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**Special Section: 2012 Human Factors Prize for Excellence
in Human Factors/Ergonomics Research: The Science
Behind Product Design**



Special Section: 2012 Human Factors Prize Winner and Finalists

Hongwei Hsiao. *Anthropometric Procedures for Protective Equipment Sizing and Design*. S. 6-35.

Objectives: This article presented four anthropometric theories (univariate, bivariate/probability distribution, multivariate, and shape-based methods) for protective equipment design decisions. **Background:** While the significance of anthropometric information for product design is well recognized, designers continue to face challenges in selecting efficient anthropometric data processing methods and translating the acquired information into effective product designs. **Methods:** For this study, 100 farm tractor operators, 3,718 respirator users, 951 firefighters, and 816 civilian workers participated in four studies on the design of tractor roll-over protective structures (ROPS), respirator test panels, fire truck cabs, and fall-arrest harnesses, respectively. Their anthropometry and participant-equipment interfaces were evaluated. **Results:** Study 1 showed a need to extend the 90-cm vertical clearance for tractor ROPS in the current industrial standards to 98.3 to 101.3 cm. Study 2 indicated that current respirator test panel would have excluded 10% of the male firefighter population; a systematic adjustment to the boundaries of test panel cells was suggested. Study 3 provided 24 principal component analysis-based firefighter body models to facilitate fire truck cab design. Study 4 developed an improved gender-based fall-arrest harness sizing scheme to supplant the current unisex system. **Conclusions:** This article presented four anthropometric approaches and a six-step design paradigm for ROPS, respirator test panel, fire truck cab, and fall-arrest harness applications, which demonstrated anthropometric theories and practices for defining protective equipment fit and sizing schemes. **Applications:** The study provided a basis for equipment designers, standards writers, and industry manufacturers to advance anthropometric applications for product design and improve product efficacy.

- **Keywords: tractor, respirator, fire truck, harness, shape, size**

Susan E. Kotowski, Kermit G. Davis, Neal Wiggermann, and Rachel Williamson. *Quantification of Patient Migration in Bed: Catalyst to Improve Hospital Bed Design to Reduce Shear and Friction Forces and Nurses' Injuries*. S. 36-47.

Objective: The study objective was to quantify the movement of hospital bed occupants relative to the bed in typical bed articulations. **Background:** Movement of a patient in bed results in two common adverse events: (a) increase in shear and friction forces between the patient and bed, which are extrinsic pressure ulcer risk factors, and (b) musculoskeletal injuries to nurses, resulting from repositioning patients who have migrated down in bed. **Method:** The study involved 12 participants who lay supine in three hospital beds, which were articulated to common positions. Body movement relative to the bed was quantified with the use of motion capture. Cumulative movement, net displacement, and torso compression (shoulder to trochanter distance) were calculated for different bed types and bed movements. **Results:** Bed design and bed movement had a significant effect on most of the dependent variables. Bed design (e.g., type) influenced cumulative movement by up to 115%, net displacement by up to 70%, and torso compression by about 20%. Bed movement (e.g., knee elevation) reduced cumulative migration by up to 35%. **Conclusion:** The quantification of patient migration provides a metric for evaluating the interaction between body and bed surfaces. Overall, the measures were sensitive to design changes in bed frames, bed articulations, and mattress inflation. **Application:** Documentation of the cumulative movement, net displacement, and torso compression provides hospital bed designers quantifiable measures for reducing migration and potentially shear and friction forces when designing bed frames, bed articulations, and mattresses. Optimization of these metrics may ultimately have an impact on patient and caregiver health.

- **Keywords:** motion capture, bed articulation, skin tears, pressure ulcers, repositioning

Edward W. Otten, Keith S. Karn, and Kelley S. Parsons. *Defining Thumb Reach Envelopes for Handheld Devices.* S. 48-60.

Objective: Our objective is to provide thumb reach envelopes to help guide the placement of controls on handheld devices and to provide useful methods to gather and analyze thumb reach data. **Background:** With the proliferation of handheld, interactive devices, such as cameras, mobile phones, game systems, and remote controls, human factors professionals involved in designing these products need data to help guide the placement of controls. Previous studies have not provided adequate two-dimensional thumb reach envelopes for the primary control surfaces of handheld devices. **Method:** A total of 90 participants in three groups (adolescent females, young mothers, and young fathers) placed representations of primary controls in preferred locations on a device model and "painted" their individual reach envelopes on a touch-screen device running a paint application. **Results:** We present two-dimensional thumb reach envelopes on the primary control surface for handheld devices. The primary reach zone for adolescent females is slightly larger and more circular than that of the adults. The preferred location for controls matches the primary thumb reach zones fairly well. **Conclusion:** The reach envelopes presented are the first of their kind and are likely to be useful to human factors professionals. The method used to obtain the data may also be useful. **Application:** The thumb reach envelopes should be applicable to the design of many handheld, interactive devices with dimensions similar to the models used in this study. The method presented allows design teams to collect and analyze thumb reach data quickly and inexpensively for different target user populations or product dimensions.

- **Keywords:** anthropometry, hand, thumb, control placement, control location, control design, interface design, camera, phone, handheld

Sarah Wiseman, Anna L. Cox, and Duncan P. Brumby. *Designing Devices With the Task in Mind: Which Numbers Are Really Used in Hospitals?* S. 61-74.

Objective: We studied the patterns of digits and numbers used when programming infusion pumps with the aim of informing the design of number entry interfaces. **Background:** Number entry systems on medical devices are designed with little thought given to the numbers that will be entered. In other fields, text and number entry interfaces are designed specifically for the task that they will be used for. Doing so allows for faster and more accurate interaction. **Method:** In Study 1, logs were taken from infusion pumps used in a hospital. Information about the numbers being typed was extracted. For Study 2, three common number entry interfaces were evaluated in light of these results to determine which were best suited to the task of programming infusions. **Results:** There are clear patterns in the numbers being used in hospitals. The digit 0 is used far more frequently than any other digit. The numbers 1,000, 100, and 50 are used in nearly half of all infusions. Study 2 demonstrates that interfaces are not optimized for entering such data. **Conclusion:** Changes could be made to the design of the number entry interface on infusion pumps, leading to a reduction in the number of key presses necessary to program a device. We offer a set of four heuristics to guide the design of number entry interfaces on infusion devices. **Application:** Improving the design of the number entry interface of medical devices, such as infusion pumps, would lead to improved efficiency and a reduction in the likelihood of errors.

- **Keywords:** number entry, digit distributions, medical devices, heuristic evaluation, interface design

Attentional Processes

David J. Bryant and David G. Smith. *Impact of Blue Force Tracking on Combat Identification Judgments.* S. 75-89.

Objective: We examined the effectiveness of blue force tracking (BFT) decision support for dismounted infantry soldiers. **Background:** Technologies to support combat identification (CID) are rapidly evolving and may be deployable to dismounted soldiers in the future. BFT systems are designed to mitigate the risk of fratricide by supplying positional information regarding friendly units to enhance situation awareness. **Method:** Participants played the role of a dismounted infantry soldier in a first-person perspective gaming environment and made engagement decisions for a series of simulated targets, half of which were enemies and half of which were friends. **Results:** Participants performed better overall when they were able to use a BFT system than when they performed the task without assistance. When a 10-s latency was added to the updating of position information in the BFT, participants made significantly more false alarms (engaged a friendly target) regardless of whether they knew about the latency. **Conclusion:** The results indicate the promise of a personal BFT device to reduce the likelihood of fratricide by dismounted infantry soldiers. The results, however, also indicate that the effectiveness of such a device can be dramatically reduced when it does not provide real-time data. **Application:** Potential applications of this research include development of performance standards for BFT devices and assessment of decision support for dismounted soldiers.

- **Keywords:** situation awareness, decision making, classification, blue force tracking, personal decision aid

Automation, Expert Systems

Thomas Loveday, Mark W. Wiggins, Jemma M. Harris, David O'Hare, and Neil Smith. *An Objective Approach to Identifying Diagnostic Expertise Among Power System Controllers.* S. 90-107.

Objective: The present study investigated whether performance across a range of cue-based cognitive tasks differentiated the diagnostic performance of power control

operators into three distinct groups, characteristic of novice, competence, and expertise. **Background:** Despite its increasing importance in the contemporary workplace, there is little understanding of the cognitive processes that distinguish novice, competent, and expert performance in the context of remote diagnosis. However, recent evidence suggests that cue acquisition and utilization may represent a mechanism by which the transition from novice to expertise occurs. **Method:** The study involved the application of four distinct cue-based tasks within the context of power system control. A total of 65 controllers, encompassing a range of industry experience, completed the tasks as part of an in-service training program. **Results:** Using a cluster analysis, it was possible to extract three distinct groups of operators on the basis of their performance in the cue-based tasks, and these groups corresponded to differences in diagnostic performance. **Conclusion:** The results indicate assessments of the capacity to extract and utilize cues were able to distinguish expert from competent practitioners in the context of power control. **Application:** Assessments of the capacity to extract and utilize cues may be used in the future to distinguish expert from nonexpert practitioners, particularly in the context of remote diagnosis.

- **Keywords:** cues, diagnostic performance, competent, expert, assessment

Biomechanics, Anthropometry, Work Physiology

Sean Gallagher and John R. Heberger. *Examining the Interaction of Force and Repetition on Musculoskeletal Disorder Risk: A Systematic Literature Review.* S. 108-124.

Objective: Our aims were (a) to perform a systematic literature review of epidemiological studies that examined the interaction of force and repetition with respect to musculoskeletal disorder (MSD) risk, (b) to assess the relationship of force and repetition in fatigue failure studies of musculoskeletal tissues, and (c) to synthesize these findings. **Background:** Many epidemiological studies have examined the effects of force and repetition on MSD risk; however, relatively few have examined the interaction between these risk factors. **Method:** In a literature search, we identified 12 studies that allowed evaluation of a force-repetition interaction with respect to MSD risk. Identified studies were subjected to a methodological quality assessment and critical review. We evaluated laboratory studies of fatigue failure to examine tissue failure responses to force and repetition. **Results:** Of the 12 epidemiological studies that tested a Force × Repetition interaction, 10 reported evidence of interaction. Based on these results, the suggestion is made that force and repetition may be interdependent in terms of their influence on MSD risk. Fatigue failure studies of musculoskeletal tissues show a pattern of failure that mirrors the MSD risk observed in epidemiological studies. **Conclusions:** Evidence suggests that there may be interdependence between force and repetition with respect to MSD risk. Repetition seems to result in modest increases in risk for low-force tasks but rapid increases in risk for high-force tasks. This interaction may be representative of a fatigue failure process in affected tissues.

- **Keywords:** systematic review, force, repetition, musculoskeletal disorders, risk factors, fatigue failure, epidemiology

Cognitive Processes

Thomas Loveday, Mark W. Wiggins, Ben J. Searle, Marino Festa, and David Schell. *The Capability of Static and Dynamic Features to Distinguish Competent From Genuinely Expert Practitioners in Pediatric Diagnosis.* S. 125-137.

Children's Hospital at Westmead, Sydney, Australia Objective: The authors describe the development of a new, more objective method of distinguishing experienced competent nonexpert from expert practitioners within pediatric intensive care. **Background:** Expert performance involves the acquisition and use of refined feature-event associations (cues) in the operational environment. Competent nonexperts, although experienced, possess rudimentary cue associations in memory. Thus, they cannot respond as efficiently or as reliably as their expert counterparts, particularly when key diagnostic information is unavailable, such as that provided by dynamic cues. **Method:** This study involved the application of four distinct tasks in which the use of relevant cues could be expected to increase both the accuracy and the efficiency of diagnostic performance. These tasks included both static and dynamic stimuli that were varied systematically. A total of 50 experienced pediatric intensive staff took part in the study. **Results:** The sample clustered into two levels across the tasks: Participants who performed at a consistently high level throughout the four tasks were labeled experts, and participants who performed at a lower level throughout the tasks were labeled competent nonexperts. The groups differed in their responses to the diagnostic scenarios presented in two of the tasks and their ability to maintain performance in the absence of dynamic features. **Conclusion:** Experienced pediatricians can be decomposed into two groups on the basis of their capacity to acquire and use cues; these groups differ in their diagnostic accuracy and in their ability to maintain performance in the absence of dynamic features. **Application:** The tasks may be used to identify practitioners who are failing to acquire expertise at a rate consistent with their experience, position, or training. This information may be used to guide targeted training efforts.

- **Keywords:** cues, diagnostic performance, competence, novice, assessment

Communication Systems

Tanja Manser, Simon Foster, Rhona Flin, and Rona Patey. *Team Communication During Patient Handover From the Operating Room: More Than Facts and Figures.* S. 138-156.

Objective: This study was aimed at examining team communication during postoperative handover and its relationship to clinicians' self-ratings of handover quality. **Background:** Adverse events can often be traced back to inadequate communication during patient handover. Research and improvement efforts have mostly focused on the information transfer function of patient handover. However, the specific mechanisms between handover communication processes among teams of transferring and receiving clinicians and handover quality are poorly understood. **Method:** We conducted a prospective, cross-sectional observation study using a taxonomy for handover behaviors developed on the basis of established approaches for analyzing teamwork in health care. Immediately after the observation, transferring and receiving clinicians rated the quality of the handover using a structured tool for handover quality assessment. Handover communication during 117 handovers in three postoperative settings and its relationship to clinicians' self-ratings of handover quality were analyzed with the use of correlation analyses and analyses of variance. **Results:** We identified significantly different patterns of handover communication between clinical settings and across handover roles. Assessments provided during handover were related to higher ratings of handover quality overall and to all four dimensions of handover quality identified in this study. If assessment was lacking, we observed compensatory information seeking by the receiving team. **Conclusion:** Handover quality is more than the correct, complete transmission of patient information. Assessments, including predictions or anticipated problems, are critical to the quality of postoperative handover. **Application:** The identification of communication behaviors related to high-quality handovers is necessary to effectively support the design and evaluation of handover improvement efforts.

- **Keywords:** communication process, handover, observation study, team cognition, teamwork, patient safety, operating room, recovery room, anesthesia

Computer Systems

Bruce N. Walker, Jeffrey Lindsay, Amanda Nance, Yoko Nakano, Dianne K. Palladino, Tilman Dingler, and Myounghoon Jeon. *Spearcons (Speech-Based Earcons) Improve Navigation Performance in Advanced Auditory Menus*. S. 157-182.

Objective: The goal of this project is to evaluate a new auditory cue, which the authors call spearcons, in comparison to other auditory cues with the aim of improving auditory menu navigation. **Background:** With the shrinking displays of mobile devices and increasing technology use by visually impaired users, it becomes important to improve usability of non-graphical user interface (GUI) interfaces such as auditory menus. Using nonspeech sounds called auditory icons (i.e., representative real sounds of objects or events) or earcons (i.e., brief musical melody patterns) has been proposed to enhance menu navigation. To compensate for the weaknesses of traditional nonspeech auditory cues, the authors developed spearcons by speeding up a spoken phrase, even to the point where it is no longer recognized as speech. **Method:** The authors conducted five empirical experiments. In Experiments 1 and 2, they measured menu navigation efficiency and accuracy among cues. In Experiments 3 and 4, they evaluated learning rate of cues and speech itself. In Experiment 5, they assessed spearcon enhancements compared to plain TTS (text to speech: speak out written menu items) in a two-dimensional auditory menu. **Results:** Spearcons outperformed traditional and newer hybrid auditory cues in navigation efficiency, accuracy, and learning rate. Moreover, spearcons showed comparable learnability as normal speech and led to better performance than speech-only auditory cues in two-dimensional menu navigation. **Conclusion:** These results show that spearcons can be more effective than previous auditory cues in menu-based interfaces. **Application:** Spearcons have broadened the taxonomy of nonspeech auditory cues. Users can benefit from the application of spearcons in real devices.

- **Keywords:** auditory menus, spearcons, auditory icons, earcons

Displays and Controls

Nadia Ali and David Peebles. *The Effect of Gestalt Laws of Perceptual Organization on the Comprehension of Three-Variable Bar and Line Graphs*. S. 183-203.

Objective: We report three experiments investigating the ability of undergraduate college students to comprehend 2×2 "interaction" graphs from two-way factorial research designs. **Background:** Factorial research designs are an invaluable research tool widely used in all branches of the natural and social sciences, and the teaching of such designs lies at the core of many college curricula. Such data can be represented in bar or line graph form. Previous studies have shown, however, that people interpret these two graphical forms differently. **Method:** In Experiment 1, participants were required to interpret interaction data in either bar or line graphs while thinking aloud. Verbal protocol analysis revealed that line graph users were significantly more likely to misinterpret the data or fail to interpret the graph altogether. **Results:** The patterns of errors line graph users made were interpreted as arising from the operation of Gestalt principles of perceptual organization, and this interpretation was used to develop two modified versions of the line graph, which were then tested in two further experiments. One of the modifications resulted in a significant improvement in performance.

Conclusion: Results of the three experiments support the proposed explanation and demonstrate the effects (both positive and negative) of Gestalt principles of perceptual organization on graph comprehension. **Application:** We propose that our new design provides a more balanced representation of the data than the standard line graph for nonexpert users to comprehend the full range of relationships in two-way factorial research designs and may therefore be considered a more appropriate representation for use in educational and other nonexpert contexts.

- **Keywords:** graph comprehension, diagrammatic reasoning, verbal protocols

Macroergonomics and the Environment

Lia Buarque de Macedo Guimarães, Jose Luis Duarte Ribeiro, Tarcísio Abreu Saurin, and Paulo Ivo Homem de Bittencourt, Jr. *Circadian Rhythms as a Basis for Work Organization: A Study With Live Line Electricians.* S. 204-217.

Objective: With the assumption that circadian rhythms influence human performance, the work of live line electricians was reorganized and evaluated. The hypothesis was that in highly physical and attention-demanding work, the organization of tasks, according to the ideal period of day and day of week, should diminish stress and consequent work risks. **Background:** There are only a few studies reporting the work of electricians and even fewer approaching work organization. Moreover, these investigations often do not consider human physiological limitations and capabilities as well as task demands. **Method:** A new work system was proposed with consideration of (a) the circadian cycles and homeostatic processes; (b) the effect of heat, which is a zeitgeber (synchronizer) for the biological clocks; and (c) the degree of physical and mental demands of the different performed tasks, which was assessed on the basis of opinions of the electricians and physiological markers of stress that are controlled by circadian rhythms. The traditional and new systems were compared on the basis of two cognitive indices (the arrangement of matchsticks and the perception of a minute) and three physiological markers of mental-to-physical loads (heart frequency and the level of adrenaline and noradrenaline). **Results:** Both physical and mental loads were reduced in the new system. **Conclusion:** Work organization should include consideration of human circadian rhythms, mainly when stressful and high-risk tasks are involved. **Application:** The findings can be applied in any work design, but they are especially suited for highly demanding work carried out outdoors.

- **Keywords:** physical stress, mental stress, work scheduling, participative ergonomics

Surface Transportation Systems

Ian J. Reagan, James P. Bliss, Ron Van Houten, and Bryan W. Hilton. *The Effects of External Motivation and Real-Time Automated Feedback on Speeding Behavior in a Naturalistic Setting.* S. 218-230.

Objective: In this field experiment, the authors tested an alerting system and a monetary incentive system with the objective of reducing speeding more than 5 mph faster than the posted speed limit. **Background:** Speeding is a factor in a significant number of traffic fatalities. The systems tested in this project have been evaluated outside but not within the United States. These studies indicated that similar systems led to reductions in speeding. **Method:** For this study, eight vehicles were instrumented such that vehicle speed and speed limits were linked in real time. A total of 50 participants drove assigned vehicles for 4 weeks. Week 1 was a baseline period; during Week 2 or

Week 3, 40 participants experienced the alerting system that issued auditory and visual advisory signals when drivers exceeded the limit by 5 mph or more. Of these 40 individuals, 20 experienced the monetary incentive system during Weeks 2 and 3; Week 4 was a return-to-baseline period. A control group of 10 drivers experienced neither system during the study. **Results:** Results indicated that the incentive system resulted in significant reductions in driving faster than the posted limit, and the feedback system led to modest changes in speeding. In the condition in which drivers experienced the feedback and incentive, reductions in speeding were similar to those found during the incentive-only condition. **Conclusion:** The technology tested in this study has potential to benefit traffic safety by reducing the incidence of driving faster than the posted limit, which should lead to a reduction in speed-related crashes. **Application:** Insurers provide incentive-based discounts on premiums. Combining this technology with such a discount program may improve traffic safety significantly.

- **Keywords: accidents, safety, and human error, driver behavior, highway and vehicle design**

Training, Education, Instructional Systems

Scott I. Tannenbaum and Christopher P. Cerasoli. *Do Team and Individual Debriefs Enhance Performance? A Meta-Analysis.* S. 231-245.

Objective: Debriefs (or “after-action reviews”) are increasingly used in training and work environments as a means of learning from experience. We sought to unify a fragmented literature and assess the efficacy of debriefs with a quantitative review. **Background:** Used by the U.S. Army to improve performance for decades, and increasingly in medical, aviation, and other communities, debriefs systematize reflection, discussion, and goal setting to promote experiential learning. Unfortunately, research and theory on debriefing has been spread across diverse disciplines, so it has been difficult to definitively ascertain debriefing effectiveness and how to enhance its effectiveness. **Method:** We conducted an extensive quantitative meta-analysis across a diverse body of published and unpublished research on team- and individual-level debriefs. **Results:** Findings from 46 samples (N = 2,136) indicate that on average, debriefs improve effectiveness over a control group by approximately 25% (d = .67). Average effect sizes were similar for teams and individuals, across simulated and real settings, for within- or between-group control designs, and for medical and nonmedical samples. Meta-analytic methods revealed a bolstering effect of alignment and the potential impact of facilitation and structure. **Conclusion:** Organizations can improve individual and team performance by approximately 20% to 25% by using properly conducted debriefs. **Application:** Debriefs are a relatively inexpensive and quick intervention for enhancing performance. Our results lend support for continued and expanded use of debriefing in training and in situ. To gain maximum results, it is important to ensure alignment between participants, focus and intent, and level of measurement.

- **Keywords: experiential learning, teams, after-action review, team training, group dynamics, feedback, organizational learning, group performance**