a 6.3-km-long oval-shaped test track: (1) a single-bandwidth (SB) algorithm, which activated assistance torques when the predicted lateral deviation from lane center exceeded 0.4 m; (2) a double-bandwidth (DB) algorithm, which activated as SB, but deactivated after returning within 0.15 m lateral deviation; and (3) an algorithm providing assistance torques continuously (Cont) toward the lane center. Fifteen participants drove four trials each, one trial without and one for each haptic assistance design. Furthermore, participants drove with and without a concurrent visually distracting task. **Results:** Compared to unsupported driving, all three assistance systems provided similar safety benefits in terms of decreased absolute lateral position and number of lane departures. Participants reported higher satisfaction and usability for Cont compared to SB. **Conclusion:** The continuous assistance was better accepted than bandwidth assistance, a finding consistent with prior driving simulator research. Research is still needed to investigate the long-term effects of haptic assistance on reliance and after-effects. **Application:** The present results are useful for designers of haptic lane-keeping assistance, as driver acceptance and performance are determinants of reliance and safety, respectively.

- **Keywords:** haptic shared control, truck driving, lane keeping, driver acceptance, driver distraction

Sophia von Salm-Hoogstraeten, Jochen Müsseler. *Human Cognition in Interaction With Robots: Taking the Robot's Perspective Into Account*. pp. 1396–1407.

Objective: The present study investigated whether and how different human–robot interactions in a physically shared workspace influenced human stimulus–response (SR) relationships Background: Human work is increasingly performed in interaction with advanced robots. Since human–robot interaction often takes place in physical proximity, it is crucial to investigate the effects of the robot on human cognition. **Method:** In two experiments, we compared conditions in which humans interacted with a robot that they either remotely controlled or monitored under otherwise comparable conditions in the same shared workspace. The cognitive extent to which the participants took the robot's perspective served as a dependent variable and was evaluated with a SR compatibility task. **Results:** The results showed pronounced compatibility effects from the robot's perspective when participants had to take the perspective of the robot during the task, but significantly reduced compatibility effects when human and robot did not interact. In both experiments, compatibility effects from the robot's perspective resulted in statistically significant differences in response times and in error rates between compatible and incompatible conditions. **Conclusion:** We concluded that SR relationships from the perspective of the robot need to be considered when designing shared workspaces that require users to take the perspective of the robot. **Application:** The results indicate changed compatibility relationships when users share their workplace with an interacting robot and therefore have to take its perspective from time to time. The perspective-dependent processing times are expected to be accompanied by corresponding error rates, which might affect—for instance—safety and efficiency in a production process.

- **Keywords:** human-robot interaction, human–robot collaboration, Simon effect, stimulus–response compatibility

METHODS AND SKILLS

Matt Holman, Guy Walker, Terry Lansdown, Paul Salmon, Gemma Read, Neville Stanton. *The Binary-Based Model (BBM) for Improved Human Factors Method Selection*. pp. 1408–1436.

Objective: This paper presents the Binary-Based Model (BBM), a new approach to Human Factors (HF) method selection. The BBM helps practitioners select the most appropriate HF methodology in relation to the complexity within the target system. **Background:** There are over 200 HF methods available to the practitioner and little guidance to help choose between them. **Method:** The BBM defines a HF "problem space" comprising three complexity attributes. HF problems can be rated against these attributes and located in the "problem space." In addition, a similar HF "approach space" in which 66 predictive methods are rated according to their ability to confront those attributes is defined. These spaces are combined into a "utility space" in which problems and methods coexist. In the utility space, the match between HF problems and methods can be formally assessed. **Results:** The method space is split into octants to establish broad groupings of methods distributed throughout the space. About 77% of the methods reside in Octant 1 which corresponds to problems with low levels of complexity. This demonstrates that most HF methods are suited to problems in low-complexity systems. **Conclusion:** The location of 77% of the rated methods in Octant 1 indicates that HF practitioners are underserved with methods for analysis of HF problems exhibiting high complexity. **Application:** The BBM can be used by multidisciplinary teams to select the most appropriate HF methodology for the problem under analysis. All the materials and analysis are placed in the public domain for modification and consensus building by the wider HF community.

- **Keywords:** HF methods, method selection, fuzzy logic, complexity

NEUROERGONOMICS

Ranjana K. Mehta, Joseph Nuamah. *Relationship Between Acute Physical Fatigue and Cognitive Function During Orthostatic Challenge in Men and Women: A Neuroergonomics Investigation*. pp. 1437–1448.

Background: Postflight orthostatic challenge (OC), resulting from blood pooling in lower extremities, is a major health concern among astronauts that fly long-duration missions. Additionally, astronauts undergo physical demanding tasks resulting in acute fatigue, which can affect performance. However, the effects of concurrent OC and acute physical fatigue on performance have not been adequately investigated. **Objective:** The purpose of this study was to determine the relationship between acute physical fatigue and cognitive function during OC. **Methods:** Sixteen healthy participants performed the mental arithmetic task and psychomotor tracking tasks in the absence and presence of a prior 1-hour physically fatiguing exercise, on separate days under OC (induced via lower body negative pressure). We recorded task performances on the cognitive tests and prefrontal cortex oxygenation using functional near-infrared spectroscopy, along with physiological and subjective responses. **Results:** The introduction of the cognitive tasks during OC increased cerebral oxygenation; however, oxygenation decreased significantly with the cognitive tasks under the acute fatigue conditions, particularly during the tracking task and in males. These differences were accompanied by comparable task performances. **Discussion:** The findings suggest that mental arithmetic is a more effective countermeasure than psychomotor tracking under acute physical fatigue during OC. Whereas females did not show a significant difference in cerebral oxygenation due to

task, males did, suggesting that it may be important to consider gender differences when developing countermeasures against OC.

- **Keywords:** fNIRS, workload, microgravity, mental arithmetic, psychomotor tracking

SIMULATION AND VIRTUAL REALITY

Hillary Maxwell, Bruce Weaver, Sylvain Gagnon, Shawn Marshall, Michel Bédard. *The Validity of Three New Driving Simulator Scenarios: Detecting Differences in Driving Performance by Difficulty and Driver Gender and Age*. pp. 1449–1464.

Objective: We explored the convergent and discriminant validity of three driving simulation scenarios by comparing behaviors across gender and age groups, considering what we know about on-road driving. **Background:** Driving simulators offer a number of benefits, yet their use in real-world driver assessment is rare. More evidence is needed to support their use. **Method:** A total of 104 participants completed a series of increasingly difficult driving simulation scenarios. Linear mixed models were estimated to determine if behaviors changed with increasing difficulty and whether outcomes varied by age and gender, thereby demonstrating convergent and discriminant validity, respectively. **Results:** Drivers adapted velocity, steering, acceleration, and gap acceptance according to difficulty, and the degree of adaptation differed by gender and age for some outcomes. For example, in a construction zone scenario, drivers reduced their mean velocities as congestion increased; males drove an average of 2.30 km/hr faster than females, and older participants drove more slowly than young (5.26 km/hr) and middle-aged drivers (6.59 km/hr). There was also an interaction between age and difficulty; older drivers did not reduce their velocities with increased difficulty. **Conclusion:** This study provides further support for the ability of driving simulators to elicit behaviors similar to those seen in on-road driving and to differentiate between groups, suggesting that simulators could serve a supportive role in fitness-to-drive evaluations. **Application:** Simulators have the potential to support driver assessment. However, this depends on the development of valid scenarios to benchmark safe driving behavior, and thereby identify deviations from safe driving behavior. The information gained through simulation may supplement other forms of assessment and possibly eliminate the need for on-road testing in some situations.

- **Keywords:** simulation and virtual reality, driver behavior, risk assessment, tools, individual differences, driving simulator, skilled performance, analysis and evaluation

SOCIAL PROCESSES

Ryosuke Yokoi, Kazuya Nakayachi. *Trust in Autonomous Cars: Exploring the Role of Shared Moral Values, Reasoning, and Emotion in Safety-Critical Decisions*. pp. 1465–1484.

Objective: Autonomous cars (ACs) controlled by artificial intelligence are expected to play a significant role in transportation in the near future. This study investigated determinants of trust in ACs. **Background:** Trust in ACs influences different variables, including the intention to adopt AC technology. Several studies on risk perception have verified that shared value determines trust in risk managers. Previous research has confirmed the effect of value similarity on trust in artificial intelligence. We focused on moral beliefs, specifically utilitarianism (belief in promoting a greater good) and deontology (belief in condemning deliberate harm), and tested the effects of shared moral beliefs on trust in ACs. **Method:** We conducted three experiments (N = 128, 71,

and 196, for each), adopting a thought experiment similar to the well-known trolley problem. We manipulated shared moral beliefs (shared vs. unshared) and driver (AC vs. human), providing participants with different moral dilemma scenarios. Trust in ACs was measured through a questionnaire. **Results:** The results of Experiment 1 showed that shared utilitarian belief strongly influenced trust in ACs. In Experiment 2 and Experiment 3, however, we did not find statistical evidence that shared deontological belief had an effect on trust in ACs. **Conclusion:** The results of the three experiments suggest that the effect of shared moral beliefs on trust varies depending on the values that ACs share with humans. **Application:** To promote AC implementation, policymakers and developers need to understand which values are shared between ACs and humans to enhance trust in ACs.

- **Keywords:** autonomous cars, trust, value similarity, moral dilemma, dual-process theory

SURFACE TRANSPORTATION

Shiyan Yang, Jonny Kuo, Michael G. Lenné. *Effects of Distraction in On-Road Level 2 Automated Driving: Impacts on Glance Behavior and Takeover Performance*. pp. 1485–1497.

Objective: The paper aimed to investigate glance behaviors under different levels of distraction in automated driving (AD) and understand the impact of distraction levels on driver takeover performance. **Background:** Driver distraction detrimentally affects takeover performance. Glance-based distraction measurement could be a promising method to remind drivers to maintain enough attentiveness before the takeover request in partially AD. **Method:** Thirty-six participants were recruited to drive a Tesla Model S in manual and Autopilot modes on a test track while engaging in secondary tasks, including temperature-control, email-sorting, and music-selection, to impose low and high distractions. During the test drive, participants needed to quickly change the lane as if avoiding an immediate road hazard if they heard an unexpected takeover request (an auditory warning). Driver state and behavior over the test drive were recorded in real time by a driver monitoring system and several other sensors installed in the Tesla vehicle. **Results:** The distribution of off-road glance duration was heavily skewed (with a long tail) by high distractions, with extreme glance duration more than 30 s. Moreover, being eyes-off-road before takeover could cause more delay in the urgent takeover reaction compared to being hands-off-wheel. **Conclusion:** The study measured off-road glance duration under different levels of distraction and demonstrated the impacts of being eyes-off-road and hands-off-wheel on the following takeover performance. **Application:** The findings provide new insights about engagement in Level 2 AD and are useful for the design of driver monitoring technologies for distraction management.

- **Keywords:** driver distraction, automated driving, glance behavior, takeover reaction, driver monitoring