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Assessment of Innovative Emergency Department Information Displays in a Clinical Simulation Center

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SUPPLEMENTARY MATERIAL

The online supplementary material is available at http://edm.sagepub.com/supplemental.

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Abstract

The objective of this work was to assess the functional utility of new display concepts for an emergency department information system created using cognitive systems engineering methods, by comparing them to similar displays currently in use. The display concepts were compared to standard displays in a clinical simulation study during which nurse-physician teams performed simulated emergency department tasks. Questionnaires were used to assess the cognitive support provided by the displays, participants' level of situation awareness, and participants' workload during the simulated tasks. Participants rated the new displays significantly higher than the control displays in terms of cognitive support. There was no significant difference in workload scores between the display conditions. There was no main effect of display type on situation awareness, but there was a significant interaction; participants using the new displays showed improved situation awareness from the middle to the end of the session. This study demonstrates that cognitive systems engineering methods can be used to create innovative displays that better support emergency medicine tasks, without increasing workload, compared to more standard displays. These methods provide a means to develop emergency department information systems —and more broadly, health information technology—that better support the cognitive needs of healthcare providers.

Keywords

cognitive systems engineering; design evaluation; healthcare delivery; human in the loop simulation

INTRODUCTION

Background

Hospital emergency departments (EDs) are unique clinical environments characterized by high acuity patients, intense time pressure, and unpredictable patient arrivals. Providers (physicians and advanced-practice providers) working in the ED must cope with high levels of patient activity that create high cognitive workloads and high decision density (Croskerry & Sinclair, 2001; Schenkel, 2000). In addition, patient information is exchanged in an environment with frequent interruptions, distractions, and multitasking. Tasks including patient hand-offs, procedures, documentation, teaching, and consulting must be conducted while maintaining situation awareness of patient flow and individual patient status (Chisholm, Collison, Nelson, & Cordell, 2000). Thus, ED team communication and coordination is critical for delivering safe, high-quality care (Bagnasco et al., 2013; Fairbanks, Bisantz, & Sunm, 2007; Kilner & Sheppard, 2010; Redfern, Brown, & Vincent, 2009), with teamwork and communication also playing a role in improving both patient and staff satisfaction (Kilner & Sheppard, 2010).

ED patient status boards (also known as patient tracking boards) are one tool commonly used to manage the challenges and cognitive stresses present in the ED (Laxmisan et al., 2007). ED status boards are used by multiple ED staff members, such as physicians, nurses, and technicians, in order to track the demographic information, health status, plans, and assigned caregivers for each patient in the ED. ED status boards have been shown to provide individual memory support, facilitate scheduling and shared cognition between team members, and allow for asynchronous communication events (Hertzum & Simonsen, 2015; Xiao, Schenkel, Faraj, Mackenzie, & Moss, 2007). Furthermore, observational studies in EDs have shown that a wide variety of information is displayed by status boards and frequent provider communication events occur at these boards, establishing their role as critical information artifacts in the ED (Bisantz et al., 2010; Wears, Perry, Wilson, Galliers, & Fone, 2006).

As part of the widespread implementation of computerized health records and processes, ED patient status boards have transitioned from dry-erase whiteboards to electronic emergency department information systems (EDISs). The benefits of these systems include the integration of information from other electronic medical record systems, increased information storage, information recovery, and the ability to use the system from any computer terminal (Bisantz et al., 2010). Although the implementation of electronic health systems is aimed at improving care, there have been unforeseen consequences that have limited the anticipated benefits (Hertzum & Simonsen, 2013). Current EDISs often exhibit a similar format to that of previous whiteboard versions (Bisantz et al., 2010). These electronic systems may lack important features present in the manual versions, particularly with respect to implicit communication among providers and tracking of work and patient progress (Bisantz et al., 2010). These limitations in the new electronic systems may lead to new sources of error (Fairbanks et al., 2008). For instance, previous work (Bisantz et al., 2010) that documented the transition from manual to electronic patient status boards identified unanticipated effects, including changes in communication and coordination. The

design of the new electronic status board made it difficult to document and track patient progress. As a result, physicians carried personal notes regarding patient status, resulting in a loss of information that was previously visible and easily shared with other clinical staff. An unanticipated use for the new system was its use to track patients' dietary needs and provide lists of diets to meal delivery staff. This new use was a benefit to some, but constraints on space meant that there was less space for clinical information (Bisantz et al., 2010; Pennathur et al., 2007; Pennathur et al., 2008).

Cognitive Systems Engineering (CSE) in Healthcare

Cognitive systems engineering supports human performance in complex, dynamic environments by providing a better understanding of human-technology systems and by providing insight for design (Bisantz, 2008; Bisantz & Roth, 2008; Rasmussen, Pejtersen, & Goodstein, 1994). CSE methods have been successfully applied to interface design in a variety of safety-focused industries including defense (Naikar, Moylan, & Pearce, 2006), process control (Jamieson, Miller, Ho, & Vicente, 2007), and aviation (Ahlstrom, 2005; Seamster, Redding, & Kaempf, 1997).

Within healthcare, use of CSE methods have aimed to characterize the complexities and demands of the environment as well as concentrated on the design of new technology and the impact of its implementation (Bisantz, 2008). One such complexity is communication and coordination within healthcare teams. Information displays (e.g., EDISs) are used to support this collaboration by fulfilling administrative and management needs (e.g., providing information about personnel, workload distribution, resource status), providing decision-making support (e.g., care algorithms), and sharing information among people (Parush, 2015). Gaining an understanding of the environment in terms of workflow, communication patterns, and information needs provides a clearer picture of the design requirements for any type of information display and should motivate their design. For example, Parush (2015) and Parush et al. (2011) used CSE methods to create information displays in support of cardiac surgical teams. An evaluation showed that the displays depicted information effectively, that clinicians understood the information, and that situation awareness was supported. Other work has also been completed using CSE methods, with the goal of improving the healthcare environment, for example in burn intensive care (Nemeth et al., 2015) and at the healthcare organizational level to demonstrate a framework for use of CSE concepts to improve patient safety (Xiao & Probst, 2015).

Cognitive work analysis, a particular CSE method, has been applied to the healthcare domain for over 20 years (Jiancaro, Jamieson, & Mihailidis, 2013). "Its goal is to help designers of complex sociotechnical systems create computer-based information support that helps workers adapt to the unexpected and changing demands of their jobs. In short, cognitive work analysis is about designing for adaptation" (Vicente, 1999, p. xiv). Previous work in applying cognitive work analysis to healthcare has had a focus on acute care such as in the intensive care unit (Effken, 2002), anesthesiology (Hajdukiewicz, Vicente, Doyle, Milgram, & Burns, 2001), and regarding trauma resuscitations (Sarcevic, Lesk, Marsic, & Burd, 2008). Specific cognitive work analysis research has focused on issues related to medical informatics, error investigation (Lim, Anderson, & Buckle, 2008), and decision

support (Effken, Brewer, Logue, Gephart, & Verran, 2011). Ecological interface design, a methodology that relies on cognitive work analyses, has also been applied in healthcare. Displays created using ecological interface design methods make apparent the various constraints and complexities of the system in a way that facilitates effective action for users to complete objectives in their environment (Burns & Hajdukiewicz, 2004). Various studies applying ecological interface design to healthcare interfaces have shown improved results when compared to standard displays. For example, application of ecological interface design in the intensive care unit demonstrated greater user satisfaction and potentially greater efficiency with the ecologically designed displays, although there was little change regarding recognition speed and overall cognitive workload (Effken, Loeb, Kang, & Lin, 2008). A study using ecological interface design methods in a neonatal intensive care unit found that physician performance improved with the new interface (Sharp & Helmicki, 1998) and a study developing interfaces on mobile devices for diabetes management demonstrated that performance was better and user satisfaction was greater on the ecological interface compared to the standard interface (Kwok & Burns, 2005).

Thus, although CSE methods have been successfully applied to design interfaces in a range of industries, including healthcare, there has been limited application of CSE methods in emergency medicine or to design aspects of health information systems. Using CSE methods may support design of information displays that provide necessary information more effectively. Our research goals were (a) to perform a CSE analysis of the ED and use the results to design novel information displays and (b) to evaluate the success of these methods using a clinical simulation study by comparing the new displays to those based on a currently implemented system. The remainder of this paper is organized as follows: an overview of the CSE analysis and display design process, followed by the evaluation study.

DISPLAY DESIGN

CSE Analysis and Display Design Process

The prototype displays were developed over a 2-year period using CSE, ecological interface design, and user-centered design methods. Responses from semistructured interviews with ED personnel along with information from three subject matter experts (R.J.F., R.L.W., S.P.) on the research team were used to create an abstraction hierarchy of the ED work system (Figure 1). Abstraction hierarchies represent relationships among system purposes, constraints, processes, and physical components of complex systems and can be used to identify information required to monitor and control such systems (Bisantz & Burns, 2008). For extensive descriptions on these methods and how to create such models, see Bisantz, Burns, and Fairbanks (2014), Bisantz and Roth (2008), Burns and Hajdukiewicz (2004), Naikar (2013), and Vicente (1999).

Information requirements identified from the model addressed the following:

- goals of providing quality care and serving as the gateway or gatekeeper to the hospital;
- constraints related to limited time, space, personnel, and equipment;

- processes involved with caring for patients, maintaining situational awareness over the ED, and communication and coordination among care providers; and
- system components such as staff, patients, facilities, and equipment.

Key insights derived from the modeling exercise included needs to:

- represent patients as they moved through phases of care from triage to disposition both individually, and across all patients;
- support quick assessment and comparison of waiting room patients;
- support identification of bottlenecks in care (such as unusual waits for testing or delays in reassessing patients); and
- support balancing workload across care providers.

See Guarrera et al. (2015) and Guarrera et al. (2012) for more details on the abstraction hierarchy models and information requirements identified.

These information requirements were next used as part of a multistep, iterative design process to develop innovative ED display concepts. A series of brainstorming and review sessions were held with members of the research team in order to develop and refine display concepts and to create a set of semifunctioning displays using Adobe Flash Builder (Version 4.6; Adobe, 2010). Of particular note were several new information concepts and system variables identified through the CSE analysis that had not typically been shown in patient tracking systems. One advantage of using CSE methods that include models of the work domain is that new variables necessary for monitoring and control can be identified, including those that are not currently included in system interfaces and, in some cases, those that are not currently being measured (Burns, Bisantz, & Roth, 2004). The new displays included variables such as patient pain level, the time beds have been occupied, and wait times for laboratory tests. These variables may be available but may not be synthesized or salient in current systems. For instance, the ED status display (one of the final prototype displays) combined eight indicator variables to give an at-a-glance indication of whether the ED was meeting high-level goals. Other concepts, such as explicit representation of the phase of patient care, were novel. This concept represented patients as they moved through five care phases (in waiting room, in ED bed waiting to been seen, assessment and treatment, orders complete/needs reassessment, and ready for discharge or admission) and was used in several of the display panels to support care coordination and flow (e.g., by conveying that orders are complete [therefore, time to recheck the patient], or which patients are discharged but still in a bed).

The initial display concepts were evaluated by ED physicians and nurses who used the displays to perform think-aloud tasks, including an orientation (i.e., after returning from a resuscitation) and planning (i.e., transitioning to a new shift) task. Assessments were generally positive, and feedback was used to create a final set of displays (Clark et al., 2014).

Final Prototype Displays

The final set of displays comprised seven display areas, with condensed/miniaturized views of each display provided on an overview display (Figure 2). The overview display was used to navigate to the seven detailed, full-screen displays.

The seven display areas were as follows (clockwise from upper left of Figure 2):

1. Waiting Room: information about waiting room patients, including triage acuity score, wait duration, demographics, initial complaint, as well as pending ED arrivals. The detailed display had two primary components: (a) a “timeline” view, in which small bars representing individual patients moved along a horizontal axis representing time, and (b) detailed patient views, where information on up to four patients at a time could be viewed and compared. Five color-coded timelines stacked vertically correspond to five triage acuity score levels, and patient details could be obtained by hovering or clicking on the small bars.
2. ED Patient Flow: line graphs of number of patients, over time, in the five phases of treatment (e.g., waiting room, being treated, dispositioned), accompanied by historical trends (dashed lines).
3. ED Status: overview of ED state based on the following eight key indicator variables: number of patients in the waiting room, number of patients in the ED, percentage of patients boarding, average patient pain level, average time to first evaluation by a physician, average time to first medication, number of patients who left without being seen, and average patient length of stay. Variables were arranged in a “spider” chart format and color-coded according to whether their values were acceptable (green), approaching unacceptable (yellow), or unacceptable (red). If all variables were in the acceptable range, the entire chart collapsed to a small green octagon; approaching unacceptable and unacceptable variable values distorted the shape and added yellow and red triangular areas, respectively. The detailed view provided variable names as well as the current and various threshold values for each variable.
4. ED Beds: display of available and unavailable beds in the ED and inpatient units (e.g., Floor, ICU). ED beds were represented as stacked squares and were categorized as empty, unavailable, or in use. In-use beds were further categorized according to the length of time they had been occupied and color-coded to indicate the occupying patient’s phase of care. Patient details could be obtained by hovering on the squares.
5. Resources and Equipment: bar graphs representing queue length and waiting time (current and historical averages) for laboratory, imaging, and consultant resources.
6. Staff Workload: Information about the number of patients assigned to each staff member was presented as a series of segmented bar graphs—one

graph per staff member, one segment per patient. Segment length corresponded to the estimated workload associated with that patient (in this study, it was directly proportional to the patient's triage acuity score) and the length of the whole bar corresponded to a particular staff member's total workload.

7. Patient Progress Overview: Evoking the traditional ED patient status boards, this display showed patient demographics, chief complaint, staff assignments, vital signs, and order information for all patients in tabular form. A color-coded timeline bar to the left of each patient represented the length of time they had spent in each of five phases of treatment. Clicking on a single patient would bring up a detailed view of patient information including order details and results, as well as staff comments.

Overall, the displays represented information related to purposes of providing quality care and serving as the "gatekeeper" or entrance to the hospital—essentially, supporting activities related to the management of patient care and patient flow through the ED; constraints related to timeliness of treatment/appropriate triaging, patient physical constraints, time constraints, flows of patients, and various resource-demand balances (testing, staff, etc.); processes related to caring for the patient, maintaining situation awareness, and communication/coordination; and system components such as patient states, personnel workloads, and availability of required laboratory and imagining facilities.

For additional information regarding the displays as well as the design process, see Guarrera et al. (2015).

EVALUATION STUDY: METHODS

Participants

Sixteen physicians and 16 nurses with emergency medicine experience were recruited from EDs within an academic healthcare system. Participants were recruited individually and then scheduled as nurse-physician teams based on availability. Data from the first two teams (four participants) were not analyzed due to technical problems with the simulation software, which resulted in lost data. Self-reported demographic data were obtained, with incomplete data obtained for nine participants (Table 1). All participants provided written consent and were compensated US$250.00 for their time. Research procedures were approved by the relevant institutional review boards.

Study Setting

The study was conducted at a clinical simulation center that was part of an academic hospital system. The set-up included two computer workstations showing the displays (one each for the physician and nurse), one large screen monitor showing the displays, and two bays where patient mannequins could be treated. Figure 3 shows the experimental set-up.

Independent Variables

There were two independent variables included: participant role (nurse vs. physician) and display type (prototype vs. control).

Prototype display—The prototype displays consisted of the seven display areas described above.

Control display—The control display closely mimicked the primary display of an existing information system used in hospitals where participants worked. This control display showed mock patient information in rows and columns, including content related to patient demographic, chief complaint, vital sign, order/result information, and comments (Figure 4). Participants could obtain additional information about orders by clicking in the lab, imaging, or x-ray order columns. A pop-up box containing information about all orders and their results would then be shown. This feature varied slightly from the actual clinical system that was in use by the healthcare workers, but this information was provided so participants in the control condition had the same access to order details as in the prototype condition.

Task Scenarios

Patient and ED data—Representative, fictional patient cases and ED characteristics were created to populate the displays and were identical between display conditions. Demographic and clinical information about each patient (e.g., name, age, gender, initial complaint, triage acuity score) along with time-stamped events and data related to the patient's ED visit (e.g., arrival and triage, orders, results, disposition) were generated by combining fictional patient details used in a previous study (Pennathur et al., 2010) with additional information (e.g., additional labs and test results, information about the size of the ED, staffing levels) added by four members of the research team with emergency medicine experience. General characteristics (e.g., rate of patient arrivals, percentage of patients with different incoming triage scores) were based on empirical studies in an actual ED (Pennathur et al., 2010). The study displays did not have any links to more detailed charts or hospital systems.

Information content—Information content was controlled so that similar data about patients were present in both display conditions. As is typical with CSE-informed displays, the prototype displays provided integrated and derived measures, often in graphical formats, which could be inferred or computed from information on the control display. For instance, the prototype displays showed "average" pain level across the ED, whereas within the control display only individual pain values were provided. Comments in the control condition were used to indicate patient information such as allergies that were present graphically on the prototype. Some ED and hospital-level information identified through the CSE methods is not typically found in current systems and was therefore not included in the control condition. This information included historical data about patient flows and wait times for resources, hospital bed availability, average times to first doctor assessment or medication administration, number of patients that left without being seen, and incoming or anticipated patients (though careful monitoring of patients in the control condition could

have provided some sense of these variables, which is the method used to currently track these types of measures in many systems).

Study Design

Participants performed the study as a nurse-physician team (each team consisted of one nurse and one physician; participants did not assume alternate "roles" for study purposes). Teams were randomly assigned to either the prototype or control display condition.

Dependent Measures

Cognitive support objectives ratings—The ability of the displays to support various cognitive objectives was assessed using 19 questions developed by the research team regarding the ability of the displays to support high-level objectives in ED oversight and patient care. This questionnaire was based on one developed to evaluate military command-and-control displays (Truxler, Roth, Scott, Smith, & Wampler, 2012). Responses were made on a 9-point rating scale from *not at all effective* (1) to *extremely effective* (9), with the additional response option of *not experienced during session* (NA).

Situation awareness—The Situation Awareness Global Assessment Technique (SAGAT; Endsley, 2000) was used to measure participant's level of situation awareness. This method employs a "simulation freeze" in which simulated tasks are stopped, information regarding the tasks is removed, and participants are queried regarding task-relevant information to assess their level of awareness of various aspects of the task and situation. Questions were developed to measure three levels of situation awareness: (a) information perception, (b) state comprehension, and (c) planning/projection into the future. Questions were administered at Phase 4 and Phase 8 (see "Experimental Session" subsection for experimental session phase descriptions). Each set (two different sets of questions, referred to as "question set" in analysis) included 15 multiple-choice questions (unique for each set) and one rating scale question (same for each set; range from 1 to 10). Example questions include the following: "Which of these patients is most likely to need an ICU bed?", "Which patient has a same name alert?", "Which nurse has the lowest patient workload right now?", and "Who might you guess will be most likely to have the next disposition decision?" Correct answers to the questions were determined by one of the subject matter experts (A.Z.H.) using the interface and information content displayed at the times of the simulation freezes. The entire SAGAT questionnaire is included (Supplemental Digital Content).

Workload—The NASA Task Load Index (NASA-TLX) was used to measure subjective workload based on six categories (physical demand, mental demand, temporal demand, performance, effort, and frustration) (Hart, 2006; Hart & Staveland, 1988).

Data Collection

SAGAT questions were administered halfway through and at the end of the session, and the cognitive support objectives questionnaire and NASA-TLX were administered at the end of the session. Additionally, three overhead cameras, four microphones (one at each computer workstation and one on each participant), and screen capture software were used to capture activities during the session. The physician also wore a portable eye tracking unit that

captured both audio and gaze data. This paper only presents results from the questionnaires (situation awareness, workload, and cognitive support ratings).

Procedure

Orientation—Upon arrival participants provided written informed consent, received an introduction to the goals of the study, were given a tour of the experimental set-up, and were oriented to how the patient mannequins functioned and the placement of supplies available for mannequin treatment. Participants were fitted with microphones and the eye tracker (for the physician).

Subsequently, participants heard a brief description of study components and watched a prerecorded computer demonstration showing how the displays worked, including available information and methods of interaction. Simulated patient and ED data used during this orientation were different than that used during data collection.

Experimental session—After orientation, the experimental session, which simulated a portion of an ED shift, started. During the session, a computer simulation was run to populate the displays with information about the ED and simulated patients, in real time. Staff assignments were included in the data profiles created to populate the displays, and the nurse-physician participant team was assigned to a set of patients for the session. These patients included the two patient mannequins and five additional "virtual" patients with whom participants did not directly interact but were able to monitor and submit orders for using the displays. At the start of the experimental session, participants listened to a 4-minute audio recording simulating provider sign-out that presented participants with information about their assigned patients. During this introductory period, participants could view and interact with the displays.

After the simulated sign-out, participants had 5 additional minutes to view and interact with the displays in order to learn about patients in the system. Then, the 45-minute computer simulation started. The computer simulation was used to update the displays with information about the patients in real time.

The 45-minute session had eight conceptual phases (Table 2), although participants experienced these phases as a continuous session. During Phases 1, 3, and 5, an experimenter provided participants with a variety of interruptions (e.g., phone calls, requests from colleagues) regarding patients represented within the displays in the form of paper requests; they responded by writing answers on the paper request. At the start of Phases 2 and 6, an experimenter announced that a patient who was either experiencing shortness of breath (Phase 2) or chest pain (Phase 6) had been brought in for treatment and directed participants to one of the two patient bays where they proceeded to provide care to the patient simulation mannequins, using typical patient simulation methods. After care was complete, participants returned to their workstations as they normally would during a shift in the ED. During Phase 7, the experimenter announced that there had been a multiple vehicle collision on a nearby highway and that the ED needed to prepare for a large number of incoming patients. This mass casualty incident interruption was intended to cause

participants to interact with all ED patients within the displays and not just with those to whom the participants were assigned.

As previously mentioned, at two points (Phases 4 and 8) the simulation was paused and participants were presented with 16 situation awareness questions. After the first set of situation awareness questions, simulation resumed. After the second set of situation awareness questions, the experimental simulation session ended and participants completed the workload and cognitive support questionnaires.

While participants were at their workstations, they were talking with their team member regarding patient care, writing orders, using the displays to review patient and ED information, as well as entering notes and comments for both mannequin and virtual patients.

Analysis

Statistical analyses were conducted on data from seven teams in each display condition using SAS 9.4. Analysis of variance (ANOVA) was conducted for the SAGAT, cognitive support objectives ratings, and NASA-TLX survey responses using a mixed model including the following factors: display type (prototype/control, between subjects), clinician role (physician/nurse, between subjects), survey item (question set, question or subscale, for SAGAT, cognitive support objectives ratings, and NASA-TLX, respectively, within-subjects), and subject nested within team (nurse-physician pair). Post hoc results are reported using Least Square Difference method and two-sample *t* test 95% confidence intervals. Additional characteristics of the SAGAT responses are also presented.

For the cognitive support objectives ratings, three of the physician participants (two prototype and one control condition) responded “NA” to one or more of the questions. For the NASA-TLX, one nurse participant using the control displays did not answer the questionnaire. Analysis was completed both using averages for these cells (within clinician role, display type, and question/subscale) and with these cases excluded from analysis; statistical results were the same in both cases. Results will be presented using the exclusion case.

RESULTS

Cognitive Support Objectives Ratings

Results for the cognitive support objectives ratings show significant main effects of display type ($F_{1, 426} = 5.68$, $p = .018$) and question ($F_{18, 426} = 4.60$, $p < .0001$). The interaction was not significant ($F_{18, 426} = 1.55$, $p = .068$). Support for cognitive objectives was significantly higher for the prototype compared to the control displays (5.72 vs. 4.53, respectively). At the question level, the prototype displays had higher cognitive support ratings for all except one question (Question 13), and post hoc testing indicated significant differences between the prototype and control displays for 7 of the 19 questions (Table 3).

Situation Awareness

There was a significant interaction between question set and display type for SAGAT scores ($F_{1, 21} = 4.56$, $p = .045$), but there were no main effects (Figure 5). Post hoc testing showed a significant difference in the percent of correct responses between question sets for the prototype displays ($t_{21} = -2.80$, $p = .011$). The average percent of correct responses increased from 35.6% on Question Set 1 to 49.2% on Question Set 2. Note that chance performance (based on the number of multiple choice answers) was 28%.

The rating question in each question set asked participants to choose a number from 1 (*running smoothly*) to 10 (*out of control*) to rate the current state of the ED. Responses on this question showed a significant display type main effect ($F_{1,24} = 4.91$, $p = .036$). Prototype display scores (6.23) were significantly greater (i.e., the ED was rated more "out of control") than control display scores (5.11).

Workload

There were no significant effects due to display type for NASA-TLX scores, but subscale was a significant main effect ($F_{5, 115} = 27.05$, $p < .0001$). Physicians had higher mean workload than nurses (50.96 vs. 40.22), but this effect was not significant ($F_{1, 115} = 3.31$, $p = .072$). Post hoc pairwise comparisons showed physical demand had significantly lower scores than the other five factors (all p values < .0001), reflecting the primarily cognitive nature of the tasks. The performance subscale was also significantly lower than the remaining four subscales (p values ≤ .026).

DISCUSSION

The primary purpose of this study was to assess the efficacy of innovative displays, developed using systematic CSE methods, for supporting the work of ED clinicians. In particular, prototype displays were compared to standard displays through a controlled experiment conducted in a clinical simulation environment. Although there has been continued discussion regarding the usability of health information technology systems, the focus is often on the basic user-interface design, such as the number of clicks, font, layout, and color (Perry, 2004). Although these factors are important, providing higher level support of the cognitive work of the end user is a critical and often underrecognized component of the overall usability of a system.

There were several important findings. First, the prototype displays were rated better with respect to the cognitive support objectives than the control displays, providing support for the use of systematic, CSE design that incorporate extensive knowledge elicitation and analysis of clinician work activities, information needs, and system constraints in the development of health information technology systems. Although CSE methods have been applied in other medical contexts (Jiancaro et al., 2013), to our knowledge this is the first application of these methods to the design of EDISs as well as the first to demonstrate the benefits of this approach through a clinical simulation study.

The concepts demonstrating improved support while using the prototype displays included those related to patient acuity, identifying the most critical patients, monitoring patient status

in the care process, and balancing workload across providers. Providing better support regarding these concepts is critical for improving the function of the ED, resulting in potentially better patient care and a generally more efficient ED.

The only cognitive support objective with a rating score not greater for the prototype compared to the control related to helping clinicians track individual patients under their care. There was no view within the prototype displays that showed only “your patients,” merely a view of all ED patients that could be sorted by provider. If this “your patient” view option was available, perhaps this support objective would have shown improvement with the prototype.

Second, although there was no overall difference in situation awareness between display conditions, there was a significant interaction between the display type (prototype/control) and question set (half-way through/at end of the 45-min session). Situation awareness for the prototype displays significantly improved from the first to second question set. This result suggests there was an effect of experience with the prototype displays. At first, participants using the prototype may have been at a disadvantage using the new displays, but with experience, situation awareness improved. Thus, participants were able to learn and take advantage of the new displays in a relatively short amount of time. This may imply that displays designed using CSE methods would better support situation awareness in the ED.

Participants using the prototype displays rated the ED as more “out of control” than the control display did (though both scores were greater than the neutral point on the scale), demonstrating different overall perspectives on the state of the ED. Although there is no objective measure of “out of control” for comparison, this result could be due to the fact that the prototype displays provided more explicit, graphic information that was particularly useful to the participants’ clinical work in the ED, such as information about the waiting time, severity of patients in the waiting room, status of beds as opened or filled, as well as an explicit representation of the ED status (the “spider” display). Taken together, this information may have allowed users a more direct assessment of the ED state.

Finally, despite the fact that the prototype included very different information representations and organization than the control display, there was no increase in workload as measured by NASA-TLX. This result is even more compelling given that the control display was very similar to displays that had been in use in the hospital system from which the participants had been recruited. Therefore, they were likely familiar with it. Thus, using the unfamiliar prototype displays did not result in increased workload in this study.

Limitations

The results from this study are based on a relatively small sample of participants. Gender demographics of the physicians in our sample differed from national statistics (75% male nationally vs. 36% male reported in our sample) (Association of American Medical Colleges, Center for Workforce Studies Colleges, 2012) but were similar for nurses (9% male nationally vs. 14% male reported in our sample) (U.S. Census Bureau, 2013); we did not attempt to balance gender due to the difficulty in recruiting experienced personnel for a relatively time- consuming study. Some participant teams may have worked together in real

ED shifts, which could have affected the results. Participant scheduling was done randomly within the constraints of participants' schedules to mitigate this issue. The scenario used was shorter in duration than a typical ED shift and therefore may not have been representative of all activity levels (i.e., lulls vs. busy periods), which may have affected the degree to which participants monitored the systems looking for changes. This could be investigated through additional study. Additionally, the study took place in a simulated environment, and the displays developed for this study were not designed to emulate a complete EDIS or full electronic health record and did not link to detailed patient charts. The use of an advanced clinical simulation center, as well as the development of detailed patient cases and sign-over information by a team of experienced emergency medicine physicians, helped to mitigate these limitations.

CONCLUSIONS

The present study demonstrated that the CSE methodology used to design these prototype displays was effective in creating displays that support the work of ED clinicians without increasing workload, with the additional potential for improved situation awareness. These results have important implications for the design of IT systems that support emergency medicine as well as other aspects of healthcare. Further analysis of participants' interaction with the prototype could be conducted to determine how and when the specific features and display areas were used. Such an analysis could guide future research to enhance the usability and usefulness of the different features of the displays. This study represents a rare comparison between a current type of EDIS with a novel, CSE-derived prototype for the ED, and as such provides valuable directions for future research and design.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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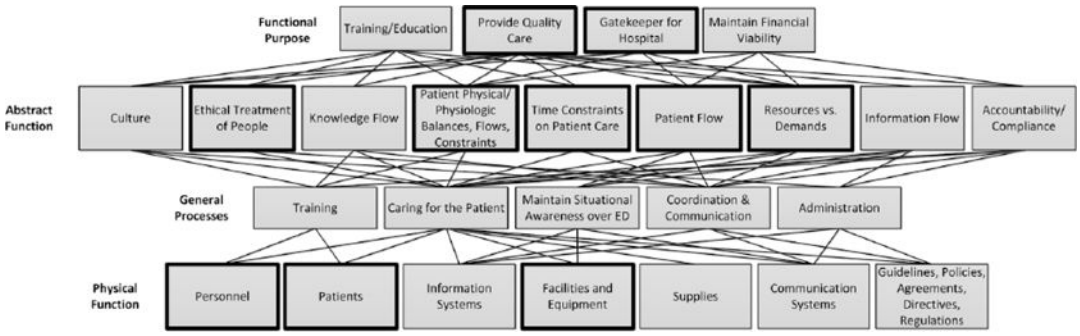


Figure 1.

Abstraction hierarchy, highlighted nodes made up the primary information displayed in the prototype screens. Copyright Ann Bisantz, University at Buffalo, The State University of New York.

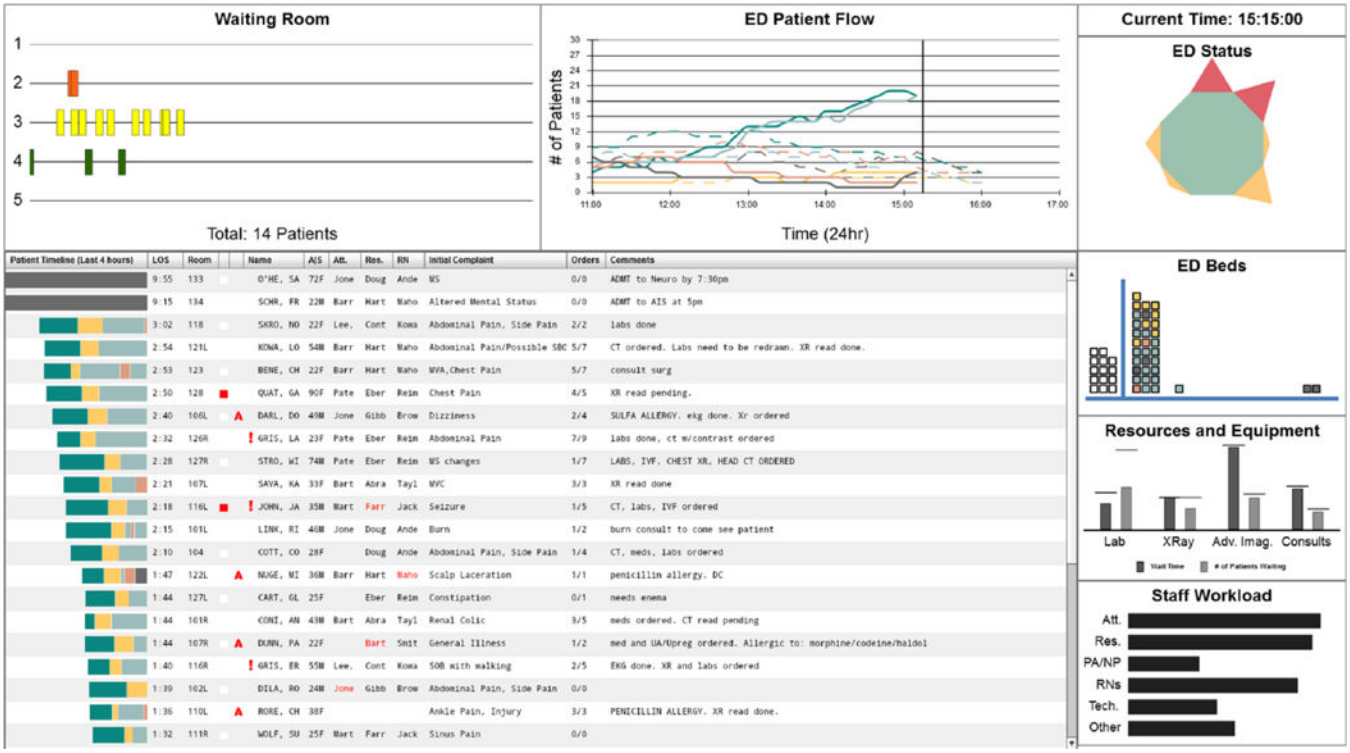


Figure 2.

The prototype overview display used to present a condensed/miniaturized version of the seven display areas and to navigate into those displays. Copyright Ann Bisantz, University at Buffalo, The State University of New York.

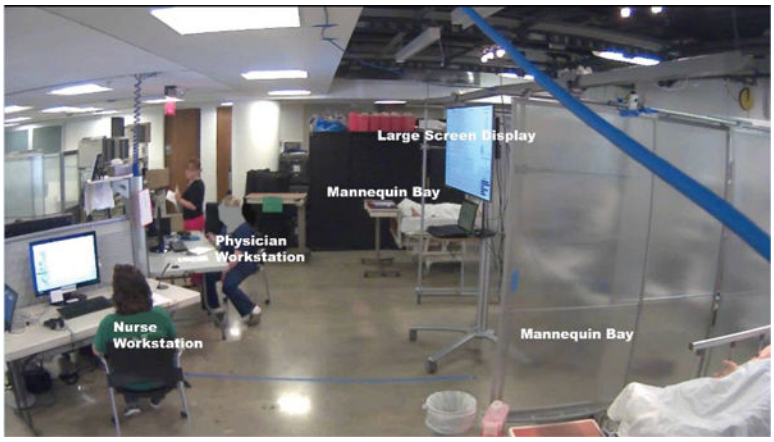
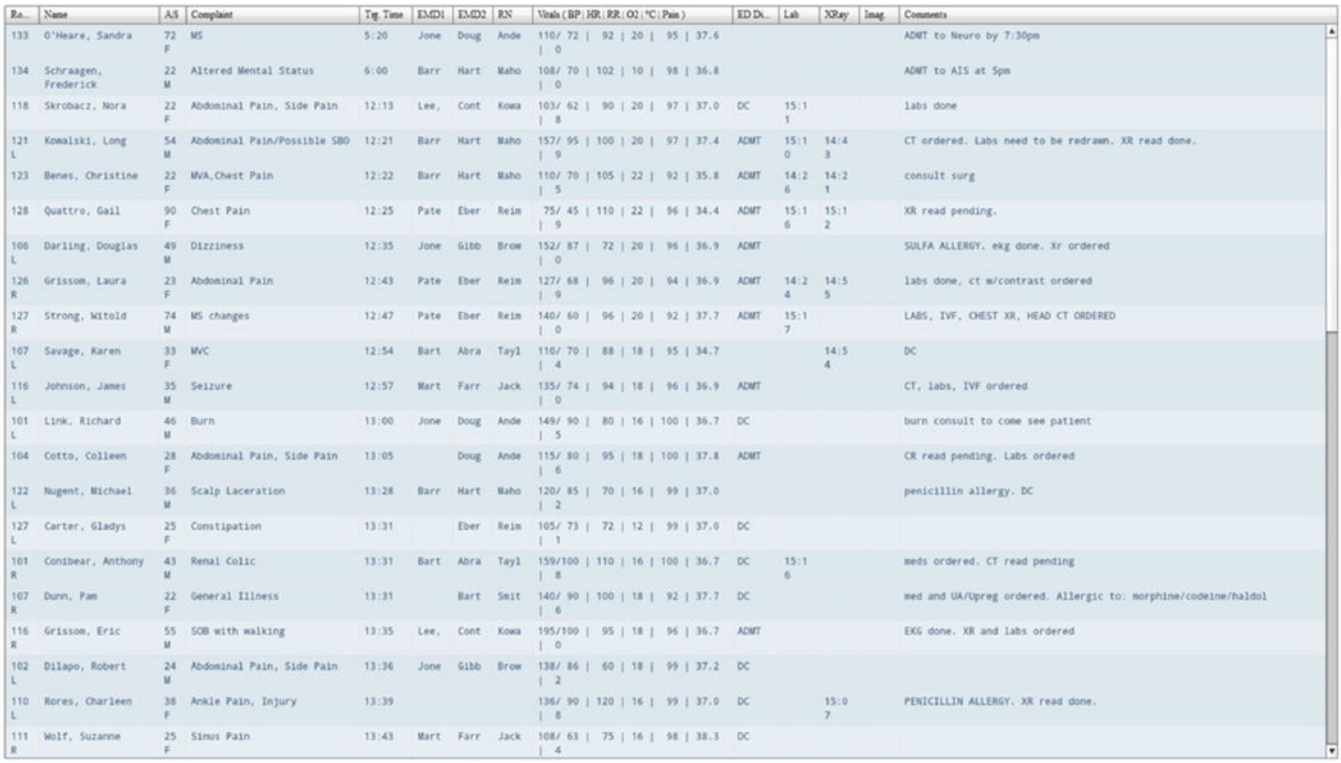


Figure 3.
Experimental set up.



Ro...	Name	A/S	Complaint	Tg. Time	EMD1	EMD2	RN	Vitals (BP | HR | RR | O2 | °C | Pain)	ED Dx...	Lab	XRay	Imag.	Comments
133	O'Heare, Sandra	72 F	MS	5:20	Jone	Doug	Ande	110/ 72 | 92 | 20 | 95 | 37.6 | 0					ADMT to Neuro by 7:30pm
134	Schraagen, Frederick	22 M	Altered Mental Status	6:00	Barr	Hart	Maho	108/ 70 | 102 | 10 | 98 | 36.8 | 0					ADMT to AIS at 5pm
118	Skrobacz, Nora	22 F	Abdominal Pain, Side Pain	12:13	Lee,	Cont	Kowa	103/ 62 | 90 | 20 | 97 | 37.0 | 8	DC	15:11			labs done
121 L	Kowalski, Long	54 M	Abdominal Pain/Possible SBO	12:21	Barr	Hart	Maho	157/ 95 | 100 | 20 | 97 | 37.4 | 9	ADMT	15:10	14:43		CT ordered. Labs need to be redrawn. XR read done.
123	Benes, Christine	22 F	MVA,Chest Pain	12:22	Barr	Hart	Maho	110/ 70 | 105 | 22 | 92 | 35.8 | 5	ADMT	14:26	14:21		consult surg
128	Quattro, Gail	90 F	Chest Pain	12:25	Pate	Eber	Reim	75/ 45 | 110 | 22 | 96 | 34.4 | 9	ADMT	15:16	15:12		XR read pending.
106 L	Darling, Douglas	49 M	Dizziness	12:35	Jone	Gibb	Brow	152/ 87 | 72 | 20 | 96 | 36.9 | 0	ADMT				SULFA ALLERGY. ekg done. Xr ordered
126 R	Grissom, Laura	23 F	Abdominal Pain	12:43	Pate	Eber	Reim	127/ 68 | 96 | 20 | 94 | 36.9 | 9	ADMT	14:24	14:55		labs done, ct w/contrast ordered
127 R	Strong, Witold	74 M	MS changes	12:47	Pate	Eber	Reim	140/ 60 | 96 | 20 | 92 | 37.7 | 0	ADMT	15:17			LABS, IVF, CHEST XR, HEAD CT ORDERED
107 L	Savage, Karen	33 F	MVC	12:54	Bart	Abra	Tayl	110/ 70 | 88 | 18 | 95 | 34.7 | 4			14:54		DC
116 L	Johnson, James	35 M	Seizure	12:57	Mart	Farr	Jack	135/ 74 | 94 | 18 | 96 | 36.9 | 0	ADMT				CT, labs, IVF ordered
101 L	Link, Richard	46 M	Burn	13:00	Jone	Doug	Ande	149/ 90 | 80 | 16 | 100 | 36.7 | 5	DC				burn consult to come see patient
104	Cotto, Colleen	28 F	Abdominal Pain, Side Pain	13:05		Doug	Ande	115/ 80 | 95 | 18 | 100 | 37.8 | 6	ADMT				CR read pending. Labs ordered
122 L	Nugent, Michael	36 M	Scalp Laceration	13:28	Barr	Hart	Maho	120/ 85 | 70 | 16 | 99 | 37.0 | 2					penicillin allergy. DC
127 L	Carter, Gladys	25 F	Constipation	13:31		Eber	Reim	105/ 73 | 72 | 12 | 99 | 37.0 | 1	DC				
101 R	Conibear, Anthony	43 M	Renal Colic	13:31	Bart	Abra	Tayl	159/100 | 110 | 16 | 100 | 36.7 | 8	DC	15:16			meds ordered. CT read pending
107 R	Dunn, Pam	22 F	General Illness	13:31		Bart	Smit	140/ 90 | 100 | 18 | 92 | 37.7 | 6	DC				med and UA/Upreg ordered. Allergic to: morphine/codeine/haldol
116 R	Grissom, Eric	55 M	SOB with walking	13:35	Lee,	Cont	Kowa	195/100 | 95 | 18 | 96 | 36.7 | 0	ADMT				EKG done. XR and labs ordered
102 L	Dilapo, Robert	24 M	Abdominal Pain, Side Pain	13:36	Jone	Gibb	Brow	138/ 86 | 60 | 18 | 99 | 37.2 | 2	DC				
110 L	Rores, Charleen	38 F	Ankle Pain, Injury	13:39				136/ 90 | 120 | 16 | 99 | 37.0 | 8	DC		15:07		PENICILLIN ALLERGY. XR read done.
111 R	Wolf, Suzanne	25 F	Sinus Pain	13:43	Mart	Farr	Jack	108/ 63 | 75 | 16 | 98 | 38.3 | 4	DC				

Figure 4.

The control display, closely mimicking the primary display of an existing information system used in hospitals. It shows mock patient information in a row and column format. Copyright Ann Bisantz, University at Buffalo, The State University of New York.

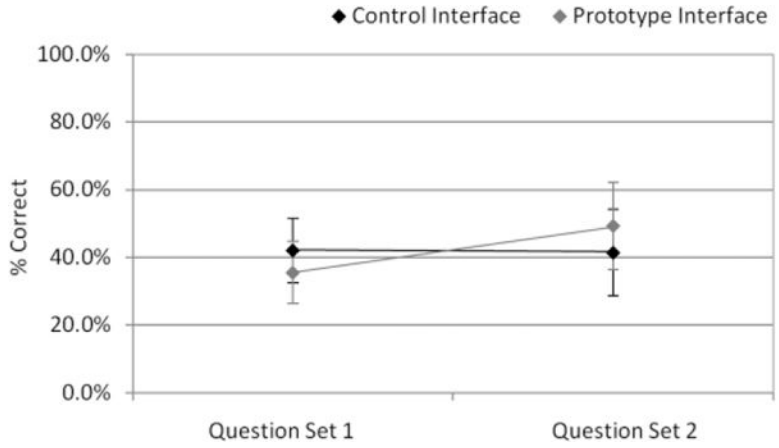


Figure 5.
Situation awareness results, significant interaction between question set and display type.

TABLE 1

Participant Demographic Information

	Gender		Age		
Clinician Role	**Male (7)**	**Female (21)**	***M***	***SD***	***n***
Physician - Attending	1	5	38.0	9.1	6
Physician - Resident	2	4	27.2	1.3	6
Physician - Unknown type	2	0		—	
Nurse	2	12	34.6	10.9	7

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TABLE 2

Conceptual Phases During Experimental Session

Phase	Time	Content
1	5 min	Interface use and interruptions
2	10 min	Treat patient mannequin with shortness of breath
3	5 min	Interface use and interruptions
4	10 min	Situation awareness questions
5	5 min	Interface use and interruptions
6	15 min	Treat patient mannequin with chest pain
7	5 min	Interface use and mass casualty motor vehicle collision notification
8	10 min	Situation awareness questions, then workload and cognitive support questions

TABLE 3

Cognitive Support Objectives, Rating Results for Each Question

Cognitive Support Objectives Question	Prototype Mean Rating	Control Mean Rating	95% Confidence Interval (Difference)
1. Assess the overall state of the ED (is it a good day or a bad day?)	5.62	5.07	(−2.02, 0.93)
2. Assess whether you have the resources required (e.g. beds, staffing) for the current patient demand	5.75	5.29	(−1.93, 1.00)
3. Project whether you will have the resources required (e.g., beds, staffing) to meet demands for the next few hours (e.g., anticipating arrivals, discharges, admissions, etc.)	4.83	4.50	(−2.01, 1.35)
4. Support effective communication and coordination among ED staff	5.86	5.00	(−2.20, 0.49)
*5. Maintain awareness of overall acuity of patients waiting and currently being treated (do we have lots of sick patients, or are they mostly nonacute?)	5.93	4.36	(−3.14, 0.00) *
*6. Identify which patients are most critical	5.71	3.64	(−3.56, −0.59) *
*7. Maintain awareness of acuity and changes in acuity of individual ED patients	4.79	3.21	(−2.86, −0.28) *
8. Identify which patients have been in the ED the longest	7.36	6.14	(−2.71, 0.28)
*9. Identify where patients are in the care process (across all patients)	7.21	4.29	(−4.36, −1.50) *
10. Identify where only my patients are in the care process	5.21	5.07	(−2.03, 1.75)
11. Identify bottlenecks or hold-ups preventing overall patient flow through the ED	4.64	3.57	(−2.44, 0.30)
12. Identify hold-ups in the care of an individual patient	5.36	4.21	(−2.42, 0.13)
13. Support effective communication and coordination among ED staff, in regard to an individual patient and that patient's treatment plan	5.21	5.21	(−1.65, 1.65)
14. Support effective planning for individual patient care	6.14	5.21	(−2.41, 0.55)
*15. Provide support for prioritizing your tasks	5.43	3.79	(−3.25, −0.04) *
16. Identify the next patient I should sign up for (e.g., patients that need to be seen out of order or seen from waiting room)	6.15	4.00	(−3.20, 0.38)
17. Understand whether individual patients are waiting for you to assess or treat them (i.e., if you are the hold-up)	5.50	4.07	(−3.24, 0.38)
*18. Assess the current state of the ED with respect to balancing patients and workload across providers	6.43	4.79	(−3.17, −0.12) *
*19. Support effective communication and coordination among ED staff, in regard to balancing patients and workload across providers	6.14	4.36	(−3.27, −0.30) *

* $p < .05$.