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Special Section: Human Factors and Automation in Vehicles



HUMAN FACTORS AND AUTOMATION IN VEHICLES SPECIAL SECTION

Natasha Merat and John D. Lee. *Preface to the Special Section on Human Factors and Automation in Vehicles: Designing Highly Automated Vehicles With the Driver in Mind.* S. 681-686.

Objective: This special section brings together diverse research regarding driver interaction with advanced automotive technology to guide design of increasingly automated vehicles. **Background:** Rapidly evolving vehicle automation will likely change cars and trucks more in the next 5 years than the preceding 50, radically redefining what it means to drive. **Method:** This special section includes 10 articles from European and North American researchers reporting simulator and naturalistic driving studies. **Results:** Little research has considered the consequences of fully automated driving, with most focusing on lane-keeping and speed control systems individually. The studies reveal two underlying design philosophies: automate driving versus support driving. Results of several studies, consistent with previous research in other domains, suggest that the automate philosophy can delay driver responses to incidents in which the driver has to intervene and take control from the automation. Understanding how to orchestrate the transfer or sharing of control between the system and the driver, particularly in critical incidents, emerges as a central challenge. **Conclusion:** Designers should not assume that automation can substitute seamlessly for a human driver, nor can they assume that the driver can safely accommodate the limitations of automation. Designers, policy makers, and researchers must give careful consideration to what role the person should have in highly automated vehicles and how to support the driver if the driver is to be responsible for vehicle control. As in other domains, driving safety increasingly depends on the combined performance of the human and automation, and successful designs will depend on recognizing and supporting the new roles of the driver.

- **Keywords:** driver behavior, surface transportation systems, highway and vehicle design, surface transportation systems, system design features, aerospace systems

Shan Bao, David J. LeBlanc, James R. Sayer and Carol Flannagan. *Heavy-Truck Drivers' Following Behavior With Intervention of an Integrated, In-Vehicle Crash Warning System: A Field Evaluation.* S. 687-697.

Objective: This study is designed to evaluate heavy-truck drivers' following behavior and how a crash warning system influences their headway maintenance. **Background:** Rear-end crashes are one of the major crash types involving heavy trucks and are more likely than other crash types to result in fatalities. Previous studies have observed positive effects of in-vehicle crash warning systems in passenger car drivers. Although heavy-truck drivers are generally more experienced, driver-related errors are still the leading factors contributing to heavy-truck-related rear-end crashes. **Method:** Data from a 10-month naturalistic driving study were used. Participants were 18 professional heavy-truck drivers who received warnings during the last 8 months of the study (treatment period) but not during the first 2 months (baseline period). Time headway and driver's brake reaction time were extracted and compared with condition variables, including one between-subjects variable (driver shift) and five within-subjects variables (treatment condition, roadway types, traffic density, wiper state, and trailer configuration). **Results:** The presence of warnings resulted in a 0.28-s increase of mean time headway with dense on-road traffic and a 0.20-s increase with wipers on. Drivers also responded to the forward conflicts significantly faster (by 0.26 s, a 15% enhancement) in the treatment condition compared with responses in the baseline condition. **Conclusion:** Positive effects on heavy-truck drivers' following performance were observed with the warning system. **Application:** The installation of such in-vehicle crash warning systems can help heavy-truck drivers keep longer headway distances in challenging situations and respond quicker to potential traffic conflicts, therefore possibly increasing heavy-truck longitudinal driving safety.

- **Keywords:** heavy truck, time headway, in-vehicle crash warning system, rear-end crash

Elke Muhrer, Klaus Reinprecht and Mark Vollrath. *Driving With a Partially Autonomous Forward Collision Warning System: How Do Drivers React?* S. 698-708.

Objective: The effects of a forward collision warning (FCW) and braking system (FCW+) were examined in a driving simulator study analyzing driving and gaze behavior and the engagement in a secondary task. **Background:** In-depth accident analyses indicate that a lack of appropriate expectations for possible critical situations and visual distraction may be the major causes of rear-end crashes. Studies with FCW systems have shown that a warning alone was not enough for a driver to be able to avoid the accident. Thus, an additional braking intervention by such systems could be necessary. **Method:** In a driving simulator experiment, 30 drivers took part in a car-following scenario in an urban area. It was assumed that different lead car behaviors and environmental aspects would lead to different drivers' expectations of the future traffic situation. Driving with and without FCW+ was introduced as a between-subjects factor. **Results:** Driving with FCW+ resulted in significantly fewer accidents in critical situations. This result was achieved by the system's earlier reaction time as compared with that of drivers. The analysis of the gaze behavior showed that driving with the system did not lead to a stronger involvement in secondary tasks. **Conclusion:** The study supports the hypotheses about the importance of missing expectations for the occurrence of accidents. These accidents can be prevented by an FCW+ that brakes autonomously. **Application:** The results indicate that an autonomous braking intervention should be implemented in FCW systems to increase the effectiveness of these assistance systems.

- **Keywords:** forward collision warning, driving behavior, expectations, gaze behavior, partially autonomous driver assistance system, rear-end crash, situation awareness

Arnaud Koustanäi, Viola Cavallo, Patricia Delhomme and Arnaud Mas. *Simulator Training With a Forward Collision Warning System: Effects on Driver-System Interactions and Driver Trust.* S. 709-721.

Objective: The study addressed the role of familiarization on a driving simulator with a forward collision warning (FCW) and investigated its impact on driver behavior. **Background:** Drivers need a good understanding of how an FCW system functions to trust it and use it properly. Theoretical and empirical data suggest that exploring the capacities and limitations of the FCW during the learning period improves operating knowledge and leads to increased driver trust in the system and better driver-system interactions. The authors tested this hypothesis by comparing groups of drivers differing in FCW familiarity. **Method:** During the familiarization phase, familiarized drivers were trained on the simulator using the FCW, unfamiliarized drivers simply read an FCW manual, and control drivers had no contact with the FCW. During the test, drivers drove the simulator and had to interact with traffic; both familiarized and unfamiliarized drivers used the FCW, whereas controls did not. **Results:** Simulator familiarization improved driver understanding of FCW operation. Driver-system interactions were more effective: Familiarized drivers had no collisions, longer time headways, and better reactions in most situations. Familiarization increased trust in the FCW but did not raise system acceptance. **Conclusion:** Familiarization on the simulator had a positive effect on driver-system interactions and on trust in the system. The limitations of the familiarization method are discussed in relation to the driving simulator methodology. **Application:** Practicing on a driving simulator with driving-assistance systems could facilitate their use during real driving.

- **Keywords:** driver assistance, driver-system interaction, driver behavior, familiarization, driver distraction, forward collision warning, system understanding, trust

Huimin Xiong, Linda Ng Boyle, Jane Moeckli, Benjamin R. Dow and Timothy L. Brown. *Use Patterns Among Early Adopters of Adaptive Cruise Control.* S. 722-733.

Objective: The objective of this study was to investigate use patterns among early adopters of adaptive cruise control (ACC). **Background:** Extended use of ACC may influence a driver's behavior in the long term, which can have unintended safety consequences. **Method:** The authors examined the use of a motion-based simulator by 24 participants (15 males and 9 females). Cluster analysis was performed on drivers' use of ACC and was based on their gap settings, speed settings, number of warnings issued, and ACC disengaged. The data were then examined on the basis of driving performance measures and drivers' subjective responses to trust in ACC, understanding of system operations, and driving styles. Driving performance measures included minimum time headway, adjusted minimum time to collision, and drivers' reaction time to critical events. **Results:** Three groups of drivers were observed on the basis of risky behavior, moderately risky behavior, and conservative behavior. Drivers in the conservative group stayed farther behind the lead vehicle than did drivers in the other two groups. Risky drivers responded later to critical events and had more ACC warnings issued.

Conclusion: Safety consequences with ACC may be more prevalent in some driver groups than others. The findings suggest that these safety implications are related to trust in automation, driving styles, understanding of system operations, and personalities. **Application:** Potential applications of this research include enhanced design for next-generation ACC systems and countermeasures to improve safe driving with ACC.

- **Keywords:** driver behavior, driver safety, driving simulator

Catherine Neubauer, Gerald Matthews, Lisa Langheim and Dyani Saxby. *Fatigue and Voluntary Utilization of Automation in Simulated Driving.* S. 734-746.

Objective: A driving simulator was used to assess the impact on fatigue, stress, and workload of full vehicle automation that was initiated by the driver. **Background:** Previous studies have shown that mandatory use of full automation induces a state of "passive fatigue" associated with loss of alertness. By contrast, voluntary use of automation may enhance the driver's perceptions of control and ability to manage fatigue. **Method:** Participants were assigned to one of two experimental conditions, automation optional (AO) and nonautomation (NA), and then performed a 35-min, monotonous simulated drive. In the last 5 min, automation was unavailable and drivers were required to respond to an emergency event. Subjective state and workload were evaluated before and after the drive. **Results:** Making automation available to the driver failed to alleviate fatigue and stress states induced by driving in monotonous conditions. Drivers who were fatigued prior to the drive were more likely to choose to use automation, but automation use increased distress, especially in fatigue-prone drivers. Drivers in the AO condition were slower to initiate steering responses to the emergency event, suggesting optional automation may be distracting. **Conclusion:** Optional, driver-controlled automation appears to pose the same dangers to task engagement and alertness as externally initiated automation. **Application:** Drivers of automated vehicles may be vulnerable to fatigue that persists when normal vehicle control is restored. It is important to evaluate automated systems' impact on driver fatigue, to seek design solutions to the issue of maintaining driver engagement, and to address the vulnerabilities of fatigue-prone drivers.

- **Keywords:** automation choice, driver behavior, fatigue, individual differences, workload

Oliver Carsten, Frank C. H. Lai, Yvonne Barnard, A. Hamish Jamson and Natasha Merat. *Control Task Substitution in Semiautomated Driving: Does It Matter What Aspects Are Automated?* S. 747-761.

Objective: The study was designed to show how driver attention to the road scene and engagement of a choice of secondary tasks are affected by the level of automation provided to assist or take over the basic task of vehicle control. It was also designed to investigate the difference between support in longitudinal control and support in lateral control. **Background:** There is comparatively little literature on the implications of automation for drivers' engagement in the driving task and for their willingness to engage in non-driving-related activities. **Method:** A study was carried out on a high-level driving simulator in which drivers experienced three levels of automation: manual driving, semiautomated driving with either longitudinal or lateral control provided, and highly automated driving with both longitudinal and lateral control provided. Drivers were free to pay attention to the roadway and traffic or to engage in a range of entertainment and grooming tasks. **Results:** Engagement in the nondriving tasks increased from

manual to semiautomated driving and increased further with highly automated driving. There were substantial differences in attention to the road and traffic between the two types of semiautomated driving. **Conclusion:** The literature on automation and the various task analyses of driving do not currently help to explain the effects that were found. Lateral support and longitudinal support may be the same in terms of levels of automation but appear to be regarded rather differently by drivers.

- **Keywords:** automation, driver behavior, dual task performance, vigilance, eye movement, task analysis

Natasha Merat, A. Hamish Jamson, Frank C. H. Lai and Oliver Carsten. *Highly Automated Driving, Secondary Task Performance, and Driver State*. S. 762-771.

Objective: A driving simulator study compared the effect of changes in workload on performance in manual and highly automated driving. Changes in driver state were also observed by examining variations in blink patterns. **Background:** With the addition of a greater number of advanced driver assistance systems in vehicles, the driver's role is likely to alter in the future from an operator in manual driving to a supervisor of highly automated cars. Understanding the implications of such advancements on drivers and road safety is important. **Method:** A total of 50 participants were recruited for this study and drove the simulator in both manual and highly automated mode. As well as comparing the effect of adjustments in driving-related workload on performance, the effect of a secondary Twenty Questions Task was also investigated. **Results:** In the absence of the secondary task, drivers' response to critical incidents was similar in manual and highly automated driving conditions. The worst performance was observed when drivers were required to regain control of driving in the automated mode while distracted by the secondary task. Blink frequency patterns were more consistent for manual than automated driving but were generally suppressed during conditions of high workload. **Conclusion:** Highly automated driving did not have a deleterious effect on driver performance, when attention was not diverted to the distracting secondary task. **Application:** As the number of systems implemented in cars increases, an understanding of the implications of such automation on drivers' situation awareness, workload, and ability to remain engaged with the driving task is important.

- **Keywords:** blink duration, blink frequency, vehicle automation, driver behavior

Chris Dijksterhuis, Arjan Stuiver, Ben Mulder, Karel A. Brookhuis and Dick de Waard. *An Adaptive Driver Support System: User Experiences and Driving Performance in a Simulator*. S. 772-785.

Objective: The aim of this study was to test the implementation of an adaptive driver support system. **Background:** Providing support might not always be desirable from a safety perspective, as support may lead to problems related to a human operator being out of the loop. In contrast, adaptive support systems are designed to keep the operator in the loop as much as possible by providing support only when necessary. **Method:** A total of 31 experienced drivers were exposed to three modes of lane-keeping support: nonadaptive, adaptive, and no support. Support involved continuously updated lateral position feedback shown on a head-up display. When adaptive, support was triggered by performance-based indications of effort investment. Narrowing lane width and increasing density of oncoming traffic served to increase steering demand, and speed was fixed in all conditions to prevent any compensatory speed reactions. **Results:** Participants preferred the adaptive support mode mainly as a warning signal and tended to ignore nonadaptive feedback. Furthermore, driving behavior was improved by adaptive support

in that participants drove more centrally, displayed less lateral variation and drove less outside the lane's delineation when support was in the adaptive mode compared with both the no-support mode and the nonadaptive support mode. **Conclusion:** A human operator is likely to use machine-triggered adaptations as an indication that thresholds have been passed, regardless of the support that is initiated. Therefore supporting only the sensory processing stage of the human information processing system with adaptive automation may not be feasible. **Application:** These conclusions are relevant for designing adaptive driver support systems.

- **Keywords:** adaptive automation, head-up display, lateral control, mental workload, driving behavior

Mark Mulder, David A. Abbink and Erwin R. Boer. *Sharing Control With Haptics: Seamless Driver Support From Manual to Automatic Control*. S. 786-798.

Objective: Haptic shared control was investigated as a human-machine interface that can intuitively share control between drivers and an automatic controller for curve negotiation. **Background:** As long as automation systems are not fully reliable, a role remains for the driver to be vigilant to the system and the environment to catch any automation errors. The conventional binary switches between supervisory and manual control has many known issues, and haptic shared control is a promising alternative. **Method:** A total of 42 respondents of varying age and driving experience participated in a driving experiment in a fixed-base simulator, in which curve negotiation behavior during shared control was compared to during manual control, as well as to three haptic tunings of an automatic controller without driver intervention. **Results:** Under the experimental conditions studied, the main beneficial effect of haptic shared control compared to manual control was that less control activity (16% in steering wheel reversal rate, 15% in standard deviation of steering wheel angle) was needed for realizing an improved safety performance (e.g., 11% in peak lateral error). Full automation removed the need for any human control activity and improved safety performance (e.g., 35% in peak lateral error) but put the human in a supervisory position. **Conclusion:** Haptic shared control kept the driver in the loop, with enhanced performance at reduced control activity, mitigating the known issues that plague full automation. **Application:** Haptic support for vehicular control ultimately seeks to intuitively combine human intelligence and creativity with the benefits of automation systems.

- **Keywords:** manual control, shared control, automation, control authority, driver support, haptics, curve negotiation, lane keeping

Frank M. F. Verberne, Jaap Ham and Cees J. H. Midden. *Trust in Smart Systems: Sharing Driving Goals and Giving Information to Increase Trustworthiness and Acceptability of Smart Systems in Cars*. S. 799-810.

Objective: We examine whether trust in smart systems is generated analogously to trust in humans and whether the automation level of smart systems affects trustworthiness and acceptability of those systems. **Background:** Trust is an important factor when considering acceptability of automation technology. As shared goals lead to social trust, and intelligent machines tend to be treated like humans, the authors expected that shared driving goals would also lead to increased trustworthiness and acceptability of adaptive cruise control (ACC) systems. **Method:** In an experiment, participants (N = 57) were presented with descriptions of three ACCs with different

automation levels that were described as systems that either shared their driving goals or did not. Trustworthiness and acceptability of all the ACCs were measured. **Results:** ACCs sharing the driving goals of the user were more trustworthy and acceptable than were ACCs not sharing the driving goals of the user. Furthermore, ACCs that took over driving tasks while providing information were more trustworthy and acceptable than were ACCs that took over driving tasks without providing information. Trustworthiness mediated the effects of both driving goals and automation level on acceptability of ACCs. **Conclusion:** As when trusting other humans, trusting smart systems depends on those systems sharing the user's goals. Furthermore, based on their description, smart systems that take over tasks are judged more trustworthy and acceptable when they also provide information. **Application:** For optimal acceptability of smart systems, goals of the user should be shared by the smart systems, and smart systems should provide information to their user.

- **Keywords:** adaptive cruise control systems, social trust, system trust, acceptance, automation level, shared value similarity

ATTENTIONAL PROCESSES

Stephen J. Guastello, Henry Boeh, Michael Schimmels, Hillary Gorin, Samuel Huschen, Erin Davis, Natalie E. Peters, Megan Fabisch and Kirsten Poston. *Cusp Catastrophe Models for Cognitive Workload and Fatigue in a Verbally Cued Pictorial Memory Task.* S. 811-825.

Objective: The aim of this study was to evaluate two cusp catastrophe models for cognitive workload and fatigue. They share similar cubic polynomial structures but derive from different underlying processes and contain variables that contribute to flexibility with respect to load and the ability to compensate for fatigue. **Background:** Cognitive workload and fatigue both have a negative impact on performance and have been difficult to separate. Extended time on task can produce fatigue, but it can also produce a positive effect from learning or automaticity. **Method:** In this two-part experiment, 129 under-graduates performed tasks involving spelling, arithmetic, memory, and visual search. **Results:** The fatigue cusp for the central memory task was supported with the quantity of work performed and performance on an episodic memory task acting as the control parameters. There was a strong linear effect, however. The load manipulations for the central task were competition with another participant for rewards, incentive conditions, and time pressure. Results supported the workload cusp in which trait anxiety and the incentive manipulation acted as the control parameters. **Conclusion:** The cusps are generally better than linear models for analyzing workload and fatigue phenomena; practice effects can override fatigue. Future research should investigate multitasking and task sequencing issues, physical-cognitive task combinations, and a broader range of variables that contribute to flexibility with respect to load or compensate for fatigue. **Applications:** The new experimental medium and analytic strategy can be generalized to virtually any real-world cognitively demanding tasks. The particular results are generalizable to tasks involving visual search.

- **Keywords:** cognitive workload, fatigue, memory, incentives, cusp catastrophe, buckling, anxiety

Jessica K. Ljungberg and Fabrice Parmentier. *The Impact of Intonation and Valence on Objective and Subjective Attention Capture by Auditory Alarms.* S. 826-837.

Objective: The objective was to study the involuntary capture of attention by spoken words varying in intonation and valence. **Background:** In studies of verbal alarms, the propensity of alarms to capture attention has been primarily assessed with the use of subjective ratings of their perceived urgency. Past studies suggest that such ratings vary with the alarms' spoken urgency and content. **Method:** We measured attention capture by spoken words varying in valence (negative vs. neutral) and intonation (urgently vs. nonurgently spoken) through subjective ratings and behavioral measures. The key behavioral measure was the response latency to visual stimuli in the presence of spoken words breaking away from the periodical repetition of a tone. **Results:** The results showed that all words captured attention relative to a baseline standard tone but that this effect was partly counteracted by a relative speeding of responses for urgently compared with nonurgently spoken words. Word valence did not affect behavioral performance. Rating data showed that both intonation and valence increased significantly perceived urgency and attention grabbing without any interaction. **Conclusion:** The data suggest a congruency between subjective ratings and behavioral performance with respect to spoken intonation but not valence. **Application:** This study demonstrates the usefulness and feasibility of objective measures of attention capture to help design efficient alarm systems.

- **Keywords:** urgency, valence, warnings, oddball, auditory alarms

Russell S. Pierce. *The Effect of SPAM Administration During a Dynamic Simulation*. S. 838-848.

Objective: The objective of this study was to determine whether administration of the situation present assessment method (SPAM) affects workload and/or task performance. **Background:** SPAM probes are thought to isolate workload from the assessment of situation awareness (SA) by including a warning signal before asking an SA-related question. However, there is a good reason to think that SPAM may still have an effect on dynamic workload and task performance. Specifically, nearly all dual tasks affect workload and performance; thus, it would be surprising if SPAM did not. **Method:** Following the methods of Durso, Bleckley, and Dattel, I evaluated workload and performance on the Air Traffic Scenarios Test in SPAM, non-SPAM probe, and no-probe conditions. **Results:** Global workload was unaffected by probe administration. However, at least with novice performers, SPAM probes affected task performance. **Conclusion:** The use of a warning signal does not eliminate performance decrements associated with secondary tasks. Moreover, there may be performance decrements unique to SPAM. **Application:** Cautious users of online assessment measures, such as SPAM, may want to remove performance immediately subsequent to probes from analysis, use an interprobe interval longer than 2.83 min, and construct their assessment measures to reduce display search times unrelated to primary task performance.

- **Keywords:** situation awareness, situation present assessment method, dual-task performance, simulation, Air Traffic Scenarios Test

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Jinhua Guan, Hongwei Hsiao, Bruce Bradtmiller, Tsui-Ying Kau, Matthew R. Reed, Steven K. Jahns, Josef Loczi, H. Lenora Hardee and Dominic Paul T. Piamonte. *U.S. Truck Driver Anthropometric Study and Multivariate Anthropometric Models for Cab Designs*. S. 849-871.

Objective: This study presents data from a large-scale anthropometric study of U.S. truck drivers and the multivariate anthropometric models developed for the design of next-generation truck cabs. **Background:** Up-to-date anthropometric information of the

U.S. truck driver population is needed for the design of safe and ergonomically efficient truck cabs. **Method:** We collected 35 anthropometric dimensions for 1,950 truck drivers (1,779 males and 171 females) across the continental United States using a sampling plan designed to capture the appropriate ethnic, gender, and age distributions of the truck driver population. **Results:** Truck drivers are heavier than the U.S. general population, with a difference in mean body weight of 13.5 kg for males and 15.4 kg for females. They are also different in physique from the U.S. general population. In addition, the current truck drivers are heavier and different in physique compared to their counterparts of 25 to 30 years ago. **Conclusion:** The data obtained in this study provide more accurate anthropometric information for cab designs than do the current U.S. general population data or truck driver data collected 25 to 30 years ago. Multivariate anthropometric models, spanning 95% of the current truck driver population on the basis of a set of 12 anthropometric measurements, have been developed to facilitate future cab designs. **Application:** The up-to-date truck driver anthropometric data and multivariate anthropometric models will benefit the design of future truck cabs which, in turn, will help promote the safety and health of the U.S. truck drivers.

▪ **Keywords: truck driver, human body size, cab design models**