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Attentional Processes

Florian Weber, Carola Haering, and Roland Thomaschke. *Improving the Human–Computer Dialogue With Increased Temporal Predictability.* S. 881-892.

Objective: An experiment was conducted to investigate the impacts of length and variability of system response time (SRT) on user behavior and user experience (UX) in sequential computing tasks. **Background:** Length is widely considered to be the most important aspect of SRTs in human–computer interaction. Research on temporal attention shows that humans adjust to temporal structures and that performance substantially improves with temporal predictability. **Method:** Participants performed a sequential task with simulated office software. Duration and variability, that is, the number of different SRTs, was manipulated. Lower variability came at the expense of on average higher durations. User response times, task execution times, and failure rates were measured to assess user performance. UX was measured with a questionnaire. **Results:** A reduction in variability improved user performance significantly. Whereas task load and failure rates remained constant, responses were significantly faster. Although a reduction in variability came along with, on average, increased SRTs, no difference in UX was found. **Conclusion:** Considering SRT variability when designing software can yield considerable performance benefits for the users. Although reduced variability comes at the expense of overall longer SRTs, the interface is not subjectively evaluated to be less satisfactory or demanding. Time design should aim not only at reducing average SRT length but also at finding the optimum balance of length and variability. **Application:** Our findings can easily be applied in any user interface for sequential tasks. User performance can be improved without loss of satisfaction by selectively prolonging particular SRTs to reduce variability.

- **Keywords:** system response times; temporal variability; temporal attention; subjective task load; waiting times; human–computer interaction; user behavior; user experience

Biomechanics, Anthropometry, Work Physiology

Haluk Ay, Carolyn M. Sommerich, and Anthony F. Luscher. *Linear Modeling of Human Hand-Arm Dynamics Relevant to Right-Angle Torque Tool Interaction.* S. 893-910.

Objective: A new protocol was evaluated for identification of stiffness, mass, and damping parameters employing a linear model for human hand-arm dynamics relevant to right-angle torque tool use. **Background:** Powered torque tools are widely used to

tighten fasteners in manufacturing industries. While these tools increase accuracy and efficiency of tightening processes, operators are repetitively exposed to impulsive forces, posing risk of upper extremity musculoskeletal injury. **Methods:** A novel testing apparatus was developed that closely mimics biomechanical exposure in torque tool operation. Forty experienced torque tool operators were tested with the apparatus to determine model parameters and validate the protocol for physical capacity assessment. **Results:** A second-order hand-arm model with parameters extracted in the time domain met model accuracy criterion of 5% for time-to-peak displacement error in 93% of trials (vs. 75% for frequency domain). Average time-to-peak handle displacement and relative peak handle force errors were 0.69 ms and 0.21%, respectively. Model parameters were significantly affected by gender and working posture. **Conclusion:** Protocol and numerical calculation procedures provide an alternative method for assessing mechanical parameters relevant to right-angle torque tool use. The protocol more closely resembles tool use, and calculation procedures demonstrate better performance of parameter extraction using time domain system identification methods versus frequency domain. **Application:** Potential future applications include parameter identification for in situ torque tool operation and equipment development for human hand-arm dynamics simulation under impulsive forces that could be used for assessing torque tools based on factors relevant to operator health (handle dynamics and hand-arm reaction force).

- **Keywords:** human hand-arm biomechanice; upper extremity dynamic modeling; impulsive forces in fastening operation; torque tool ergonomics; work-related musculoskeletal disorders

Marina Ciccarelli, Leon Straker, Svend Erik Mathiassen, and Clare Pollock. *Variation in Muscle Activity Among Office Workers When Using Different Information Technologies at Work and Away From Work.* S. 911-923.

Objective: To determine differences in muscle activity amplitudes and variation of amplitudes when using different information and communication technologies (ICT). **Background:** Office workers use different ICT to perform tasks. Upper body musculoskeletal complaints are frequently reported by this occupational group. Increased muscle activity and insufficient variation are potential risk factors for musculoskeletal complaints. **Method:** Muscle activity of right and left upper trapezius and right wrist extensor muscle bundle (extensor carpi radialis longus and brevis) of 24 office workers (performing their usual tasks requiring different ICT at work and away from work) were measured continuously over 10 to 12 hours. Muscle activity variation was quantified using two indices, amplitude probability distribution function and exposure variation analysis. **Results:** There was a trend for electronics-based *New ICT* tasks to involve less electromyography (EMG) variation than paper-based *Old ICT* tasks. Performing*Combined ICT* tasks (i.e., using paper- and electronics-based ICT simultaneously) resulted in the highest muscle activity levels and least variation; however, these Combined ICT tasks were rarely performed. Tasks involving no ICT (*Non-ICT*) had the greatest muscle activity variation. **Conclusion:** Office workers in this study used various ICT during tasks at work and away from work. The high EMG amplitudes and low variation observed when using Combined ICT may present the greatest risk for musculoskeletal complaints, and use of Combined ICT by workers should be kept low in office work. Breaking up combined, New, and Old ICT tasks, for example, by interspersing highly variable Non-ICT tasks into office workers' daily tasks, could increase overall muscle activity variation and reduce risk for musculoskeletal complaints.

- **Keywords:** long duration; electromyography; exposure variation; ICT

Cognitive Processes

Marcin Zajenkowski. *Energetic Arousal and Language: Predictions From the Computational Theory of Quantifiers Processing.* S. 924-934.

Objective: The author examines the relationship between energetic arousal (EA) and the processing of sentences containing natural-language quantifiers. **Background:** Previous studies and theories have shown that energy may differentially affect various cognitive functions. Recent investigations devoted to quantifiers strongly support the theory that various types of quantifiers involve different cognitive functions in the sentence–picture verification task. **Method:** In the present study, 201 students were presented with a sentence–picture verification task consisting of simple propositions containing a quantifier that referred to the color of a car on display. Color pictures of cars accompanied the propositions. In addition, the level of participants' EA was measured before and after the verification task. **Results:** It was found that EA and performance on proportional quantifiers (e.g., "More than half of the cars are red") are in an inverted *U*-shaped relationship. **Conclusion:** This result may be explained by the fact that proportional sentences engage working memory to a high degree, and previous models of EA–cognition associations have been based on the assumption that tasks that require parallel attentional and memory processes are best performed when energy is moderate. **Application:** The research described in the present article has several applications, as it shows the optimal human conditions for verbal comprehension. For instance, it may be important in workplace design to control the level of arousal experienced by office staff when work is mostly related to the processing of complex texts. Energy level may be influenced by many factors, such as noise, time of day, or thermal conditions.

- **Keywords:** energetic arousal; language; quantifiers; working memory; attention

Communication Systéme

Caitlan A. Rizzardo and Herbert A. Colle. *Dual-Coded Advisory Turn Indicators for GPS Navigational Guidance of Surface Vehicles: Effects of Map Orientation.* S. 935-945.

Objective: The aim of the study was to compare the decision times for left–right decisions for a dual-coded advisory turn indicator and a typical spatial-only turn indicator in a GPS navigational map display. **Background:** Track-up maps are useful for turn decision making but do not facilitate configural knowledge acquisition of an area. North-up maps present a stable orientation for this type of learning, but typical implementations of north-up map displays lead to misaligned and confusing turn information. We compared a typical spatial-only indicator with a dual-coded spatial-plus-verbal indicator, systematically manipulating vehicle heading and measuring reaction time. The new display, the Dual-Coded Advisory Turn Indicator for Maps (DATIM), was based on an assumption of the advantages of concurrent verbal and spatial processing of advisory turn indicators in map displays. **Method:** The experimental design was a 2 × 2 × 24 mixed design with indicator type as a between-subjects factor and turn direction (left, right) and 24 heading angles (15° intervals) as repeated-measures factors. Participants made turn decisions while viewing static displays of intersections at variably rotated headings. **Results:** Reaction time for the DATIM display was consistently faster than the typical spatial-only indicator at all heading angles but especially at heading angles beyond ±45° (520-ms difference at 180°). **Conclusion:** The DATIM display produced faster turn decisions at all heading angles. **Application:** DATIM displays could allow north-up maps to be used for turn-by-turn decision making in GPS navigational systems. Drivers could have the advantages of both the stable orientation to facilitate planning and the easy turn-by-turn guidance. Limitations are discussed.

- **Keywords:** driving; north-up and track-up maps; verbal and spatial cosiny; stimulus-response kompatibility; you-are-here maps; mental rotation; configural spatial knowledge

Displays and Controls

Anita Vuckovic, Penelope Sanderson, Andrew Neal, Stephen Gaukrodger, and B. L. William Wong. *Relative Position Vectors: An Alternative Approach to Conflict Detection in Air Traffic Kontrol.* S. 946-964.

Objective: We explore whether the visual presentation of relative position vectors (RPVs) improves conflict detection in conditions representing some aspects of future airspace concepts. **Background:** To help air traffic controllers manage increasing traffic, new tools and systems can automate more cognitively demanding processes, such as conflict detection. However, some studies reveal adverse effects of such tools, such as reduced situation awareness and increased workload. New displays are needed that help air traffic controllers handle increasing traffic loads. **Method:** A new display tool based on the display of RPVs, the Multi-Conflict Display (MCD), is evaluated in a series of simulated conflict detection tasks. The conflict detection performance of air traffic controllers with the MCD plus a conventional plan-view radar display is compared with their performance with a conventional plan-view radar display alone. **Results:** Performance with the MCD plus radar was better than with radar alone in complex scenarios requiring controllers to find all actual or potential conflicts, especially when the number of aircraft on the screen was large. However performance with radar alone was better for static scenarios in which conflicts for a target aircraft, or target pair of aircraft, were the focus. **Conclusion:** Complementing the conventional plan-view display with an RPV display may help controllers detect conflicts more accurately with extremely high aircraft counts. **Applications:** We provide an initial proof of concept that RPVs may be useful for supporting conflict detection in situations that are partially representative of conditions in which controllers will be working in the future.

- **Keywords:** air traffic management; decision support; detection performance; visual display design; Multi-Conflict Display; radar display

Psychological States and Neuroergonomics

James C. Christensen and Justin R. Estepp. *Coadaptive Aiding and Automation Enhance Operator Performance.* S. 965-975.

Objective: In this work, we expand on the theory of adaptive aiding by measuring the effectiveness of coadaptive aiding, wherein we explicitly allow for both system and user to adapt to each other. **Background:** Adaptive aiding driven by psycho- physiological monitoring has been demonstrated to be a highly effective means of controlling task allocation and system functioning. Psychophysiological monitoring is uniquely well suited for coadaptation, as malleable brain activity may be used as a continuous input to the adaptive system. **Method:** To establish the efficacy of the coadaptive system, physiological activation of adaptation was directly compared with manual activation or no activation of the same automation and cuing systems. We used interface adaptations and automation that are plausible for real-world operations, presented in the context of a multi–remotely piloted aircraft control simulation. Each participant completed 3 days of testing during 1 week. Performance was assessed via proportion of targets successfully engaged. **Results:** In the first 2 days of testing, there were no significant differences in performance between the conditions. However, in the third session, physiological adaptation produced the highest performance. **Conclusion:** By extending the data collection across multiple days, we offered enough time and repeated experience for user

adaptation as well as online system adaptation, hence demonstrating coadaptive aiding. **Application:** The results of this work may be employed to implement more effective adaptive works-tations in a variety of work domains.

- **Keywords:** neuroergonomics; mental workload; function allocation; human/computer interaction

Jia Han, Gordon Waddington, Judith Anson, and Roger Adams. *Does Elastic Resistance Affect Finger Pinch Discrimination?* S. 976-984.

Objective: The sensitivity of pinch movement discrimination between the thumb and index finger was assessed with and without elastic resistance. **Background:** Researchers have examined the effect of elastic resistance on control of single upper-limb movements; however, no one has explored how elastic resistance affects proprioceptive acuity when using two digits simultaneously in a coordinated movement. **Method:** For this study, 16 right-handed, healthy young adults undertook an active finger pinch movement discrimination test for the right and left hands, with and without elastic resistance. We manipulated pinch movement distance by varying the size of the object that created the physical stop to end the pinch action. **Results:** Adding elastic resistance from a spring to the thumb–index finger pinch task did not affect accuracy of pinch discrimination measured as either the just noticeable difference, $F(1, 15) = 1.78$, $p = .20$, or area under the curve, $F(1, 15) = 0.07$, $p = .80$. **Conclusion:** Having elastic resistance to generate lever return in pincers, tweezers, and surgical equipment or in virtual instruments is unlikely to affect pinch movement discrimination. **Application:** Elastic resistance did not affect finger pinch discrimination in the present study, suggesting that return tension on equipment lever arms has a practical but not perceptual function. An active finger pinch movement discrimination task, with or without elastic resistance, could be used for hand proprioceptive training and as a screening tool to identify those with aptitude or decrements in fine finger movement control.

- **Keywords:** movement discrimination; proprioception; perception; movement kontrol; hand; fatigue; surgical equipment design

Psychomotor Processes

Hans Gerisch, Gerhard Staude, Werner Wolf, and Gerhard Bauch. *A Three-Component Model of the Control Error in Manual Tracking of Continuous Random Signále.* S. 985-1000.

Objective: The performance of human operators acting within closed-loop control systems is investigated in a classic tracking task. The dependence of the control error (tracking error) on the parameters display gain, k_{display}, and input signal frequency bandwidth, f_q , which alter task difficulty and presumably the control delay, is studied with the aim of functionally specifying it via a model. **Background:** The human operator as an element of a cascaded human–machine control system (e.g., car driving or piloting an airplane) codetermines the overall system performance. Control performance of humans in continuous tracking has been described in earlier studies. **Method:** Using a handheld joystick, 10 participants tracked continuous random input signals. The parameters f_q and k_{display} were altered between experiments. **Results:** Increased task difficulty promoted lengthened control delay and, consequently, increased control error. Tracking performance degraded profoundly with target deflection components above 1 Hz, confirming earlier reports. **Conclusion:** The control error is composed of a delay-induced component, a demand-based component, and a novel component: a human tracking limit. Accordingly, a new model that allows concepts of the observed control error to be split into these three components is suggested. **Application:** To achieve optimal performance in control systems that include a human operator (e.g., vehicles, remote controlled rovers, crane control), (a) tasks should be kept as simple as possible

to achieve shortest control delays, and (b) task components requiring higher-frequency (>1 Hz) tracking actions should be avoided or automated by technical systems.

- **Keywords:** tracking performance; human operator; error model

Surface Transportation Systems

Joel M. Cooper, Nathan Medeiros-Ward, and David L. Strayer. *The Impact of Eye Movements and Cognitive Workload on Lateral Position Variability in Driving.* S. 1001-1014.

Objective: The objective of this work was to understand the relationship between eye movements and cognitive workload in maintaining lane position while driving. **Background:** Recent findings in driving research have found that, paradoxically, increases in cognitive workload decrease lateral position variability. If people drive where they look and drivers look more centrally with increased cognitive workload, then one could explain the decreases in lateral position variability as a result of changes in lateral eye movements. In contrast, it is also possible that cognitive workload brings about these patterns regardless of changes in eye movements. **Method:** We conducted three experiments involving a fixed-base driving simulator to independently manipulate eye movements and cognitive workload. **Results:** Results indicated that eye movements played a modest role in lateral position variability, whereas cognitive workload played a much more substantial role. **Conclusions:** Increases in cognitive workload decrease lane position variability independently from eye movements. These findings are discussed in terms of hierarchical control theory. **Applications:** These findings could potentially be used to identify periods of high cognitive workload during driving.

- **Keywords:** eye movements; cognitive workload; driving behavior; lane maintenance; hierarchical control theory