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HUMAN FACTORS PRIZE WINNER

Sebastiaan M. Petermeijer, David A. Abbink, and Joost C. F. de Winter. *Should Drivers Be Operating Within an Automation-Free Bandwidth? : Evaluating Haptic Steering Support Systems With Different Levels of Authority.* S. 5-20.

Objective: The aim of this study was to compare continuous versus bandwidth haptic steering guidance in terms of lane-keeping behavior, aftereffects, and satisfaction.

Background: An important human factors question is whether operators should be supported continuously or only when tolerance limits are exceeded. We aimed to clarify this issue for haptic steering guidance by investigating costs and benefits of both approaches in a driving simulator. **Methods:** Thirty-two participants drove five trials, each with a different level of haptic support: no guidance (Manual); guidance outside a 0.5-m bandwidth (Band1); a hysteresis version of Band1, which guided back to the lane center once triggered (Band2); continuous guidance (Cont); and Cont with double feedback gain (ContS). Participants performed a reaction time task while driving. Toward the end of each trial, the guidance was unexpectedly disabled to investigate aftereffects.

Results: All four guidance systems prevented large lateral errors (>0.7 m). Cont and especially ContS yielded smaller lateral errors and higher time to line crossing than Manual, Band1, and Band2. Cont and ContS yielded short-lasting aftereffects, whereas Band1 and Band2 did not. Cont yielded higher self-reported satisfaction and faster reaction times than Band1. **Conclusions:** Continuous and bandwidth guidance both prevent large driver errors. Continuous guidance yields improved performance and satisfaction over bandwidth guidance at the cost of aftereffects and variability in driver torque (indicating human–automation conflicts). **Application:** The presented results are useful for designers of haptic guidance systems and support critical thinking about the costs and benefits of automation support systems.

- **Keywords:** haptic feedback, shared control driving simulator, secondary task, human–automation interaction

HUMAN FACTORS PRIZE FINALISTS

Przemyslaw A. Lasota and Julie A. Shah. *Analyzing the Effects of Human-Aware Motion Planning on Close-Proximity Human–Robot Collaboration.* S. 21-33.

Objective: The objective of this work was to examine human response to motion-level robot adaptation to determine its effect on team fluency, human satisfaction, and perceived safety and comfort. **Background:** The evaluation of human response to adaptive robotic assistants has been limited, particularly in the realm of motion-level adaptation. The lack of true human-in-the-loop evaluation has made it impossible to determine whether such adaptation would lead to efficient and satisfying human–robot interaction. **Method:** We conducted an experiment in which participants worked with a robot to perform a collaborative task. Participants worked with an adaptive robot incorporating human-aware motion planning and with a baseline robot using shortest-path motions. Team fluency was evaluated through a set of quantitative metrics, and human satisfaction and perceived safety and comfort were evaluated through questionnaires. **Results:** When working with the adaptive robot, participants completed the task 5.57% faster, with 19.9% more concurrent motion, 2.96% less human idle time, 17.3% less robot idle time, and a 15.1% greater separation distance. Questionnaire responses indicated that participants felt safer and more comfortable when working with an adaptive robot and were more satisfied with it as a teammate than with the standard robot. **Conclusion:** People respond well to motion-level robot adaptation, and significant benefits can be achieved from its use in terms of both human–robot team fluency and human worker satisfaction. **Application:** Our conclusion supports the development of technologies that could be used to implement human-aware motion planning in collaborative robots and the use of this technique for close-proximity human–robot collaboration.

- **Keywords:** human–robot interaction, motion-level adaptation, team fluency, human satisfaction

Stephanie M. Merritt, Deborah Lee, Jennifer L. Unnerstall, and Kelli Huber. *Are Well-Calibrated Users Effective Users? : Associations Between Calibration of Trust and Performance on an Automation-Aided Task. S. 34-47.*

Objective: We present alternative operationalizations of trust calibration and examine their associations with predictors and outcomes. **Background:** It is thought that trust calibration (correspondence between aid reliability and user trust in the aid) is a key to effective human–automation performance. We propose that calibration can be operationalized in three ways. Perceptual accuracy is the extent to which the user perceives the aid’s reliability accurately at one point in time. Perceptual sensitivity and trust sensitivity reflect user adjustment of perceived reliability and trust as the aid’s actual reliability changes over time. **Method:** One hundred fifty-five students completed an X-ray screening task with an automated screener. Awareness of the aid’s accuracy trajectory and error type was examined as predictors, and task performance and aid failure detection were examined as outcomes. **Results:** Awareness of accuracy trajectory was significantly associated with all three operationalizations of calibration, but awareness of error type was not when considered in conjunction with accuracy trajectory. Contrary to expectations, only perceptual accuracy was significantly associated with task performance and failure detection, and combined, the three operationalizations accounted for only 9% and 4% of the variance in these outcomes, respectively. **Conclusion:** Our results suggest that the potential importance of trust calibration warrants further examination. Moderators may exist. **Application:** Users who were better able to perform the task unaided were better able to identify and correct aid failure, suggesting that user task training and expertise may benefit human–automation performance.

- **Keywords:** rust, automation, awareness, performance, error

BIOMECHANICS, ANTHROPOMETRY, WORK PHYSIOLOGY

Angela C. Macedo, André V. Morais, Henriqueta F. Martins, João C. Martins, Silvina M. Pais, and Olga S. Mayan. *Match Between Classroom Dimensions and Students' Anthropometry: Re-Equipment According to European Educational Furniture Standard. S. 48-60.*

Objective: The aim of this study was to investigate mismatch between students and classroom furniture dimensions and evaluate the improvement in implementing the European furniture standard. **Background:** In Portugal, school furniture does not meet any national ergonomic criteria, so it cannot fit students' anthropometric measures. **Method:** A total of 893 students belonging to third (7th through 9th grades) and secondary (10th through 12th grades) cycles participated in the study. Anthropometric measurements of the students were gathered in several physical education classes. The furniture dimensions were measured for two models of tables and seats. Several two-way equations for match criteria based on published studies were applied to data. **Results:** The percentage of students who match with classroom furniture dimensions is low (24% and 44% between table and students, 4% and 9% between seat and students at 7th and 12th grades, respectively). Table is high for the third cycle, seat is high for both cycles, and seat depth fits well to students. No significant relationship was found between ergonomic mismatch and prevalence of pain. **Conclusion:** For each cycle, at least two different sizes indicated in the European standard should be available to students, considering the large variability in body dimensions within each cycle. The match criteria used gives a large percentage of students without pain in a mismatch situation. **Application:** Future measures applying to secondary schools should revise the decision of selecting a single size of classroom furniture and improve the implementation of the European standard. New criteria for ergonomic mismatch are needed that more closely model the responses about discomfort/pain.

- **Keywords:** ergonomic, school, adolescents, furniture, mismatch, discomfort

COGNITION

Nadine Moacdieh and Nadine Sarter. *Display Clutter : A Review of Definitions and Measurement Techniques. S. 61-100.*

Objective: We aimed to synthesize the literature on display clutter by reviewing definitions and measurement techniques and to develop a comprehensive, ergonomics-oriented perspective on clutter. We provide guidance for the selection of measurement approaches that can capture the various aspects and effects of clutter on visual search in particular. **Background:** There is agreement that clutter may represent a significant problem to operators. The challenge is to determine the ideal middle ground between excessive data and insufficient information. However, definitions of clutter vary widely, which explains the range of measurement approaches, including image-processing algorithms, performance evaluation, subjective evaluation, and eye tracking. It is important to understand the affordances of each technique and provide guidance for their use. **Method:** We provide a systematic review of clutter definitions and develop a performance-oriented perspective for ergonomics research. Next, we present a critical overview of clutter measurement approaches. The benefits and limitations of each technique are detailed, and recommendations for best practice are provided. **Results:** From an ergonomics perspective, clutter matters to the extent that it affects performance, particularly, visual search. A combination of measurement techniques can be employed in order to assess the performance costs stemming from the multiple aspects of clutter. **Conclusion:** Display clutter is a multifaceted construct that is a problem when it results in performance and attentional costs. The assessment of these costs is critical and requires the use of appropriate and complementary techniques. **Application:** It is important that the performance costs of clutter are detected reliably to be able to better support attention management.

- **Keywords:** display clutter, visual search, image processing, eye tracking

Morten Hertzum and Kristin Due Holmegaard. *Thinking Aloud Influences Perceived Time*. S. 101-109.

Objective: We investigate whether thinking aloud influences perceived time. **Background:** Thinking aloud is widely used in usability evaluation, yet it is debated whether thinking aloud influences thought and behavior. If thinking aloud is restricted to the verbalization of information to which a person is already attending, there is evidence that thinking aloud does not influence thought and behavior. **Method:** In an experiment, 16 thinking-aloud participants and 16 control participants solved a code-breaking task 24 times each. Participants estimated task duration. The 24 trials involved two levels of time constraint (timed, untimed) and resulted in two levels of success (solved, unsolved). **Results:** The ratio of perceived time to clock time was lower for thinking-aloud than control participants. Participants overestimated time by an average of 47% (thinking aloud) and 94% (control). The effect of thinking aloud on time perception also held separately for timed, untimed, solved, and unsolved trials. **Conclusion:** Thinking aloud (verbalization at Levels 1 and 2) influences perceived time. Possible explanations of this effect include that thinking aloud may require attention, cause a processing shift that overshadows the perception of time, or increase mental workload. **Application:** For usability evaluation, this study implies that time estimates made while thinking aloud cannot be compared with time estimates made while not thinking aloud, that ratings of systems experienced while thinking aloud may be inaccurate (because the experience of time influences other experiences), and that it may therefore be considered to replace concurrent thinking aloud with retrospective thinking aloud when evaluations involve time estimation.

- **Keywords:** verbalization, thinking aloud, perceived time, usability evaluation, attention

DISPLAYS AND CONTROLS

Shanqing Yin, Christopher D. Wickens, Martin Helander, and Jason C. Laberge. *Predictive Displays for a Process-Control Schematic Interface*. S. 110-124.

Objective: Our objective was to examine the extent to which increasing precision of predictive (rate of change) information in process control will improve performance on a simulated process-control task. **Background:** Predictive displays have been found to be useful in process control (as well as aviation and maritime industries). However, authors of prior research have not examined the extent to which predictive value is increased by increasing predictor resolution, nor has such research tied potential improvements to changes in process control strategy. **Method:** Fifty nonprofessional participants each controlled a simulated chemical mixture process (honey mixer simulation) that simulated the operations found in process control. Participants in each of five groups controlled with either no predictor or a predictor ranging in the resolution of prediction of the process. **Results:** Increasing detail resolution generally increased the benefit of prediction over the control condition although not monotonically so. The best overall performance, combining quality and predictive ability, was obtained by the display of intermediate resolution. The two displays with the lowest resolution were clearly inferior. **Conclusion:** Predictors with higher resolution are of value but may trade off enhanced sensitivity to variable change (lower-resolution discrete state predictor) with smoother control action (higher-resolution continuous predictors). **Application:** The research provides guidelines to the process-control industry regarding displays that can most improve operator performance.

- **Keywords:** visual, pictorial, object displays, process control, situation awareness, prediction, information visualization

NEUROERGONOMICS

Gerald Matthews, Lauren E. Reinerman-Jones, Daniel J. Barber, and Julian Abich IV. *The Psychometrics of Mental Workload: Multiple Measures Are Sensitive but Divergent.* S 125-143.

Objective: A study was run to test the sensitivity of multiple workload indices to the differing cognitive demands of four military monitoring task scenarios and to investigate relationships between indices. **Background:** Various psychophysiological indices of mental workload exhibit sensitivity to task factors. However, the psychometric properties of multiple indices, including the extent to which they intercorrelate, have not been adequately investigated. **Method:** One hundred fifty participants performed in four task scenarios based on a simulation of unmanned ground vehicle operation. Scenarios required threat detection and/or change detection. Both single- and dual-task scenarios were used. Workload metrics for each scenario were derived from the electroencephalogram (EEG), electrocardiogram, transcranial Doppler sonography, functional near infrared, and eye tracking. Subjective workload was also assessed. **Results:** Several metrics showed sensitivity to the differing demands of the four scenarios. Eye fixation duration and the Task Load Index metric derived from EEG were diagnostic of single-versus dual-task performance. Several other metrics differentiated the two single tasks but were less effective in differentiating single- from dual-task performance. Psychometric analyses confirmed the reliability of individual metrics but failed to identify any general workload factor. An analysis of difference scores between low- and high-workload conditions suggested an effort factor defined by heart rate variability and frontal cortex oxygenation. **Conclusions:** General workload is not well defined psychometrically, although various individual metrics may satisfy conventional criteria for workload assessment. **Application:** Practitioners should exercise caution in using multiple metrics that may not correspond well, especially at the level of the individual operator.

- **Keywords:** mental workload, dual-task performance, psychometrics, psychophysiology, neuroergonomics

SIMULATION AND VIRTUAL REALITY

Sergio Casas, Inmaculada Coma, José Vicente Riera, and Marcos Fernández. *Motion-Cuing Algorithms: Characterization of Users' Perception.* S. 144-162.

Objective: The aim of this study was to characterize the human response to motion-cuing algorithms (MCAs) by comparing users' perception to several proposed objective indicators. **Background:** Other researchers have proposed several MCAs, but few improvements have been achieved lately. One of the reasons for this lack of progress is that fair comparisons between different algorithms are hard to achieve, for their evaluation needs to be performed with humans and the tuning process is slow. **Method:** This characterization is performed by means of a comparison of the subjective perception of vehicle simulation users (90 participants) against several proposed objective indicators that try to measure MCA performance. Two motion platforms (3 and 6 degrees of freedom [DoF]) and two vehicle simulators (a driving simulator and a speedboat simulator) were tested using the classical washout algorithm, considered to be the main reference in MCA literature. **Results:** Results show that users are more sensitive to correlation and delay with respect to the expected motion rather than its magnitude and that specific force is more of a factor than angular speed in the driving

simulator. The opposite happens in the speedboat simulator. **Conclusions:** Human drivers' reaction to MCA is mainly characterized by the normalized Pearson correlation between output and input signals of the algorithm. This finding validates the main MCA strategy that consists of downscaling the signals and slightly distorting their frequency spectrum. The 6-DoF simulator is perceived as a modest improvement of the 3-DoF platform. **Applications:** These results set the basis for future automatic tuning, evaluation, and comparison of MCA in motion platforms.

- **Keywords:** motion perception, human factors, vehicle simulators

TEAMS AND GROUPS

Andrew M. Naber, Jennifer N. McDonald, Olabisi A. Asenuga, and Winfred Arthur, Jr. *Team Members' Interaction Anxiety and Team-Training Effectiveness : A Catastrophic Relationship?* S. 163-176.

Objective: In the present study, we examined the relationship between team members' interaction anxiety and team-training effectiveness. **Background:** Training in the context of teams can be focused on either individual or team outcomes. Relatedly, the individual differences of team members can hinder or facilitate the effectiveness of training for both individuals and the team as a collective. Interaction anxiety is an understudied individual difference that has been shown to be negatively related to training effectiveness in individual contexts. However, its effects in team-training contexts are yet to be investigated. **Method:** A sample of 492 students in 123 four-person teams was trained to operate a complex, computer-based team task. **Results:** Interaction anxiety negatively related to team cohesion and team-training effectiveness. A cusp catastrophe model fit the data and showed that teams with more than one high-interaction-anxiety member were negatively affected. **Conclusion:** Interaction anxiety inhibits the social activities of team training, in turn reducing team-training effectiveness when there is more than one high-interaction-anxiety individual on the training team. **Application:** These results highlight the importance of examining interaction anxiety as a training team compositional variable that may inhibit behaviors and team processes necessary to capitalize on the positive social activities on which team training depends since the interaction anxiety composition of training teams may serve as an important boundary condition on the effectiveness team-training interventions.

- **Keywords:** interaction anxiety, team training, training effectiveness, catastrophe theory, cusp catastrophe model, teams, training

TRAINING, EDUCATION, INSTRUCTIONAL SYSTEMS

Nadine Rauh, Thomas Franke, and Josef F. Krems. *Understanding the Impact of Electric Vehicle Driving Experience on Range Anxiety.* S. 177-187.

Objective: The objective of the present research was to increase understanding of the phenomenon of range anxiety and to determine the degree to which practical experience with battery electric vehicles (BEVs) reduces different levels of range anxiety. **Background:** Limited range is a challenge for BEV users. A frequently discussed phenomenon in this context is range anxiety. There is some evidence suggesting that range anxiety might be a problem only for inexperienced BEV drivers and, therefore, might decrease with practical experience. **Method:** We compared 12 motorists with high BEV driving experience ($M = 60,500$ km) with 12 motorists who had never driven a BEV before. The test drive was designed to lead to a critical range situation (remaining range < trip length). We examined range appraisal and range stress (i.e., range anxiety) on different levels (cognitive, emotional, and behavioral). **Results:** Experienced BEV drivers

exhibited less negative range appraisal and range anxiety than inexperienced BEV drivers, revealing significant, strong effects for all but one variable. **Conclusion:** Hence, BEV driving experience (defined as absolute kilometers driven with a BEV) seems to be one important variable that predicts less range anxiety. **Application:** In order to reduce range anxiety in BEV drivers even when there is a critical range situation, it is important to increase efficiency and effectiveness of the learning process.

- **Keywords:** range appraisal, range stress, field study, user behavior