Design of a Wearable Stress Monitoring Tool for Intensive Care Unit Nursing: Functional Information Requirements Analysis

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Nurses are the last line of defense to reduce preventable medical errors; however, they suffer from poor systems design and human factors issues (e.g., long shifts, dynamic workload, stressful situations, and fatigue), contributing to a reduced quality of care. A smart nursing system based on physiological monitoring is being designed to help nurses and their managers to efficiently communicate, reduce interruptions that affect critical task performance, and monitor acute stress and fatigue levels. This paper documents the systematic process of deriving information requirements through a group-participatory usability study, conducted with nurses working in various Southeastern Texas hospitals. Information requirements derived from these studies include: a need for accessing patients' vital signs as well as laboratory results, memory aid tools for various critical nursing tasks, and options to call for help and to reduce interruptions for critical tasks. The system shows promise to meet these requirements.

INTRODUCTION

Working environment, critical tasks, and attributes of the nurse play an important role in the quality of patient care and patient safety in healthcare systems. Stress and fatigue lead to individual burnout that results in degraded performance and medical errors (Laschinger & Leiter, 2006). In one of the most cited statistics, the Institute of Medicine (IOM) reported 44,000-98,000 deaths annually due to medical errors (IOM, 2000). This report underestimates the current magnitude of the problem, as the 2016 statistics state over 250,000 deaths in the US were a result of medical errors (Makary & Daniel, 2016). The highest rate of nursing errors are attributed to errors in compiling and reviewing medical history (31.75%) and disregard for appropriate time to administer medications (31.75%); managerial factors were mentioned by more than 84% of the 239 nurses involved in the study as one of the important factors contributing to medical errors (Eslamian et al., 2010).

Nursing errors are particularly difficult to catch. In the case of medication administration, if the physician makes an error, the pharmacist who prepares the drug or the nurse who administers it can catch the error. In the case of a pharmacist's error the nurse is the second line of defense, but for the medication-administering nurse, there are little to no safety barriers (Anderson & Townsend, 2015). The causes for errors might include systematic design problems (IOM, 2000), education and training for healthcare staff (Henneman, 2007), and human factors and ergonomics involving different aspects of stress and fatigue (Barker Steege et al., 2011; Rogers, 2008; Barker Steege et al., 2015; Barker Steege & Nussbaum, 2013). It is difficult to operationalize fatigue in the healthcare setting due to the dynamic nature of the environment, tasks and the greater organization culture (Khanade et al., 2018). Along with issues with monitoring and measurement techniques to sustain effective programs that track and improve the system, it is important to study critical aspects of the interaction between nurses, nursing work, and the nursing environment that might lead to errors. In recent years, systems engineering approaches have been put forth to improve performance. The framework of the Systems Engineering Initiative for Patient Safety (SEIPS) model (Carayon et al., 2006) has been used to analyze complex dependent constructs in nursing (Barker Steege & Rainbow, 2017).

Smart wearables with built-in biometric sensors are being used for data collection in healthcare research. Although wearables have gained acceptance in the healthcare community, evidence of the effectiveness of an overall system that uses wearables along with systems engineering principles seems lacking in the literature (Khanade et al., 2018). This paper details the front-end engineering of a Smart Nursing System (SNS) that utilizes principles on human factors and systems engineering to improve communications between the nurses and their managers; provides memory aids; lowers access cost of information of patients for the nurses; and provides active monitoring of nurses' stress and cognitive, physical, and emotional fatigue based on biometric parameters.

METHODS

In this usability study and in the user centered design process, participants were involved in design considerations and design decisions regarding trade-offs and feature development. Participants were recruited through a nursing school in Southeast Texas, based on their profession of nursing, and were expected to be proficient in nursing tasks and to fulfill nursing knowledge requirements of an associate degree in nursing. The participants were not expected to have prior experience in using smartwatch applications. Fourteen nurses participated in the usability tests.

The setting of the study was a conference room within the nursing school facility. A laptop (loaded with the *proto.io* prototype review tool), pencil, paper for notes, a recording device, and a smartwatch were used as tools. Basic demographic information, suggestions for improvements, satisfaction ratings, and performance measures, such as time on task, critical errors, and noncritical errors were the broad themes in which subjective information was collected.

The participants' responsibilities included attempting to complete a set of representative task scenarios presented to them in as efficient and timely a manner as possible, and to provide feedback regarding the usability and acceptability of the user interface. The participants were directed to provide honest opinions regarding the usability of the application, and to participate in the post-session subjective questionnaire and debriefing.

The laptop with the smartwatch prototype, created with *proto.io*, was used in the conference room environment (Figure 1).

Figure 1. Representation of the home screen of the smartwatch application as shown to the participants for their feedback

The participants' interaction with the smartwatch application was monitored by the facilitator seated in the same room. Note takers and data logger(s) were present to monitor the sessions in the room. The sessions were audio recorded after receiving consent from the participants.

The first section of the usability task consisted of search questions asking the users to find specific features in the application. The second section featured specific tasks for the user to complete. For example, the users were asked to check their biometrics for a given date from the smartwatch application. In this example, the user was asked to navigate to the heart rate feature in the application, scroll down to check the heart rate trends and from the trend data click on the required date for obtaining more information on heart rate parameters.

Debriefing and user centered design process sessions were conducted after the usability study to receive additional feedback and to guide the feature development for the smartwatch application.

RESULTS

The four most-demanded functions are: 1) note-taking, 2) notifications, 3) do-not-disturb, and 4) basic watch capabilities.

Note-taking

Many nurses of the focus group agreed that note-taking is an important feature that should be incorporated in the application. At the end of each shift, nurses usually rely on notes that were taken throughout the day to write reports about their patients. Some nurses stated that they also use notes to recall the details of a task that they return to after being interrupted from that task. They were worried about the effectiveness of typing notes on such a small device. To avoid this, they agreed that recording voice notes was a good compromise.

Notifications

Notifications is another feature that the nurses determined to be important for the smartwatch application. Nurses wanted notifications to remind them to complete tasks after an interruption, to program a pump, to give medications, and to contact doctors or other nurses at specific times. Nurses in this focus group also mentioned the importance of maintaining consistent units with hospitals when creating notifications, such as implementing military time when setting a reminder.

Do-not-disturb

A "do-not-disturb" function on the application would also benefit the nurses. The participants of the focus group wanted the ability to notify others that a critical task is being performed to avoid being interrupted. Nurses stated they would use this function for focus-intensive tasks such as setting meters, as well as tasks that require privacy, such as cleaning up a patient or speaking with a patient about serious matters. The ability to avoid interruptions for these tasks would help reduce stress and increase concentration on the task at hand. After finishing the task, the nurses should be able to turn this function off quickly to allow for secondary tasks.

Basic watch capabilities

The participants of the focus group also found it imperative for the watch to maintain the capabilities of a typical smartwatch for keeping time, sending and receiving messages, and making phone calls. Nurses that currently use smartwatches typically use the messages and health features most frequently. Other features requested by nurses were timers and stopwatches. The participants stated that some medications are administered over a period of time, so these functions make it easier to complete these tasks. In addition, nurses stated concerns about the battery life of the smartwatch. It is important to develop efficient functions on the application to allow the smartwatch to stay active throughout each nurse's shift.

Other Requirements

The participants also mentioned concerns related to patient privacy and HIPAA while using this type of technology. Generally, the nurses wanted to know how the use of a smartwatch would be administered and how the data would be stored.

Nurses in this focus group also mentioned that improving communication would help them be more efficient. They would no longer have to walk across the hospital to check on a patient because they would be updated through the smartwatch by the unit secretary or other personnel.

In this focus group, nurses also discussed the benefits of real-time monitoring of patients' vital signs through a smartwatch. The participants mentioned how having access to this information would allow them to easily analyze trends in vital signs such as heart rate, which would help the nurses attend to their patients' needs better.

The System Usability Scale (SUS) was administered after the participants had completed their usability test and answered post-testing questions. The SUS scores were calculated using the standard SUS=2.5 [20+Q1 + Q3 + Q5 + Q7 + Q9 - Q2 - Q4 - Q6 - Q8 – Q10] (Brooke, 1996). The results from the SUS show acceptance of the smart nursing system application prototype. The range of scores was 65-100 with the average at 76.25/100. A score of more than 68 is considered to be above average for usability studies for interface designs; this indicates the prototype shows promise of user acceptance.

DISCUSSION

Data gathered from the interviews were input into a set of tables called Functional and Information Requirements (FIR). FIR tables contain all the tasks and information, which are required to be in a system in terms of the system's feedback and users' input (Khanade et al., 2018; Sadeghi, Thomassie, & Sasangohar, 2017). Generally, these charts have three levels: 1- high level functions, 2- low level functions, and 3- information requirements.

High level functions are broad functionalities that need to be in the system. These functions usually break down into low level functions and include more precise tasks. It is important to bear in mind that the words "low level" here do not indicate priority or usefulness, but posit only that these types of functions (low level) are driven from general functions (high level). Moreover, low level functions are decomposed into information requirements (Figure 2). Information requirements which are the most crucial part of the FIR carry all the information required to be in the system.

Functional Information Requirements can synthesize design guidelines (Scott et al., 2009). By the completion of FIR analysis, programmers and designers may have access to the set of requirements that they need to include in their designs for the smartwatch interface.

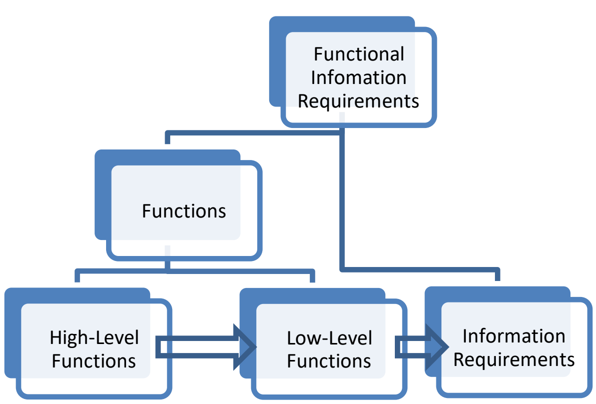

Figure 2: FIR Structure, three different levels of Functional Information Requirements

The FIR analysis, based on responses from nurse focus groups and literature reviews, resulted in eight, high-level functions, discussed below by type. *Nota bene*: these functions are neither listed in order of importance nor significance.

The first high-level function was "View Nurses' Information". Table 1 shows the three layers from the high-level function "View Nurse Information". This high-level function indicates general information about nurses such as their name, ID and shift. It can notify nurses about their stress and fatigue level by measuring their heart rate and steps walked during their shifts. This information can be reported to the administrator to aid nurses in case of relatively high stress and fatigue.

Table 1: FIR - View Nurse Information

High Level Function	Low Level Function	Information Requirements
View Nurse Information	General Information	Nurse's name Nurse's ID Nurse's shift
	Measure Heart Rate	Maximum heart rate Minimum heart rate Average heart rate Current heart rate Heart rate trend (diagram)
	Count Steps	Number of steps during the day Average number of steps (Past 10 days) Steps trend (Diagram)

The second high-level function was "View Patient Information", the most in-demand function based on focused groups' interviews. Nurses wanted to access patients' vital signs and medications on the watch in order to minimize the use of working memory. Therefore, users can avoid errors that may occur due to their dependency on working memory, which has a limited storage. Table 2 displays this high-level function and the associated lower level requirements.

Table 2: FIR –View Patient Information

High Level Function	Low Level Function	Information Requirements
View Patient Information	View Vital Signs	Patients' room number Patient vital signs Patient status
	View Medications	Patients' room number Patient medications Medication times

"Recording Information" is the next high-level function (Table 3). Nurses asked for a voice-recording function, enabling later playback of reminders and important information. This high-level function lets nurses record voices, view notes and view text messages from the administration. This function also may aid in reducing reliance on short term memory.

Table 3: FIR – Record Information

High Level Function	Low Level Function	Information Requirements

Record Information	View Text Messages	Contacts names Message Time Date
	Record Voice	Time; Date; Patient room number; General records (about general stuff not specific patient); Volume control diagram (to control recorded voices' volume)
	View Notes	Notes; Date; Time

"View Availability" is another high-level task. This function enables nurses to access an option called "Do not disturb" (see Table 4). Nurses may use this option to avoid interruptions while accomplishing critical tasks. Additionally, this option has a timer within, which nurses can activate for the desired period of time when they wish to avoid distractions. The watch activates automatically after this period of time, in case the nurse forgets to reactivate it.

Table 4: FIR – View Availability

High Level Function	Low Level Function	Information Requirements
View Availability	Do Not Disturb (timer)	Time duration

The Health Insurance Portability and Accountability Act of 1996 (HIPAA) is a United States regulation that protects the privacy of patients' health information (https://www.hhs.gov/hipaa/). HIPAA concerns were one of the integral issues that nurses pointed out during the interviews. In order to comply with HIPAA regulations, the nursing application should provide an access code for each nurse to view confidential forms and privacy policies (Table 5). Patient information in the watch needs to remain inside the area of the hospital. Therefore, without this high-level function, nurses will not be able to take the watches out of the hospital, not even for a coffee break.

Table 5: FIR - Ensure Privacy/Security

High Level Function	Low Level Function	Information Requirements
Ensure Privacy/Security (HIPAA)	Log In/ Log Out	Nurses' ID; Password
	View Confidential Forms	Consent form; Privacy policy

"Alerting" is a function which encourages nurses to utilize their watches due to help them to minimize the need to memorize their tasks and to do-lists. Alerts incorporate reminders, which may inform nurses about their upcoming meetings, patient medication times, laboratory times, and so forth. In addition to reminders, the timer and stopwatch are low level functions for this high-level task (see Table 6).

Table 6: FIR – Alerts

High Level Function	Low Level Function	Information Requirements
Alerts	Reminders	Time; Date; Roundly hour; Timer; Med time; Neuro checks; Call physicians; Room number Medication times & names; Call to make; Physician time; Lab time; Infusion time; Meetings; Preset checklist
	Timer (Set alarm)	Time
	Stopwatch	Time

"Customization" is the penultimate high level function for the nursing smartwatch application. Through this function, nurses can sync the watch with the computer, connect to WIFI, and change the settings of the application (Table 7).

Table 7: FIR – Customization

High Level Function	Low Level Function	Information Requirements
Customization	Sync with Computer	Nurses' ID; Password
	Connect to Bluetooth	Bluetooth name
	Connect to Wi-Fi	Wi-Fi name
	Change the Sound Level	Maximum sound level Minimum sound level
	Input Nurse Information	Nurse's name; Nurse's ID; Nurse's shift

"Communication" is the last high level function for the application (Table 8). "Call for help" is the low-level function. This feature might be supplied in the application to enable nurses to ask for help from other nurses or administrators.

Table 8: FIR – Communication

High Level Function	Low Level Function	Information Requirements
Communication	Call for Help	Administration's contact; Nurses' contacts; Desk contact (secretary contact); Urgency rate; Icon for help

The main limitation of this research is the limited number of focus group studies. It is obvious that larger samples provide better results. However, it is claimed that results were relatively saturated due to the fact that quite a few repetitive answers could be observed in the focus group. Bias related to focus group format is another integral limitation in this study. Participants might be biased by the answers provided by the other interviewees in the group. It may be that some participants did not offer their real opinion because of the fear of being judged by their peers. Three different qualitative data analysts surveyed the interviews; therefore, limitations due to the bias of these analysts are considered minimal.

It is also important to bear in mind that the utilization of FIR varies from unit to unit in a hospital. Different combinations of these functions and required information may be used for different units of a hospital.

Future studies may include increasing the number of focus group interviews while adding individual interviews to minimize the issue of biased participants and small sample size. Likewise, conducting the survey in dissimilar units of a variety of hospitals in different locations with diverse specialties and sizes can help the research to be more generalizable.

CONCLUSION

The paper provides front-end analysis for the key information requirements in the development and design of a Smart Nursing System (SNS) for addressing the issue of performance degradation and preventable medical errors that are a reality in the present work in nursing. The design was accomplished using a participatory group design process and focus groups with the main stakeholders: the nurses and nurse managers. Initial requirements from focus groups were validated in the group participatory design process that involved displaying the initial prototype to externally validate the system to continue the design process and initialize the field studies and observations phase. This process addresses the gap of customer validation for the system and involves customers to design a tool that will be an integral part of their work life. The participatory group process, in addition to using the FIR framework that was collaborative in nature, provides a sound base for further design and validation of the system from the point of view of the primary stakeholders. The paper highlights an alternative approach to designing a system that addresses a critical issue within the healthcare sector.

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