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What is This?
Integrated Information Displays for ICU Nurses: Field Observations, Display Design, and Display Evaluation

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Preventable adverse events are one of the leading causes of patient mortality in hospitals. Many of these adverse events occur in Intensive Care Units (ICUs) where nurses often work under cognitive, perceptual, and physical overloads. One contributing factor to these overloads is the display of treatment orders, monitoring information, and equipment status on numerous, spatially separated information displays. If these separate displays were combined into a single integrated display at the bedside, the display could potentially reduce nursing workload and improve nurse awareness of the patients’ treatment plans and physiological status. We performed a study with three parts. First, we observed ICU nurses at work and found that task-relevant information was often presented in a sub-optimal format, it was unavailable at the point of care and/or it was laborious to retrieve. Second, we designed an integrated information display that presents the information needed by nurses at the patient bedside in a more optimal format. Finally, we evaluated paper-based prototypes of both the integrated display and existing ICU displays with pilot participants. The results for participants in a pilot study showed that nurses using the integrated display could answer questions about the patient’s status and treatment significantly faster and more accurately. Integrated displays could potentially reduce adverse events in ICUs and reduce cognitive overloads.

Medical errors are widespread and often result in significant harm to patients. Up to an estimated 98,000 annual deaths in US hospitals alone are attributed to preventable adverse events (Kohn, Corrigan, & Donaldson, 1999). A portion of the errors could be attributed to the ICU setting and the significant cognitive overload of ICU nurses’ work (DeLucia, Ott, & Palmieri, 2009). Cognitive overload is exacerbated by the poor ergonomics of information displays in the ICU (Alexander & Staggers, 2009). Improving the design of information displays could potentially reduce nurses’ workload and thereby reduce medical errors (Morrow, North, & Wickens, 2005).

Nurses monitor patients, manage medications, provide direct patient care, and plan future treatments using information presented on electronic displays such as patient monitors, ventilators, and electronic medical records (Hendrich, Chow, Skierczynski, & Lu, 2008). However, the myriad of displays are typically located on the specific devices, grouped by device function, rather than by nursing tasks. To perform their tasks, nurses must seek and mentally integrate information from multiple displays in different physical locations. Indeed, information displays would help nurses detect significant changes in patient status by presenting the right information at the right time (Stead, Miller, Musen, & Hersh, 2000).

Several authors have argued that this can be achieved with a single integrated information display at the patient’s bedside (Egan, 2006). Prior research has shown that integrated graphical displays of multiple patient variables can help anesthesiologists detect significant changes faster than when they use traditional displays (Michels, Gravenstein, & Westenskow, 1997; Tarassenko, Hann, & Young, 2006; Zhang, et al., 2002). However, it is unclear whether presenting task-relevant information required by nurses on a single, integrated display would help them perform their tasks faster or more accurately. Situation awareness was chosen as the conceptual framework for our research.

To address nurses’ information needs at the bedside through an information display, we performed three steps (see Figure 1): 1) field observations of nurses’ information needs, 2) display design, and 3) evaluation of the new display.

FIELD OBSERVATIONS

The goals of the field observations were 1) to identify the types of information needed by nurses at the patient’s bedside, and 2) to determine whether any information deficits existed that led to a decreased level of situation awareness. For example information that is not readily available at the point of care or information presented in a sub-optimal format can be laborious to retrieve.

Methods

Nineteen ICU nurses were observed using an ethnographic approach for two hours each during their regular day shifts at three different types of ICUs (Medical-, Surgical-, and Shock Trauma ICU). Two observers recorded the tasks performed by nurses and the type of information required to complete the tasks.
Figure 1: Overview of the integrated display development. a) observations of nurses revealed that information was often presented in a sub-optimal format, unavailable at the point of care or laborious to retrieve. Designs in b) and c) include an integrated display developed and refined through an iterative user centered approach based on nurses’ preferences and performance. The evaluation of paper prototypes of the integrated display in d) and existing devices showed that nurse answered patient care related questions faster and more accurately with the new device.
Observational data were coded into categories representing similar types of tasks performed by nurses. Implications for display design were determined through analysis of the observations using an affinity diagram to identify unsatisfied information needs.

Results

Nurses used a total of seven distinct information displays to complete their routine tasks (see Figure 1a). Deficiencies in information support for nurses were in four main areas. First, half of the identified tasks required them to gather information from two or more separate displays. Second, information on medication compatibility, monitoring needs, and protocols for rarely performed procedures was not readily available at the bedside. Third, to retrieve information about compatibility, protocols, and medication orders, nurses had to log into a system located outside the patient’s room and navigate its unintuitive interface – a laborious and time-consuming task. Finally, when nurses performed in-room tasks related to one patient they were not automatically informed of changes in orders and equipment settings related to the second patient under their care.

Medication administration was a particularly challenging task (see Figure 2). To administer a medication, nurses needed to know the medication order, compatibility of the medication with the patient’s existing and prior medications, and possible side effects of the new medication – but none of this information was readily available at the bedside. Nurses had to retrieve the required information from five different displays: intravenous infusion pumps, electronic medical record, medication reference library (compatibility and adverse effects), and the patient monitor. Nurses’ approach to work was found to be proactive (desire for high awareness of patient and treatment), or reactive (acting upon alarms and urgent problems).

DISPLAY DESIGN

The aim of the display design was to develop a single, integrated information display for ICU nurses that would address the information gaps and deficiencies with the displays currently used in practice (as identified in the field observations). The goals for this display were to support both nurses’ approaches to work (proactive and reactive), to create a display which was very intuitive and to enable nurses to correctly extract information.

Different design alternatives were explored and the prototype was iteratively adapted in seven design iterations to satisfy nurses’ preferences, information needs, to be intuitive, and to allow correct extraction of information.

Methods

First, nurses evaluated three design iterations while viewing paper-based prototypes in three semi-structured interview sessions. Then four display iterations were refined based on nurses’ answers to multiple choice questionnaires showing prototype details.

For the first interview session, nurses were asked for their preferences on three design alternatives. These design alternatives were created based on the information deficits identified and nurses’ proactive and reactive approaches to work (field observations). The urgency-centered design alternative (Figure 1b left) supported reactive work, and the vital sign-centered visualization (Figure 1b center) supported proactive work. The enhanced traditional visualization (Figure 1b right) had the goal to support both work approaches. The second and third interview session asked nurses to identify the required information content and interaction.

The information presentation was refined in four iterations using nurses’ answers to multiple choice questions asking them to identify display elements and extract information. For the last prototype nurses were asked to rate the support of nursing workflow of the new display compared to displays they currently use.
Results

Initial descriptive results indicated that nurses preferred a conventional information layout with medication management support. Nurses rated the resulting new prototype display more highly in support of nursing workflow than the display they currently use. By the last iteration, nurses identified 96% of the design elements and extracted 97% of the displayed information accurately.

DISPLAY EVALUATION

The next step was to determine if the integrated information presentation improves the efficiency and effectiveness of nursing tasks. We report the results of the pilot study – a final evaluation is underway.

The goal of the evaluation was to identify whether ICU nurses using our novel integrated information display would have a higher level of situation awareness of patients and treatments and faster response time compared to current displays. We evaluated a paper-based prototype of our integrated display because the integrated display requires functionality not available in existing medical devices such as the ability to control the operation of infusion pumps remotely.

Methods

The design was a 2 (Traditional vs. Integrated) display by 3 (medication management, patient treatment, and team interaction) scenarios repeated-measures design. Scenarios and displays were counter-balanced. We operationalized the three levels of situational awareness as follows: perception as recognition accuracy, comprehension as accurate situation model, and projection as the accuracy of future estimation of events. Performance was measured as response time (in sec).

The pilot study was conducted in an ICU break room. Four ICU nurses completed the study and answered 34 questions about information on the displays. The questions required nurses to identify information from the displays relevant to the types of tasks identified during the field observations. All devices were represented on paper using the same size and colors as the real devices. Participants entered their answers into a custom web-based measurement tool that recorded the accuracy of answers and response time.

Results

Participants using the integrated display answered 84% of the questions correctly vs. 63% for participants using the traditional displays (p = 0.02, Fishers exact test). Correct answers ranged from 71% to 94% using the integrated display compared to 58% to 71% using traditional displays.

Median response times were 21 sec. and 33 sec respectively (p>0.01, $\chi^2=13.8$, Friedman’s Repeated Measures ANOVA). Median response times ranged from 21 to 35 sec using the integrated display and from 28 to 54 sec using the traditional displays.

DISCUSSION

Nurses were found to have deficiencies in information support which required them to gather information from multiple displays, information was not readily available at the bedside, and nurses were not automatically informed of changes in orders and equipment settings.

The integrated display prototype we designed addressed these deficiencies, increased information availability at the bedside and reduced the various required displays to just one. Information which is distributed over several tabs and screens on traditional devices was directly accessible or could be
obtained with a single click. For example in medication administration (Figure 3) using the new display saved nurses looking at three screens and leaving the room twice.

Results from the pilot evaluation suggest that nurses have increased situation awareness of patients and treatments with the new integrated display – a final evaluation is underway. Using the integrated display compared to traditional devices, nurses had higher situation awareness and faster response times.

Other research confirms that nurses are struggling to perceive all relevant information (DeLucia, et al., 2009; Potter, et al., 2005), and that many nursing tasks are not completely supported by a single display (Weir, et al., 2007). In other studies, nurses preferred new displays over the ones they currently had (Ireland, James, Howes, & Wilson, 1997; Miller & Sanderson, 2003; Thursky & Mahemoff, 2007). Other research in health care settings confirms that integrated information displays can increase situation awareness, e.g. for anesthesia (Zhang, et al., 2002), and can decrease detection time (Michels, et al., 1997).

The generalizability of our findings is limited because the paper prototypes did not allow system interaction and the screens with relevant information were directly provided. Furthermore, the decision about information visualization on the display was based on nurses’ preferences – a decision based on practice with novel designs might have resulted in another selection. During the design, we did not control for repetitive exposure, but also did not reveal the correct answers to the questions. However, this might have influenced improvement in information extraction. The evaluation did not require that nurses use devices in different locations as they would traditionally. Therefore our time measurement might not be representative. Finally, participants in all three studies were from the same hospitals, using standard devices. Therefore, the integrated display might address and solve specific problems occurring with these particular devices and in this specific setting.

Future research could evaluate if integrated displays can support other nursing tasks, and if these displays improve nurses’ performance in simulated or real ICU settings. Other studies might examine this effect in different hospitals and in simulated environments with actual devices. Other design ideas and their influence on situation awareness could be explored as well. Designers must take into account trade-offs between minimizing display clutter and satisfying the information requirements for nurses’ situation awareness, and maintaining intuitiveness and usability. Prior to technical implementation, devices which can be remotely controlled from an integrated interface, need to be developed.

CONCLUSION

In current ICU settings, nurses have information deficits. An integrated display could address these deficits by combining information and making it more accessible. Integrated information displays can provide easier access to pertinent information for ICU nurses, could reduce their cognitive overload, prevent errors, and associated harm in patients.

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