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Elham A. Yousef, Kathleen M. Sutcliffe, Kathryn M. McDonald, David E. Newman-Toker. *Crossing Academic Boundaries for Diagnostic Safety: 10 Complex Challenges and Potential Solutions From Clinical Perspectives and High-Reliability Organizing Principles. S. 6–20.*

Objective: We apply the high-reliability organization (HRO) paradigm to the diagnostic process, outlining challenges to enacting HRO principles in diagnosis and offering solutions for how diagnostic process stakeholders can overcome these barriers. **Background:** Evidence shows that healthcare is starting to organize for higher reliability by employing various principles and practices of HRO. These hold promise for enhancing safer care, but there has been little consideration of the challenges that clinicians and healthcare systems face while enacting HRO principles in the diagnostic process. To effectively deploy the HRO perspective, these barriers must be seriously considered. **Method:** We review key principles of the HRO paradigm, the diagnostic errors and harms that potentially can be prevented by its enactment, the challenges that clinicians and healthcare systems face in executing various principles and practices, and possible solutions that clinicians and organizational leaders can take to overcome these challenges and barriers. **Results:** Our analyses reveal multiple challenges including the inherent diagnostic uncertainty; the lack of diagnosis-focused performance feedback; the fact that diagnosis is often a solo, rather than team, activity; the tendency to simplify the diagnostic process; and professional and institutional status hierarchies. But these challenges are not insurmountable—there are strategies and solutions available to overcome them. **Conclusion:** The HRO lens offers some important ideas for how the safety of the diagnostic process can be improved. **Application:** The ideas proposed here can be enacted by both individual clinicians and healthcare leaders; both are necessary for making systematic progress in enhancing diagnostic performance.

- **Keywords:** patient safety, reliability issues, communication and teamwork in healthcare, team situation awareness, organizational factors, safety culture and behavior change

Anjali Joseph, Kapil Chalil Madathil, Roxana Jafarifiroozabadi, Hunter Rogers, Sahar Mihandoust, Amro Khasawneh, Nathan McNeese, Christine Holmstedt, James T. McElligott. *Communication and Teamwork During Telemedicine-Enabled Stroke Care in an Ambulance. S. 21–41.*

Objective: The purpose of this study is to understand the communication among care teams during telemedicine-enabled stroke consults in an ambulance. **Background:** Telemedicine can have a significant impact on acute stroke care by enabling timely intervention in an ambulance before a patient reaches the hospital. However, limited research has been conducted on understanding and supporting team communication during the care delivery process for telemedicine-enabled stroke care in an ambulance. **Method:** Video recordings of 13 simulated stroke telemedicine consults conducted in an ambulance were coded to document the tasks, communication events, and flow disruptions during the telemedicine-enabled stroke care delivery process. **Results:** The majority (82%) of all team interactions in telemedicine-enabled stroke care involved verbal interactions among team members. The neurologist, patient, and paramedic were almost equally involved in team interactions during stroke care, though the neurologist initiated 48% of all verbal interactions. Disruptions were observed in 8% of interactions, and communication-related issues contributed to 44%, with interruptions and environmental hazards being other reasons for disruptions in interactions during telemedicine-enabled stroke care. **Conclusion:** Successful telemedicine-enabled stroke care involves supporting both verbal and nonverbal communication among all team members using video and audio systems to provide effective coverage of the patient for the clinicians as well as vice versa. **Application:** This study provides a deeper understanding of team interactions during telemedicine-enabled stroke care that is essential for designing effective systems to support teamwork.

- **Keywords :** communication and teamwork in healthcare, telemedicine, computer-supported collaborations, distractions and interruptions, team cognition

Jackie S. Cha, Denny Yu. *Objective Measures of Surgeon Non-Technical Skills in Surgery: A Scoping Review. S. 42–73.*

Objective: The purpose of this study was to identify, synthesize, and discuss objective behavioral or physiological metrics of surgeons' nontechnical skills (NTS) in the literature. **Background:** NTS, or interpersonal or cognitive skills, have been identified to contribute to safe and efficient surgical performance; however, current assessments are subjective, checklist-based tools. Intraoperative skill evaluation, such as technical skills, has been previously utilized as an objective measure to address such limitations. **Methods:** Five databases in engineering, behavioral science, and medicine were searched following PRISMA reporting guidelines. Eligibility criteria included studies with NTS objective measurements, surgeons, and took place within simulated or live operations. **Results:** Twenty-three articles were included in this review. Objective metrics included communication metrics and measures from physiological responses such as changes in brain activation and motion of the eye. Frequencies of content-coded communication in surgery were utilized in 16 studies and were associated with not only the communication construct but also cognitive constructs of situation awareness and decision making. This indicates the underlying importance of communication in evaluating the NTS constructs. To synthesize the scoped literature, a framework based on the one-way communication model was used to map the objective measures to NTS constructs. **Conclusion:** Objective NTS measurement of surgeons is still preliminary, and future work on leveraging objective metrics in parallel with current assessment tools is needed.

Application: Findings from this work identify objective NTS metrics for measurement applications in a surgical environment.

- **Keywords:** physiological measurement, communication and teamwork in healthcare, decision making, situation awareness, eye movements tracking

Elizabeth Austin, Brette Blakely, Paul Salmon, Jeffrey Braithwaite, Robyn Clay-Williams. *Identifying Constraints on Everyday Clinical Practice: Applying Work Domain Analysis to Emergency Department Care. S. 74–98.*

Background: Emergency departments (EDs) are complex socio-technical work systems that require staff to manage patients in an environment of fluctuating resources and demands. To better understand the purpose, and pressures and constraints for designing new ED facilities, we developed an abstraction hierarchy model as part of a work domain analysis (WDA) from the cognitive work analysis (CWA) framework. The abstraction hierarchy provides a model of the structure of the ED, encompassing the core objects, processes, and functions relating to key values and the ED's overall purpose. **Methods:** Reviews of relevant national and state policy, guidelines, and protocol documents applicable to care delivery in the ED were used to construct a WDA. The model was validated through focus groups with ED clinicians and subsequently validated using a series of WDA prompts. **Results:** The model shows that the ED system exhibits extremely interconnected and complex features. Heavily connected functions introduce vulnerability into the system with function performance determined by resource availability and prioritization, leading to a trade-off between time and safety priorities. **Conclusions:** While system processes (e.g., triage, fast-track) support care delivery in ED, this delivery manifests in complex ways due to the personal and disease characteristics of patients and the dynamic state of the ED system. The model identifies system constraints that create tension in care delivery processes (e.g., electronic data entry, computer availability) potentially compromising patient safety. **Application:** The model identified aspects of the ED system that could be leveraged to improve ED performance through innovative ED system design.

- **Keywords :** cognitive work analysis, socio-technical system, abstraction hierarchy, systems thinking, ergonomics, human factors

Sylvia J. Hysong, Richard SoRelle, Ashley M. Hughes. [Prevalence of Effective Audit-and-Feedback Practices in Primary Care Settings: A Qualitative Examination Within Veterans Health Administration.](#) S. 99–108.

Objective: The purpose of this study is to uncover and catalog the various practices for delivering and disseminating clinical performance in various Veterans Affairs (VA) locations and to evaluate their quality against evidence-based models of effective feedback as reported in the literature. **Background:** Feedback can enhance clinical performance in subsequent performance episodes. However, evidence is clear that the way in which feedback is delivered determines whether performance is harmed or improved. **Method:** We purposively sampled 16 geographically dispersed VA hospitals based on high, low, consistently moderate, and moderately average highly variable performance on a set of 17 outpatient clinical performance measures. We excluded four sites due to insufficient interview data. We interviewed four key personnel from each location (n = 48) to uncover effective and ineffective audit and feedback strategies. Interviews were transcribed and analyzed qualitatively using a framework-based content analysis approach to identify emergent themes. **Results:** We identified 102 unique strategies used to deliver feedback. Of these strategies, 64 (62.74%) have been found to be ineffective according to the audit-and-feedback research literature. Comparing

features common to effective (e.g., individually tailored, computerized feedback reports) versus ineffective (e.g., large staff meetings) strategies, most ineffective strategies delivered feedback in meetings, whereas strategies receiving the highest effectiveness scores delivered feedback via visually understood reports that did not occur in a group setting. **Conclusions:** Findings show that current practices are leveraging largely ineffective feedback strategies. Future research should seek to identify the longitudinal impact of current feedback and audit practices on clinical performance. **Application** Feedback in primary care has little standardization and does not follow available evidence for effective feedback design. Future research in this area is warranted.

- **Keywords :** clinical performance, primary care, audit and feedback, content analysis

Anjum Naweed, Jana Stahlut, Valerie O’Keeffe. *The Essence of Care: Versatility as an Adaptive Response to Challenges in the Delivery of Quality Aged Care by Personal Care Attendants.* S. 109–125.

Objective: The strategies adopted by personal care attendants (PCAs) to deliver quality care when faced with challenges potentially impacting clinical outcomes were assessed using phenomenological methods. **Background:** In Australia, recent outcry of unsatisfactory standards of care in residential facilities has instigated a national public inquiry. This study investigated how PCAs adapted to challenges in stressful and ambiguous everyday work scenarios to deliver quality care. **Method:** A phenomenological approach was used to obtain insights into PCAs’ experiences, perceptions, opinions, and decision processes for enacting care. Ten PCAs working in rural-based residential aged care were interviewed using a novel scenario construction task with thematic and co-occurrence network mapping applied to derive insights. **Results:** Seven themes were identified, revealing that participants formed close relationships with residents, influencing care provision but blurring personal boundaries. Key contextual factors in scenarios highlighted inadequate staffing and procedures, inadequate training, challenging residents, time poverty, and low support. Individually directed adaptive strategies were used to alleviate dissonance and maintain emotional resilience, including dynamic risk assessment involving rule breaking. **Conclusion:** The findings suggest that in negotiating care delivery, PCAs strive to optimize rule-based compliance with safety, efficiency, and individualized attention to provide “good enough” care with fluidity. Implications for policy and practice are considered. **Application:** Findings have implications for workforce development in the context of ever-increasing industry pressures. Findings identified challenging scenarios and role complexity, with decision-making occurring as a fluid and ongoing process across a flexible boundary of risk assessment influencing interactions between PCAs, registered nurses, and clients.

- **Keywords :** decision-making, aging, communication and teamwork in healthcare, qualitative methods, scenario invention task technique

Emily S. Patterson, Michael F. Rayo, Judy Reed Edworthy, Susan D. Moffatt-Bruce. *Applying Human Factors Engineering to Address the Telemetry Alarm Problem in a Large Medical Center.* S. 126–142.

Objective: Address the alarm problem by redesigning, reorganizing, and reprioritizing to better discriminate alarm sounds and displays in a hospital. **Background:** Alarms in hospitals are frequently misunderstood, disregarded, and overridden. **Method:** Discovery-oriented, intervention, and translational studies were conducted. Study objectives and measures varied, but had the shared goals of increasing positive predictive value (PPV) of critical alarms by reducing low-PPV alarms in the background, prioritizing alarms, redesigning alarm sounds to increase information content, and transparently conveying who initiated alarms. An alarm ontology was iteratively generated and refined until consensus was achieved. **Results:** The ontology distinguishes

five levels of urgency that incorporate likely PPV, three categories for who initiates the alarm (hospital staff, patient, or machine), whether it is clinical or technical, and clinical functions. **Conclusion:** This unique collaboration allowed us to make progress on the alarm problem by making unintuitive leaps, avoiding common missteps, and refuting conventional healthcare approaches. **Application:** Hospitals can consistently redesign, reorganize, reprioritize, and better discriminate alarms by priority, PPV, and content to reduce nurse response times.

- **Keywords :** alarms, automation, decision-making, health, Information Technology, medical devices, decision support systems, clinical

Ken Catchpole, Alicia Privette, Laura Roberts, Myrte de Alfred, Brittan Carter, Erick Woltz, Dulaney Wilson, Bruce Crookes. *A Smartphone Application for Teamwork and Communication in Trauma: Pilot Evaluation "in the Wild"*. S. 143–158.

Objective: To evaluate the potential for a smartphone application to improve trauma care through shared and timely access to patient and contextual information. **Background:** Disruptions along the trauma pathway that arise from communication, coordination, and handoffs problems can delay progress through initial care, imaging diagnosis, and surgery to intensive care unit (ICU) disposition. Implementing carefully designed and evaluated information distribution and communication technologies may afford opportunities to improve clinical performance. **Methods:** This was a pilot evaluation "in the wild" using a before/after design, 3 month, and pre- post-intervention data collection. Use statistics, usability assessment, and direct observation of trauma care were used to evaluate the aS. Ease of use and utility were assessed using the technology acceptance model (TAM) and system usability scale (SUS). Direct observation deployed measures of flow disruptions (defined as "deviations from the natural progression of an procedure"), teamwork scores (T-NOTECHS), and treatment times (total time in emergency department [ED]). **Results:** The app was used in 367 (87%) traumas during the trial period. Usability was generally acceptable, with higher scores found by operating room (OR), ICU, and neuro and orthopedic users. Despite positive trends, no significant effects on flow disruptions, teamwork scores, or treatment times were observed. **Conclusions:** Pilot trials of a clinician-centered smartphone app to improve teamwork and communication demonstrate potential value for the safety and efficiency of trauma care delivery as well as benefits and challenges of "in-the-wild" evaluation.

- **Keywords :** perioperative care, care transitions, communication, emergency medicine, health-information technology, patient safety, trauma care, teamwork, smartphone

Nima Ahmadi, Farzan Sasangohar, Tariq Nisar, Valerie Danesh, Ethan Larsen, Ineen Sultana, Rita Bosetti. *Quantifying Occupational Stress in Intensive Care Unit Nurses: An Applied Naturalistic Study of Correlations Among Stress, Heart Rate, Electrodermal Activity, and Skin Temperature*. S. 159–172.

Objective: To identify physiological correlates to stress in intensive care unit nurses. **Background:** Most research on stress correlates are done in laboratory environments; naturalistic investigation of stress remains a general gap. **Method:** Electrodermal activity, heart rate, and skin temperatures were recorded continuously for 12-hr nursing shifts (23 participants) using a wrist-worn wearable technology (Empatica E4). **Results:** Positive correlations included stress and heart rate ($\rho = .35, p < .001$), stress and skin temperature ($\rho = .49, p < .05$), and heart rate and skin temperatures ($\rho = .54, p = .0008$). **Discussion:** The presence and direction of some correlations found in this study

differ from those anticipated from prior literature, illustrating the importance of complementing laboratory research with naturalistic studies. Further work is warranted to recognize nursing activities associated with a high level of stress and the underlying reasons associated with changes in physiological responses. **Application:** Heart rate and skin temperature may be used for real-time detection of stress, but more work is needed to validate such surrogate measures.

- **Keywords:** critical care, job stress, physiological measurement, nursing and nursing systems, naturalistic study

Mahnoosh Sadeghi, Farzan Sasangohar, Anthony D. McDonald, Sudeep Hegde. *Understanding Heart Rate Reactions to Post-Traumatic Stress Disorder (PTSD) Among Veterans: A Naturalistic Study.* S. 173–187.

Objective: We collected naturalistic heart rate data from veterans diagnosed with post-traumatic stress disorder (PTSD) to investigate the effects of various factors on heart rate. **Background:** PTSD is prevalent among combat veterans in the United States. While a positive correlation between PTSD and heart rate has been documented, specific heart rate profiles during the onset of PTSD symptoms remain unknown. **Method:** Veterans were recruited during five cycling events in 2017 and 2018 to record resting and activity-related heart rate data using a wrist-worn device. The device also logged self-reported PTSD hyperarousal events. Regression analyses were performed on demographic and behavioral covariates including gender, exercise, antidepressants, smoking habits, sleep habits, average heart rate during reported hyperarousal events, age, glucocorticoids consumption, and alcohol consumption. Heart rate patterns during self-reported PTSD hyperarousal events were analyzed using Auto Regressive Integrated Moving Average (ARIMA). Heart rate data were also compared to an open-access non-PTSD representative case. **Results:** Of 99 veterans with PTSD, 91 participants reported at least one hyperarousal event, with a total of 1023 events; demographic information was complete for 38 participants who formed the subset for regression analyses. The results show that factors including smoking, sleeping, gender, and medication significantly affect resting heart rate. Moreover, unique heart rate patterns associated with PTSD symptoms in terms of stationarity, autocorrelation, and fluctuation characteristics were identified. **Conclusion:** Our findings show distinguishable heart rate patterns and characteristics during PTSD hyperarousal events. **Application:** These findings show promise for future work to detect the onset of PTSD symptoms.

- **Keywords:** stress, physiological measurement, wearable sensors, mental disabilities, PTSD, heart rate

Pratima Saravanan, Jessica Menold. *Deriving Effective Decision-Making Strategies of Prosthetists: Using Hidden Markov Modeling and Qualitative Analysis to Compare Experts and Novices.* S. 188–206.

Objective: This research focuses on studying the clinical decision-making strategies of expert and novice prosthetists for different case complexities. **Background:** With an increasing global amputee population, there is an urgent need for improved amputee care. However, current prosthetic prescription standards are based on subjective expertise, making the process challenging for novices, specifically during complex patient cases. Hence, there is a need for studying the decision-making strategies of prosthetists. **Method:** An interactive web-based survey was developed with two case studies of varying complexities. Navigation between survey pages and time spent were recorded for 28 participants including experts (n = 20) and novices (n = 8). Using these data, decision-making strategies, or patterns of decisions, during prosthetic prescription were derived using hidden Markov modeling. A qualitative analysis of participants' rationale regarding decisions was used to add a deep contextualized understanding of decision-making strategies derived from the quantitative analysis. **Results:** Unique decision-

making strategies were observed across expert and novice participants. Experts tended to focus on the personal details, activity level, and state of the residual limb prior to prescription, and this strategy was independent of case complexity. Novices tended to change strategies dependent upon case complexity, fixating on certain factors when case complexity was high. **Conclusion:** The decision-making strategies of experts stayed the same across the two cases, whereas the novices exhibited mixed strategies. **Application:** By modeling the decision-making strategies of experts and novices, this study builds a foundation for development of an automated decision-support tool for prosthetic prescription, advancing novice training, and amputee care.

- **Keywords:** decision-making, cognition, experience, computational modeling, qualitative methods

Molly P. Kilcullen Tiffany M. Bisbey Madelene J. Ottosen Kuojen Tsao Eduardo Salas Eric J. Thomas. *The Safer Culture Framework: An Application to Healthcare Based on a Multi-Industry Review of Safety Culture Literature.* S. 207–227.

Background: Errors and preventable harm to patients remain regrettably common and expensive in healthcare. Improvement requires transforming the culture of the healthcare industry to put a greater emphasis on safety. Safety culture involves holding collective attitudes, values, and behaviors that prioritize safety. The Safer Culture framework, previously established through a narrative review of literature in multiple industries, provides a consensus on what impacts safety culture, how it manifests in behavior, and how it influences safety-related outcomes. **Methods:** Through a theoretical review, we validate, refine, and provide nuance to this framework for the development of safety culture in healthcare contexts. To accomplish this, we conceptually map existing dimensions pulled through the literature onto our Safer Culture framework. **Results:** A total of 360 articles were reviewed. We present specific elements for each dimension in our framework and apply the dimension to healthcare contexts. **Conclusion:** We provide an evidence-based and comprehensive framework that can be used by patient safety leaders and researchers to guide the evaluation of safety culture and develop interventions to foster patient safety culture and improve patient safety outcomes.

- **Keywords:** patient safety, safety culture and behavior change, group processes, communication and teamwork in healthcare, affective factors

Omer Perry, Eli Jaffe, Yuval Bitan. [Dynamic Communication Quantification Model for Measuring Information Management During Mass-Casualty Incident Simulations.](#) S. 228–249.

Objective: To develop a new model to quantify information management dynamically and to identify factors that lead to information gaps. **Background:** Information management is a core task for emergency medical service (EMS) team leaders during the prehospital phase of a mass-casualty incident (MCI). Lessons learned from past MCIs indicate that poor information management can lead to increased mortality. Various instruments are used to evaluate information management during MCI training simulations, but the challenge of measuring and improving team leaders' abilities to manage information remains. **Method:** The Dynamic Communication Quantification (DCQ) model was developed based on the knowledge representation typology. Using multi point-of-view synchronized video, the model quantifies and visualizes information management. It was applied to six MCI simulations between 2014 and 2019, to identify factors that led to information gaps, and compared with other evaluation methods. **Results:** Out of the three methods applied, only the DCQ model revealed two factors that led to information gaps: first, consolidation of numerous casualties from different areas, and second, tracking of casualty arrivals to the medical treatment area and

departures from the MCI site. **Conclusion:** The DCQ model allows information management to be objectively quantified. Thus, it reveals a new layer of knowledge, presenting information gaps during an MCI. Because the model is applicable to all MCI team leaders, it can make MCI simulations more effective. **Application:** This DCQ model quantifies information management dynamically during MCI training simulations.

- **Keywords:** communication, teamwork, mass-casualty incident, information management, simulation

Joseph R. Keebler Michael A. Rosen Dean F. Sittig Eric Thomas Eduardo Salas. *Human Factors and Ergonomics in Healthcare: Industry Demands and a Path Forward*. S. 250–258.

This article reviews three industry demands that will impact the future of Human Factors and Ergonomics in Healthcare settings. These demands include the growing population of older adults, the increasing use of telemedicine, and a focus on patient-centered care. Following, we discuss a path forward through improved medical teams, error management, and safety testing of medical devices and tools. Future challenges are discussed.

- **Keywords:** Healthcare, Aging, Telemedicine, Teamwork, Errors