Cognitive Engineering for Complex Decision Making & Problem Solving in Acute Care

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Structured Abstract

Purpose: The overall goal of this grant was to use cognitive systems engineering approaches to understand the decision-making process in the emergency department (ED) and propose models and solutions to some of the biggest challenges in practicing medicine in this complex environment.

Scope: This research focused on the cognitive needs and decision making of nurses, physicians and advance practice providers in the ED.

Methods: The research team used a mixed methods approach, including focus groups, interviews, observations and electronic health record (EHR) data analysis to develop a deep understanding of the cognitive needs of emergency medicine staff. These findings were then used to iteratively develop tools and models based on those needs.

Results: A series of publications and presentations were used to disseminate the diverse set of findings from this research with a focus on: nurse-physician communication, monitoring workload drivers for front-line staff, workflow decision making and opioid prescribing considerations. Prototype interfaces were built around concepts for a patient-centered chart, automatic workflow monitoring and clinical chart reviews. This research has advanced our understanding of the time sensitive and high acuity environment of the ED. These findings and prototype interfaces represent a step forward in using cognitive systems engineering in supporting the needs of front-line emergency medicine clinicians with an ultimate goal of reducing burden and increasing safety.

Keywords: health information technology, human factors engineering, cognitive systems engineering, emergency department

Section I: Purpose

Objectives of the study

The overall goal of this grant was to use cognitive systems engineering (CSE) approaches to understand the decision-making process in the emergency department (ED) and propose models and solutions to some of the biggest challenges in practicing medicine in this complex environment.

This project included four parts: cognitive systems analysis (Specific Aim 1), prototype development and refinement (Specific Aim 2), usability evaluation of the prototype (Specific Aim 3), and dissemination and influence (Specific Aim 4).

Specific Aim 1: Perform a cognitive engineering analysis of emergency medicine, across EDs with varying characteristics, and a variety of staff roles (physicians, nurses, technicians) using qualitative methods (interviews, document review and ethnographic observation) and standard modeling techniques. The outputs of this aim consisted of analyses of emergency medicine operational complexities, required forms of expertise, key decisions and challenging activities related to the provision of high-quality patient care.

Specific Aim 2: Iteratively develop design guidance, recommendations, and solutions for specific targeted problems with potential for high impact and generalizability, identified through analyses conducted in Specific Aim 1. We applied user-centered and cognitive engineering design methods to iteratively prototype solutions which allowed the design concepts to be assessed.

Specific Aim 3: Evaluate the solutions prototype in Specific Aim 2 with standard user-centered evaluation methods, as well as in realistic simulated tasks set in a clinical simulation center.

Specific Aim 4: Disseminate results to health information technology (IT) developers and the general academic community via publications and presentations.

Section II: Scope

Background

Health information systems are rapidly being implemented and optimized in a variety of healthcare contexts, including EDs. These systems offer promising solutions to challenges related to cost, efficiency, patient safety, and medical errors. New technologies are often designed with only a limited understanding of the nature of cognition, tasks, and workflow in the setting in which they will be used. Without a careful understanding of how new technologies will be used in practice, unanticipated or undesirable consequences can arise. From increased workload to "workarounds," patient and provider safety can be compromised if systems and tasks are bypassed, abandoned, or interrupted.

Context

To address these deficits, the MedStar Health National Center for Human Factors in Healthcare and MedStar Emergency Physicians recognized an opportunity to leverage their partnership – one of the few existing collaborations between human factors scientists, informaticians, and clinicians. They partnered with the University at Buffalo's Department of Industrial Engineering to use CSE methods to design and test prototype ED information systems. In collaboration with consultants from Roth Cognitive Engineering and University of Florida's Department of Emergency Medicine, they worked to understand how new technologies will be used in practice, the cognitive work technologies support, and how technologies' design can be optimized for this support. While there have been applications of cognitive engineering to medical environments, none have provided a comprehensive understanding of the nature of cognitive clinical work and activities across an acute care environment.

Settings

This research used the ED as a "field laboratory" for two reasons. First, the ED is home to some of the most challenging conditions for cognitive work – high risk, time pressure, and uncertainty – and therefore provides a strong opportunity to generalize findings to other complex healthcare environments. Second, the ED can clearly benefit from the decision aids, visualizations, and other supportive technologies that can result from cognitive engineering analyses. We approached the ED as a joint cognitive system, distributed across people, roles, social and technical artifacts (such as policies and health information technology), and time.

Participants

This research focused on front-line healthcare team members in the ED, specifically emergency medicine nurses and physicians. Other associated team members, including administrative staff, technicians, respiratory therapists and others play critical roles in the care of patients but were not the focus of this research.

Section III: Methods

Due to the long nature of this study and multiple components, the report has been split into the specific aims and various sub-projects. For **Specific Aims 1 and 2**, electronic health record (EHR) data from MedStar Health EDs was collected for three separate types of analyses, focus groups, interviews, and observations were conducted:

1) **Nurse-Physician Communication Observations:** Communication among healthcare teams has been previously cited as a critical component in the provision of safe, effective patient care. Face-to-face communication has been found to be the most common method of information exchange; however, complexities of the ED environment, such as crowding, interruptions, and transitions of care, make successful communication particularly challenging. The purpose of this study was to analyze the content and patterns of physician-nurse communication in EDs which utilize EHRs and to characterize the role that verbal communication plays in these work environments. Specifically, we studied who exchanges in and initiatives communication events, where these events occur, and what types of information are discussed. Observations were conducted by two members of the research team. Target participants included emergency medicine nurses, residents, and attending physicians from a single ED.

2) **Nurse-Physician Communication Focus Groups:** The current state of scientific knowledge regarding communication between emergency medicine providers indicates that communication is critical to safe and effective patient care. In this study, we identified communication needs of emergency medicine physicians and nurses from; in particular, what information should be conveyed, when, how and to whom. Semi-structured focus groups were conducted with questions addressing how emergency medicine personnel use and share information about patients and clinical work, what information tends to be exchanged, and what additional information would be helpful to share. Focus groups were led by a single researcher and target participants included emergency medicine nurses, residents, and attending physicians from two EDs within the same healthcare system.

3) **Emergency Department Workload Drivers**: We know from previous human factors research that cognitive workload can be associated with increased stress and higher rates of errors. Previous research in the area of measuring clinician workload has often focused on markers that require retrospective analysis or markers that need to be collected over a 24-hour period. Most of these studies were completed in the ICU or inpatient medical/surgical units where these types of measures are more meaningful, but not available during the evaluation and care of patients in the ED. Our team acquired data from approximately 100,000 patient records and clinician interactions in the EHR from multiple EDs across the healthcare system to create an algorithm and connected display in order to monitor clinician workload in real-time. This model is limited by the use of a single health system as a data source and will require further testing and refinement in other settings.

4) **Physician Workflow Decision Making**: The ED patient volume at any given moment is incredibly dependent on the decision making by experienced and trained physicians. Part of emergency medicine training for physicians is how to manage an entire team or department of patients in parallel. Decision making on when to see a new patient or disposition a patient home or admit to the hospital can have a major impact on the flow of patients in the ED and have important ramifications on team performance and safety in the ED. The current feedback that clinicians receive on their performance is often limited to crude measures that give limited insight on how to improve and is often only given during monthly or annual reviews. For this project, the team identified metrics and visualizations for the development of a clinician workflow tool to display workflow patterns and management strategies used across providers (attending and resident physicians). EHR data was extracted for one year (2018 to 2019) for an ED with more than 80,000 cases seen on an annual basis, resulting in a total of 6,427 shifts across 50 attending physicians and 30 resident physicians being captured. This methodology was limited to a single training site and will need further refinement across other training programs.

5) **Nurse Decision Making in Complex Cases**: The team conducted interviews on cognitive decision-making strategies with expert versus novice nurses at a single emergency department. This body of work used the Critical Decision Method to elicit decision making strategies using a structured methodology shown to be effective in other domains but has not been previously used with emergency medicine nurses. In particular, the work focused on expert versus novice strategies in caring for patients and managing emergency department workflow. Data were collected as free-text notes and later analyzed for emerging themes. Target participants included emergency medicine nurses from a single ED.

6) **Nurse-Physician Communication Strategies**: The goal of this line of work was to uncover differences in strategies used between physicians and nurses for developing shared awareness of patient tasks and ways in which this is or is not supported. One specific method was to analyze EHRs for instances of emergency medicine nursing documentation containing phrases like “MD aware,” physician aware,” “NP/PA aware” and similar permutations of this language. During previous research projects, this phrase was identified as a potential marker for increased clinician workload, safety events and/or disagreements between providers. Retrospective data from 2016 to 2019 were iteratively extracted and analyzed to better understand the context, medications and vital signs around nurse’s documentation with this verbiage.

7) **Opioid Prescribing in the Emergency Department**: Considering the worsening opioid crisis in the United States, the research team decided to focus on the cognitive decision-making strategies surrounding opioid prescriptions and subsequent work processes based on emergency medicine nurse and physician experiences. The team elected to gather

foundational data using semi-structured interviews using an abbreviated variant of the Critical Decision Method. Interviews were conducted by three members of the research team, data were collected as free-text notes and participants included a total of six emergency medicine physicians, three attending physicians, and three nurses from two EDs.

For **Specific Aim 3**, three functional prototypes were developed and are discussed in detail below:

1) **Workload Monitoring Prototype:** Using data obtained in Specific Aim 1, we created an embedded workload display tool in the EHR. The tool visually quantifies the individual work associated with individual patients while monitoring the distribution of work across clinicians. The tool and workload algorithm have undergone initial usability and usefulness analysis. Two researchers administered questionnaires to participants during their shifts, where participants would provide subjective ratings regarding the workload associated with their patients, which were then matched with the scores calculated by the algorithm. Target participants included emergency medicine physicians and nurses from a single ED.

2) **Patient-Centered Display**: This display has been created as a high-fidelity prototype developed for interactive testing. The overall goal of the interface was to incorporate information needs and communication strategies across physicians and nurses to facilitate a holistic view of the patient and communication between providers. Current EHRs typically store information in silos, often displaying critical information in different formats or not sharing across provider roles. In addition, our research from Specific Aim 1 found that physicians and nurses often have key insights and decision-making strategies that when shared can make the team higher performing. For example, after the initial assessment of a patient the provider may have a strong sense that the patient will either be discharged or admitted to the hospital once diagnostic testing has resulted. By sharing this expected disposition with the nurse early in the patient's ED visit the nurse can help ensure a safe disposition home or initiate paperwork to get the patient ready for a bed as soon as it is available. The prototype specifically contained a field for the nurses and physicians to enter an expected disposition for the patient to make sure the team discusses this early in the process. While some clinicians currently discuss this or use work-around strategies in commercially available EHRs, our team believes this is a critical component of high functioning teams that the EHR should explicitly support this cognitive decision-making process among others discussed in the published research. In order to evaluate the prototype, a usability study was conducted with target participants including emergency medicine attendings, residents, and nurses from two EDs within a single healthcare system. Study sessions were conducted in a simulated setting with de-identified patient data, and data were collected via surveys and questionnaires. Participants were presented various scenarios requiring patient prioritization and care-planning tasks to be performed using the prototyped display. Participants rated the display in terms of its cognitive

support, usability, and usefulness, their performance on the various tasks, as well as their feedback on the display design and utility were also analyzed.

3) **Clinical Timeline Chart Review Tool**: Due to the aforementioned silos of information in the EHR, the team elected to develop a tool that helped create a timeline-based platform to review the events of patient care as they happened to the patient. Under the current design of the EHR, most types of information are very challenging to see in relation to each other and require significant cognitive effort by the clinician in either real-time or necessitate the use of a paper artifact to plot the path of the patient in the ED. For example, when reviewing the care of a patient, it is crucial to understand the relationship of medications in time to vital signs. The tool integrates multiple areas of the clinical chart into a single timeline allowing users to filter and search in real-time and ultimately improve both the accuracy and efficiency of the review. It has been iteratively modified to incorporate additional features based on feedback from subject matter experts prior to conducting a pilot usability study. The tool is designed to provide end users with a more holistic approach to address the operational complexities of reviewing the EHR for clinical care as well as quality and safety purposes. It has been developed to support three primary end users: quality and safety personnel who conduct unstructured chart reviews, department level clinical personnel who conduct retrospective event review analyses by extracting specific data events, and researchers performing data extraction around research-related questions. The pilot usability study was conducted with target participants including emergency medicine attendings, residents, nurses, and administrative staff (e.g., nurse managers and patient safety personnel) from two EDs within a single healthcare system. Participants were presented various scenarios requiring a review of a patient's care to be performed using the prototyped tool. Study sessions were conducted in a simulated setting with patient data and data were collected via free-text notes.

Section IV: Results

Due to the long duration and scope of this research grant, the final report includes a breakdown by specific aim and sub-projects. For **Specific Aims 1 and 2**, key findings and implications are described below:

1) **Nurse-Physician Communication Observations:** 18 emergency nurses and physicians (nine each) were observed for a total of 36 hours. A qualitative analysis of communication event content revealed 5 types of communication and 13 content themes. Content themes covered a broad range of topics including exchange of patient health information, management of the ED, and coordination of orders. Physician participants experienced significantly more communication events than nurse participants, while nurses initiated significantly more communication events than physicians. Our results provide an overview of information exchanged in the ED which can serve as a basis for designing improved information support systems.

2) **Nurse-Physician Communication Focus Groups:** Six focus groups of emergency medicine attending physicians, residents and nurses were conducted independently across three research sites. A grounded theory qualitative analysis was conducted. A total of 19 codes emerged and could be broadly categorized as technological, interpersonal, individual, environmental, or organizational factors affecting physician-nurse information sharing. Additional analysis of the data pertaining to developing shared awareness was done to better describe how this is/is not supported and to identify potential differences in strategies between physicians and nurses for developed shared awareness. The team also explored relevant codes and added sub-codes to concretely identify differences between attendings and residents in how they communicate with nurses. All described similar communicative behaviors, with mild nuances between roles and levels of experience. This work includes the development of 11 concept maps to highlight the critical communication needs between nurses and physicians.

3) **Emergency Department Workload Drivers**: The team has successfully modeled five different proxies of workload with patient data from the EHR (highest $R^2 = 0.995$ with the data from an entire patient's visit and $R^2 = 0.406$ with data from the first hour). The model predicts the amount of work that individual patients contribute to the workload of clinicians. Current best results from analyses being done with four machine learning classification algorithms to predict the five workload proxies show a 95.9% accuracy with data from an entire patient's visit and 80% accuracy with data from the first hour. This can potentially aid in the management of clinician workload by supporting the decision of assigning new patients.

4) **Physician Workflow Decision Making:** The analyses for the clinician workflow tool have resulted in descriptive statistics across physician types (attending and residents) from multiple shifts in the effort to identify patterns, trends, and strategies used by experience level and refine targeted data points to later incorporate into the prototype. Preliminary visualizations have been developed to show the number of patients seen in one shift and average time between shifts for each physician type. These visualizations have shown clear differences between novice and experienced clinicians and have garnered interest from the emergency medicine residency training program as a strategy to give targeted feedback to trainees.

5) **Nurse Decision Making in Complex Cases**: A total of 10 interviews with emergency care nurses were conducted, which comprised of a total of 21 separate scenarios described for them. A major portion of the analysis of the nurses' critical decision methods consisted of the creation of Decision Requirements Tables (DRTs). A DRT identifies key decision-making elements, such as cues (used in the simulation), key decisions and actions, the justification for each decision, and the implication of experience in the decision-making process. Findings demonstrated that nurse decisions are dynamic, and they frequently need to adapt to the needs of each situation and patient. Additionally, more experienced nurses adapt to their situations faster than less

experienced nurses. This highlights the importance of initiative and adaptation in nurse decision making and forms the basis for further study and discussion around how nurses may be better empowered, or how factors constraining initiative may be mitigated.

6) **Nurse-Physician Communication Strategies**: From 2016 to 2019, sample sizes for nursing notes ranged from 4,600 to 8,000 and totaled to 25,980 notes. An average of 3.9% of target terms were identified in these notes, with a minimum of 2.6% and maximum of 4.0% per year. Although we focused on the unstructured nursing notes, our research identified "MD aware" notations adjacent to vital signs or in structured assessment fields. We have also looked at iView comments (another documentation section where the nurses document everything from vitals to anesthesia) in the EHR and tried to link that to the ED nursing notes to see if any additional information can be found out about terms such as "MD aware" or if the iView comments contained some information about the patient that was missing from the ED nursing notes. This could help us potentially identify early patient status changes and/or potential conflict or disagreement within the clinical team, suggesting a missed opportunity to intervene at an early stage of an illness. Additionally, it could help us identify the differences between documentation types.

7) **Opioid Prescribing in the Emergency Department**: Participants included a total of six emergency medicine physicians, three attending physicians, and three nurses. Nurse responses were most commonly related to gaps in communication between physicians and patients and ensuring patient satisfaction. Physician responses most commonly reported challenges with existing tools and databases, particularly the lack or lag of information available from previous healthcare visits and pharmacy interactions, and disregard or unawareness of existing guidelines. While existing resources were said to be extremely helpful, a number of improvements were given by each group. This data catalogs major challenges providers face when making decisions about prescribing opioids. By understanding these types of challenges and dynamic between physicians and nurses in the ED, we can better identify ways to improve the design of decision-making aids in the future.

For **Specific Aim 3**, key findings and implications are described below:

1) **Workload Monitoring Prototype:** A total of six emergency medicine physicians and nurses participated in this study who provided subjective workload ratings for a total of 43 patients. While clinicians found the interface valuable, evaluation of the algorithm demonstrated that different clinicians have different ways of conceptualizing workload and more sophisticated mechanisms, such as machine learning, may be necessary to produce a valid algorithm for calculating clinician workload. Additionally, this study demonstrated the feasibility of incorporating design prototypes into the EHR using real-time, dynamic patient data, and utilizing such prototypes for in-situ studies.

2) **Patient-Centered Display:** A total of 20 clinicians participated in this study, including 10 nurses and 10 attending physicians, residents, or physician assistants. Participants provided ratings for usability and usefulness for the display sections using a work-centered usability questionnaire – mean scores for nurses and providers were 7.56 and 6.6 (1 being lowest and 9 being highest), respectively. General usability scores, based on the System Usability Scale tool, were rated as acceptable or marginally acceptable. Similarly, participants also rated the display highly in terms of support for specific cognitive artifacts. These results demonstrate the value of work-centered usability testing of an electronic system that has been produced using an intensive user-centered design process and provide a scope for improving the design of the display. Additionally, analysis of qualitative feedback collected from the participants during the study also generated several insights for improvement. Implications of these findings will be used for improving health IT design in the ED on a broader scale.

3) **Clinical Timeline Chart Review Tool:** A total of seven nurses, physicians, and quality and safety personnel participated in the pilot usability study. Five participants identified themselves as typically conducting structured abstractions when trying to understand what care had been given to patients, and two identified themselves as conducting more unstructured abstractions. On a scale of 1 to 5 (1 = easiest, 5 = hardest), an average score of 2 was reported when participants were asked to rank using the tool to review charts compared to their traditional methods. Five of the seven participants reported safety chart reviews to be a part of their day-to-day job and the tool being useful for their current work-related activities. A combination of positive and negative feedback, as well as suggested edits/additions were obtained at the end of each study session via a semi-structured interview. All feedback has been consolidated, labeled by a priority level (high, medium, low), and has been incorporated into the design of the tool. The tool was initially developed to create de-identified use cases for testing the other prototypes, but the value quickly became apparent when using it. While primarily used for the retrospective review of charts, the tool has been rolled out to multiple departments in a pilot trial with a goal to roll it out system wide.

Conclusion

This research has demonstrated the significant value in using the CSE methodology to study complex clinical environments like the ED. The adoption of health IT has made the need to study this high acuity and time sensitive environment even more critical. Our findings have touched on a wide array of these cognitive needs, including communication strategies, EHR data visualization, workload monitoring and clinical decision making. Future research may build off of both the application of CSE in healthcare environments and the use of emergency medicine specific findings for future health IT applications. For future health IT systems to continue to improve the safety and efficiency of healthcare delivery, we must support the cognitive needs of our front-line clinical staff in taking care of patients.

Significance

Prior to this research grant, existing literature had demonstrated that health IT systems can improve quality in healthcare and stakeholders have agreed that health IT systems are key to safer and more efficient healthcare. However, questions remained around why implementation and adoption of these system have been considered to be challenging and how we can get to point where health IT is better supporting clinicians and not a source of frustration and safety concerns. The findings from this research grant demonstrates the utility of applying CSE methodology to better understand cognitive and workflow needs of frontline providers who these systems are intended to serve. Through this lens, we were not only able to identify gaps and challenges related to existing health IT but also strategies for improving the way in which they are developed and tested before implementation. Additionally, we have developed several strategies and prototypes to better support the clinical decision-making process that would aid in the current workflow of frontline ED clinicians. As such, this work provides potential solutions to guide future innovations in health IT.

Implications

Key implications from this research grant are geared towards the both health IT vendors community, healthcare organizations, emergency medicine frontline staff, and healthcare researchers. Regarding health IT vendors, the overview of information exchange between nurses and physicians, 11 concept maps highlighting their critical communication needs, and challenges identified around using health IT for the prescription of opioids in the ED can serve as a basis for designing improved information support systems. Additionally, the patient-centered display demonstrated the value of leveraging work-centered usability testing of an electronic system prior to design and implementation while applying a user-centered design processes for improving the cognitive support of tightly integrated clinical teams. The additional prototypes – algorithm to compute clinician workload drivers and clinician timeline chart review tool – could serve as a starting point for providing clinical decision support to frontline staff that could be adopted and modified by healthcare organizations and other critical care settings to meet their needs, including training, education and performance monitoring beyond the current coarse metrics. The nurse-physician communication strategies, visualization prototype of physician workflow decision making strategies, and findings around nurse decision making in complex cases could be used by frontline staff for training purposes and to enhance awareness among working groups. The clinician timeline chart review tool has already been rolled out to multiple departments within a single healthcare system with future EHR products offering similar functionality. The visualization prototype of physician workflow decision making strategies has garnered interest from an emergency resident training program as a strategy to give more targeted feedback to trainees. Lastly, future research may further the application of CSE in healthcare environments beyond the ED and leverage our findings for the development of health IT applications for other clinical settings.

Section V: List of Publications and Products

For **Specific Aim 4**, the team has employed multiple dissemination strategies leading to 8 peer-reviewed manuscripts, 6 conference proceedings paper presentations, 1 book chapter, and 10 abstracts:

Manuscripts

1. Hettinger AZ, Benda N, Roth E, Hoffman D, Iyer A, Franklin E, Perry S, Fairbanks RJ, Bizantz AM. Ten best practices for improving emergency medicine provider-nurse communication. J Emerg Med. 2020 April 1; 58(4):581-593. doi: 10.1016/j.jemermed.2019.10.035.
2. Wang X, Kim T, Hegde S, Hoffman DJ, Benda NC, Franklin ES, Lavergne D, Perry SJ, Fairbanks RJ, Hettinger AZ, Roth EM, Bisantz AM. Design and evaluation of an integrated, patient-focused electronic health record display for emergency medicine. Appl Clin Inform. 2019 Aug;10(4):693-706. doi: 10.1055/s-0039-1695800.
3. Benda NC, Blumenthal HJ, Hettinger AZ, Hoffman DJ, LaVergne DT, Franklin ES, Roth EM, Perry SJ, Bisantz AM. Human factors design in the clinical environment: Development and assessment of an interface for visualizing emergency medicine clinician workload. IISE Trans Occup Ergon Hum Factors. 2018 Dec;6(3-4):225-237. doi: 10.1080/24725838.2018.1522392.
4. Benda NC, Hettinger AZ, Bisantz AM, Hoffman DJ, McGeorge NM, Berg RL, Roth EM, Franklin ES, Perry SJ, Wears RL, Fairbanks RJ. Communication in the electronic age: An analysis of face-to-face physician-nurse communication in the emergency department. Healthc Inform Res. 2017 October 24;1(4):218-230. doi: 10.1007/s41666-017-0008-3
5. Benda NC, Fairbanks RJ, Fairbanks RJ. Are you paying attention? Related guidance on how concepts of attention may inform effective time sharing of tasks in emergency medicine. Ann Emerg Med. 2017 May;69(5):669-670. doi: 10.1016/j.annemergmed.2017.01.027.
6. Clark LN, Benda NC, Hegde S, McGeorge NM, Guarrera-Schick TK, Hettinger AZ, LaVergne DT, Perry SJ, Wears RL, Fairbanks RJ, Bisantz AM. Usability evaluation of an emergency department information system prototype designed using cognitive systems engineering techniques. Appl Ergon. 2017 April;60:356-365 doi: 10.1016/j.apergo.2016.12.018.
7. Hettinger AZ, Roth E, Bisantz AM. Cognitive engineering and health informatics: Applications and intersections. J Biomed Inform. 2017 March; 67:23-33. doi: 10.1016/j.jbi.2017.01.010.

Book Chapters

8. Hettinger AZ, Roth EM, Fairbanks RJ, Bisantz A. Clinical Workflow and Human Factors. In Cognitive Informatics K Zheng, J Westbrook, T Kannampallil, V Patel (Eds), 2019 (pp. 211-234). Springer, Cham. doi: 978-3-030-16916-9_13

Proceedings Paper Presentations

9. Wang X, Roth EM, Kim T, Arora J, Franklin ES, Hettinger AZ, Bisantz AM. Preliminary interview study on the opioid prescription decision making process. *Conference Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care*. 2020 September;9(1):234-237. doi: 10.1177/2327857920091061
10. Wang X, Blumenthal HJ, Hoffman D, Benda N, Kim T, Perry S, Franklin ES, Roth E, Hettinger AZ, Bizantz AM. Patient- related workload prediction in the emergency department: A big data approach. *Conference Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care*. 2019 September 19;8(1):33-36. doi: 10.1177/2327857919081008.
11. Wang X, Berg R, McGeorge N, LaVergne D, Benda N, Bisantz A. Assessing interaction strategies for health IT: An entropy based approach. *Conference Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care.* 2018 June;7(1):82-86. doi: 10.1177/2327857918071017.
12. LaVergne D, Casucci S, McGeorge N, Guarrera-Schick T, Clark L, Hettinger AZ, Wears R, Perry S, Lin L, Fairbanks T, Bisantz A. Development and description of a synthetic, high-fidelity, emergency department patient dataset for the evaluation of healthcare IT products. *Conference Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care.* 2017 May;6(1):75-78. doi: 10.1177/2327857917061017.
13. Fairbanks RJ, Bisantz A, Hettinger AZ, Ratwani R, Patterson E, Roth E. Usability in health IT: Beyond compliance to meaningful design and assessment. *Conference Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* 2016 September;60(1):643-646. doi: 10.1177/1541931213601148.

Abstract Presentations (Poster, Oral, Panels)

14. Mathur S, Blumenthal J, Bisantz A, Franklin E, Kim T, Hettinger AZ. MD aware: Quantifying nurse-provider communication in the emergency department. Poster presented at: *AMIA 2020 Clinical Informatics Conference*; May 19, 2020; Virtual.
15. Bennet S, Blumenthal J, Bisantz A, Mathur S, Kim T, Hettinger AZ. A tool to study clinician workflow in the emergency department. Poster presented at: *AMIA 2020 Clinical Informatics Conference*; May 19, 2020; Virtual.
16. Blumenthal HJ, Hoffman DJ, Kim T, Bisantz AM, Hettinger AZ. Development and implementation of a clinical event review tool: The timelinER. Podium presentation at: *AMIA 2019 Clinical Informatics Conference*; May 2, 2019; Atlanta, GA.
17. Blumenthal HJ. Who is up for the next patient? A human factors approach to designing an mPage to monitor clinician workload in the emergency department. Lecture presented at: *Cerner Health Conference*; October 9, 2018; Kansas City, MO.
18. Kim T, Bisantz A, Benda N, LaVergne D, Blumenthal J, Hoffman D, Chow K, Fairbanks RJ, Hettinger AZ. Assessing the usability of a prototype emergency medicine patient-centered electronic health record display. Poser presented at: *Sixth IEEE International Conference on Healthcare Informatics;* June 4, 2018; New York, NY.
19. Roth E, Bisantz A, Hettinger AZ. Using cognitive engineering methods to evaluate IT systems: Developing user feedback questionnaires around cognitive support design

objectives. Lecture presented at: *International Symposium on Human Factors and Ergonomics in Health Care;* March 26, 2018; Boston, MA.

20. Benda N, Blumenthal J, Hettinger AZ, Hoffman D, Franklin E, Lavergne D, Roth E, Perry S, Bisantz A. Investigating drivers of clinician workload in the emergency department: An exploratory study. Poster Presented at: *International Symposium on Human Factors and Ergonomics in Health Care*; March 26, 2018; Boston, MA.
21. Berg R, Iyer A, Benda N, Hoffman D, Roth E, McGeorge L, Franklin ES, Perry S, Wears R, Ratwani R, Hettinger AZ, Bisantz A, Fairbanks RJ. Identifying information requirements of emergency medicine nurses and physicians. Poster presented at: *International Symposium on Human Factors and Ergonomics in Health Care*; March 6, 2017; New Orleans, LA.
22. Benda N, Hettinger AZ, Hoffman D, McGeorge N, Berg R, Franklin E, Roth E, Fairbanks RJ, Bisantz A. Analyzing communication events in the emergency department: What insights can be drawn from physician-nurse communication?. Lecture presented at: *International Symposium on Human Factors and Ergonomics in Health Care*; April 17-19 2016; San Diego, CA.
23. McGeorge N, Benda N. Analysis of screen use and transition patterns for novel EDIS displays. Poster presented at: *International Symposium on Human Factors and Ergonomics in Health Care;* April 15, 2016; San Diego, CA.