

Deriving Information Requirements for a Smart Nursing System for Intensive Care Units

**Kunal Khanade, MSc; Farzan Sasangobar, PhD;
Steven C. Sutherland, PhD; Karen E. Alexander, PhD**

The workplace environment for intensive care nursing is highly stressful, with long working hours and a dynamic workload that may induce fatigue. The resulting stress and fatigue may reduce nurses' efficiency and may contribute to medical errors. A smart wearable system is being designed to help nurses who experience high levels of stress and fatigue at work. This article documents the systematic process of deriving information requirements from 2 focus groups conducted separately with nurses and nurse managers working in various Southeastern Texas hospitals. While nurses expected functionality such as memory aid tools, health assessment, and stress-reducing exercises, nurse managers expected information about the overall status of the unit's fatigue/stress levels as well as nurses' communication and movement patterns. The derived information requirements will act as an objective assessment of needs and would set the stage for the design of a stress-monitoring tool. **Key words:** *fatigue, intensive care nursing, stress, wearable devices, workload*

NATIONAL ACADEMY of Medicine (formally The Institute of Medicine) estimates that in the United States, 100 000 deaths are caused by preventable medical errors.¹ In the US intensive care units (ICUs)

alone, 1.7 errors per patient per day are reported.^{2,3} Stress and fatigue are 2 important factors that contribute to medical errors in nursing.³ A study of 263 Brazilian ICU nurses stated that approximately 60% of ICU nurses experienced medium to high levels of stress.⁴ About 65% of nurses reported that they were fatigued and struggled to stay awake at work.⁵ Fatigued nurses may commit errors in clinical judgment or the administration of medication and may fail to intercept errors made by other nurses or physicians.

Factors that affect nurses' stress and fatigue in the workplace are well documented.⁶⁻¹⁰ A longitudinal study of 277 nurses from 4 hospitals in South Africa revealed that health workforce's well-being is not prioritized and mostly lacking, with existing policies failing to address psychosocial stressors among nurses.¹¹ The authors among others suggest the need for further studies using biomarker assessments and other cellular variables to investigate the health impact

Author Affiliations: *Department of Industrial and Systems Engineering, Texas A&M University, College Station (Mr Khanade and Dr Sasangobar); Department of Psychology, University of Houston-Clear Lake, Houston (Dr Sutherland); and Department of Clinical and Applied Sciences-Nursing, University of Houston-Clear Lake, Houston (Dr Alexander).*

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Correspondence: *Farzan Sasangobar, PhD, Department of Industrial and Systems Engineering, Texas A&M University, 3131 TAMU, College Station, TX (Sasangobar@tamu.edu).*

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of stress, burnout, and job satisfaction. Moreover, a cross-sectional correlation-based survey design, with 102 nursing staff members, examined work stressors, coping strategies, and self-efficacy and found significant correlations between nursing staff burnout and psychological distress.¹² Caring behaviors were also correlated with coping strategies and self-efficacy.

Subjective measurements such as inquiry, interviews, or surveys have been used to measure stress^{4,9,10,13,14} and fatigue¹⁵⁻¹⁷ in the ICU. In addition, physiological measures such as heart rate variability,¹⁸ electro-oculography,¹⁹ isometric exercises,²⁰ and energy expenditure²¹ have been used to measure fatigue symptoms in ICU nurses. Despite these measurement efforts, no validated interventions or continuous monitoring systems or tools exist to mitigate the negative effects of stress and fatigue among ICU nurses.²² Broadly stated, detection of stress and fatigue levels remains a research gap mainly due to intrusiveness of tools and methods to the nurse and their general interruptiveness to the ICU nursing tasks. Despite these challenges, a system that provides continuous monitoring and alerts regarding abnormal physiological reactions might help in increasing nurses' awareness regarding personal responses to their tasks and environment and may contribute to improved patient safety and nurses' well-being. By making this information visible, such systems may also help nurse managers and administrators to manage their resources more efficiently and to improve work environment practices to reduce stressful tasks and reduce the effects of fatigue and stress on their nurses.

In recent years, advancements in mobile technology have made wearable tools such as smartwatches easily accessible and widely used.²³ The nursing profession is adapting to technological advancements through its inclusion of electronic health and medication administration records, as well as simulation experiences in education. The adoption of smart wearables shows promise as the next step to assist caregivers in their daily work

life.²⁴ Research in large clinical care settings shows that patients and nurses respond favorably to wearable sensor technologies and perceive them as useful and easy to use and encourage the implementation of such technologies in critical care areas.²⁵ Wrist-wearable devices such as smartwatches are becoming increasingly popular among working professionals for heart rate monitoring and have shown high levels of accuracy (range, 79%-99%) compared with a professional clinical pulse oximeter.²⁶

Work is in progress to develop a smartwatch-based smart stress-monitoring and intervention system for nurses. This article documents our recent user-centered efforts to derive Functional and Information Requirements (FIRs) for this system from 2 focus group studies conducted with nurses and nurse managers from various hospitals in Southeastern Texas.

METHODS

To ensure that our smart nursing system was designed to meet the needs of nurses and nurse managers for whom it is being designed, we employed a user-centered design approach. This article discusses the results of the first steps in this process. We conducted 2 focus groups with nurses and nurse managers separately. The first focus group was conducted to obtain a more in-depth understanding of nurses' expectations of a tool that can help with periods of high stress and fatigue, as well as some of the problems nurses face in their daily work life. The second focus group was conducted to inform the design of an information display for nurse managers to monitor the ICU's status in terms of collective stress and fatigue levels. The feedback from participants was documented as FIRs to inform the design of a smartwatch-based tool for nurses and supervisory-level interface for nurse managers. The study also sought to determine how the use of technology could assist nurses during the periods of high stress and/or workload. The study has received institutional review board approval from

University of Houston-Clear Lake where the main research activities were performed.

Participants

Nurses from various hospitals and nurse managers from a midsize hospital in Southeastern Texas were asked to participate in these focus group interviews. The first focus group included 4 delivery care nurses (1 male, 3 female) from different domains such as emergency department (ED), ICU, and long-term care. The second focus group included 5 nurse managers (1 male, 4 female) from various care areas such as ED, cardiothoracic, and intermediate care unit.

Procedure

A moderator and 2 comoderators led the focus group interviews. Previously formulated questions were presented to the group to guide the discussions. There were 13 higher-level questions, followed by additional probing questions to obtain more information or clarification. Questions were organized into 4 groups to investigate (1) participants' tasks/roles, (2) situations where high levels of stress/fatigue are experienced and their effects on performance, (3) expectations from a tool to help in those instances, and (4) specific expectations from a smart-watch (or supervisory-control) interface. The first and second focus group sessions lasted approximately 1 hour 35 minutes and 1 hour 9 minutes, respectively.

Analytic methods

After the focus groups were conducted, all audio recordings were transcribed. One researcher analyzed and coded all interviews, after which codes and patterns were used to first develop high-level functions that should be supported by the tools. Subsequently, high-level functions were decomposed into subfunctions from which information requirements were derived. Information requirements describe what the tool needs to either display to users as feedback or accept as input from the users to ensure that all of the necessary information that is expected by

the users is captured in the design. The FIR method provides a set of design-independent requirements that can be used as objective assessment of needs for displays. The derived information could be used in the design phase as required design features; however, such requirements do not restrict the designer to use any particular design form. While the overall findings from the focus groups are discussed later, the FIRs are out of the scope of this article and will be reported elsewhere.

RESULTS

Primary stakeholder: Nurses

General stressors at work

According to the nurses, the documentation task was a unanimous stressor because the process is extremely detail-oriented. Overall, the participants felt they had insufficient time to complete tasks or had too many tasks for the time allotted. They mentioned that there were times they had to work off-the-clock in order to finish their work for the day. They also stated that they were often needed in multiple places at the same time, forcing them to prioritize tasks of equal importance. One nurse noted that interruptions were an issue because it required her to stop and refocus on her task when she was already multitasking, whether that included providing medicine to her patient or speaking to a physician. In addition, nurses mentioned that they needed to remember all their interactions with patients and doctors throughout the day, for documentation purposes, which caused high mental workload to analyze and process during their shift.

Indicators of high stress levels

The participants identified that their stress manifests physically through tremors and palpitations and/or through emotional changes such as anxiety, depression, or feelings of inadequacy. The participants also noted that they believe that stress led to mistakes. One nurse specifically said, "I think that when you

start to have confusion, you start to make mistakes. That's when I notice that the job is stressful right now. Maybe I need help or maybe need to take a break." The nurses also explained that stress led to disorganization and the inefficient delegation of tasks because when they become overwhelmed, they cannot think clearly. One nurse mentioned that, generally, when one is stressed, pleasantries are scarce and conversations in the unit become curt and concise. The participants felt that the manifestation of stress led to an overall reduction in patient care.

Indicators of high or low workload

Participants felt they had high workloads when they did not have time for necessary breaks or had to prioritize tasks that were equally important. In addition, the nurses stated that workload is dependent on the volume and acuity of their attending patients. The participants acknowledged that if they were not on track for delivering medication to their patients, they perceived that as high workload. Low workload was also a topic of discussion; however, participants generally viewed it as a nonissue because it allowed them to catch up on documentation, continue to build relationships with their colleagues, or complete trainings.

Current techniques for mitigating high stress/workload levels

The nurses had several techniques they used to help them cope with their high stress or workload. The participants explained that they take long breaths to help them refocus or take short breaks (~5 minutes) to decompress. One nurse discussed the role charge nurses play. She stated that they were there to help mitigate and make appropriate changes to balance the workload. Charge nurses are also in charge of "techs" who are there to assist the nurses when they are overloaded with work. The participants also spoke about sharing responsibilities with their coworkers to help reduce stress/workload so that the overall unit operates as smoothly as possible. However, the participants were often un-

willing to interrupt their colleagues because they believed their coworkers had an equal amount of workload.

Smartwatch tools

Technology is a necessary and beneficial tool in the nursing profession, so understanding how such technology is going to be used by the intended users is insightful. Our nurse participants stated that watches were a necessity and fundamental for their work. They used watches to check the pulse, respiration, and other vital signs of their patients. In addition, watches are used to check the time and set alarms to ensure the medication delivery or therapies are on track. The nurses were asked to envision a tool that could assist them with the challenges they faced in their daily tasks and to identify the functions this tool would need to have. The participants mentioned that a memory aid tool, allowing them to take notes, set alerts and reminders, and complete checklists for common patient care items such as intravenous pumps, would be helpful. They also desired a tool that would facilitate communication between themselves and physicians/therapists. However, they emphasized the importance of making these functions easily accessible. A few nurses were also interested in a self-assessment tool that would indicate their stress/workload levels based on physiological metrics such as heart rate.

Privacy concerns associated with the smartwatch tool

The nurses were asked what information would be appropriate to communicate to their nurse managers/administrators regarding current stress or workload levels. They generally felt that providing too much personal information, such as heart rate data, would be undesirable because stress is generally viewed negatively; however, they agreed that general or more abstract information that does not identify a particular nurse would be appropriate to help management and the nursing unit as a whole.

Primary stakeholder: Nurse managers***Methods to track the ability of nurses to perform tasks***

Managers perform real-time audits, post-care audits, and direct observations to understand the status of their unit. They also rely on documentation to track nurses and the level of care provided. While the role of clinical coordinators in providing performance-related feedback was highlighted, according to the participants, nurses also report their workload-, stress-, and fatigue-related issues voluntarily. Participants mentioned that this type of reporting is typically unofficial and involves conversational interaction.

Determination of nurses' workload

Nurse managers mentioned using information related to the patient assignment in addition to the acuity of the patients to determine workload. Performing a walk-through to survey the unit also gave them a sense of the nurses' workload. One participant stated that body language and facial expressions were important cues. The nurse managers mentioned that when nurses look calm and relaxed, it typically indicates a low workload. However, when there are multiple nurses in one area "rushing," they know the workload is high. There was a consensus that workload is typically linked to the volume and acuity of the patients. Acuity was more clearly defined as the number of intravenous pumps a patient is connected to and/or number of drips the patient receives, alongside other medical necessities such as blood pressure monitoring or dialysis.

Determination of high stress

The nurse managers discussed techniques they used to identify whether the nurses are experiencing high levels of stress. Managers mentioned that generally nurses communicate high stress levels voluntarily, but sometimes managers obtain this information by planned observation of and interaction with nurses. Managers observed the tracking board of patients in the unit that indicated the acuity

of the patients alongside other visual cues. Constant communication between nurses and the charge nurse, as well as performing follow-ups with the staff, also helped identify stress levels. One participant claimed that conversations with nurses are concise and to the point when they are busy. The participants also mentioned that it was important to know the staff well because one assignment might be more stressful to particular nurses than to others. For example, some nurses are more apt in dealing with large families of patients. Nurse managers were also asked about the techniques they used to mitigate nurses' stress. Several interventions were discussed including the modification of the assignment as well as assigning them a "buddy" (other nurses), who is someone they can talk to and learn from to help them cope with the stress.

Communication gaps between nurses and nurse managers

According to the participants, there were a few existing communication barriers. The most significant barrier was nurses' insufficient time to communicate their status or make calls for help. Another barrier was the perceived stress of other nurses and the reluctance to interrupt colleagues who are perceived to have a similar workload. The participants also provided some background information regarding the tools they were currently using to communicate, which included *Spectra* link phones and pagers. Nurses in a particular hospital in Texas currently use a program with the *Spectra* link phones, which allows them to directly communicate with doctors, depending on how they wanted to be reached (ie, e-mail, text, or phone call); however, the nurses must use the computers to utilize this tool and not all physicians are part of the program.

Smartwatch tool

The idea of a smartwatch tool that had the capabilities to assist nurses in their daily work was presented to the nurse managers. The participants were then asked what that tool should look like and what functions it

should perform. They listed several features, which included a general watch functionality, calculator, movement monitoring, heart rate monitoring, conversion tables, patient teaching tools, reminder lists (eg, for laboratory values), and a link capability with the nurse call system. They also mentioned a “Do Not Disturb” function on the watch, which would help deter interruptions while performing critical tasks. Participants emphasized keeping the tool’s functions easily accessible. Features for a nurse manager display were also discussed. All participants favored a display that allows nurse managers to have an overview of all the staff members to enable inference about when a nurse is stressed or overloaded. This functionality would help nurse managers to intervene in a timely fashion. According to the participants, having access to workload, stress levels, and the number of visits to and time spent in each room would help them gauge the current status of the unit. Some participants found availing the information about what tasks nurses were performing and how long they took to complete the tasks to be helpful.

Privacy concerns associated with the tool

Utilizing information from physiological sensors such as heart rate to assess stress and workload may be perceived as personal and private information. Participants were asked whether sharing heart rate data would be acceptable. Indeed, managers felt that nurses would consider this information private information. However, they believed this information would be beneficial to the nurses themselves to monitor their own behavior and reactions to stress or high workload. One participant mentioned that qualitative data (eg, color-coded elements based on nurses’ stress levels) could be passed on to supervisors if the nurses chose to share that information. Overall, participants felt that sharing some of this information with charge nurses in real time would be beneficial because it would help them intervene immediately and not after the shift was over.

DISCUSSION

The information gathered from 9 nurses and nurse managers sheds light on important requirements for a wearable continuous monitoring tool to assess and communicate high levels of stress and workload among nurses. A formal FIR method can be used to document specific high- and low-level functions, as well as the specific information required for each task. Such information is needed to be present in the user interface to support users’ interaction with the system. While the complete set of information requirements is out of the scope of this article, we discuss some of these important requirements in the following text.

Information requirements for a nurse-facing display

Smartwatch acceptance and adoption

Nurses generally favored the idea of using a smartwatch since a watch is most familiar and not a new addition to their working environment. Nurses use their watches for a number of tasks. The smartwatch tool can add several augmenting functionalities. For example, nurses expected a counter to perform tasks such as taking a patient’s pulse, a clock and date feature, a timer, and a stopwatch.

Communication capability

Evidence suggests the need for efficient communication of high stress and workload periods among nurses and nurse managers. To enable such functionality, the nurses’ stress and workload status should be either automatically assessed or self-reported. Some well-established methods, such as typed or voice-enabled text messaging or voice-recorded messages, can be implemented into watch functionality. An important information requirement identified was the need for input from nurses when they do not want to be disturbed, for example, during high-severity tasks such as medication preparation or programming intravenous pumps. The watch interface can accommodate the entry of interruptability status.

Memory aid

The evidence from the focus groups suggests that nurses are often involved in a variety of tasks that have to be prioritized or scheduled. This complexity may tax their limited prospective memory and may lead to lapses (ie, forgetting to execute certain tasks). The prioritization task itself is often challenging. It seems that nurses need a memory aid tool that could be integrated into other task management systems (eg, calendars) to allow nurses to input tasks and assign priorities to those tasks. Another important functionality that could be used as a memory aid is the ability for note-taking. It seems that nurses currently do not have an accessible tool to write down quick notes, especially under pressure and in critical situations. While the smartwatch display's real estate may not allow for such note-taking, selection of an appropriate code (eg, task or information) on the watch interface is possible. Because the watch usually works in combination with a smartphone, the note-taking functionality could also be implanted into the smartwatch interface to allow users to type more specific notes on their phones when needed. Nurses also favored the option to share such notes. In addition, a preset checklist can be implemented to help nurses remember their routine or safety critical tasks. Finally, nurses who prefer to record their voice and review notes later, in order to remember tasks and minimize manual inputs, favored short voice-recording segments for notes/key words.

Health tracking

The nurses received health-monitoring aspects of the technology very well. In addition to information about their stress and workload, nurses expected visualization of their heart rate activity, a sleep-tracking display, battery life information, and a pedometer display for the number of steps walked each day as an indication of daily activities. In addition, providing heart rate and sleep trends, to allow nurses to compare their health status based on previous data, was expected. Nurses men-

tioned their desire to use the sleep data to calculate sleep debt. The sleep-quality trend is additional information that can be used as an indicator of general health.

Stress mitigation

The smartwatch tool can provide basic tools such as mindfulness and breathing exercises to allow nurses to perform calming exercises when they are experiencing high levels of stress.

Information requirements for a manager-facing display

Nurse managers should be able to monitor nurses' stress and workload indicators, as well as incoming communication from nurses. While individual indicators were perceived to be private, information regarding the overall status of the unit, in terms of stress and workload, was expected. The nurse managers were aware of privacy issues and sensitivity associated with monitoring high-fidelity data from individual nurses and suggested abstract, low-fidelity visualization such as displaying high, medium, and low levels of overall workload or stress. In addition, means of direct communication with nurses as well as information about the instances in which nurses requested help or asked for "no interruptions" were deemed important for overall assessment of the unit's health.

Weekly trend data for the unit's health status would also help nurse managers in their strategic planning and resource management decisions. These data could include aggregate heart rate, movement, and communication patterns. Nurse managers expected a search functionality to be able to track information related to nurses' workloads such as the name of the nurse and patients' room numbers for which the nurse was currently responsible, as well as the patient acuity. In addition, providing information about the number of available float nurses or working nurses for a chosen period, previous patient forecasts, and trends for improved resource allocation was expected.

While this study showed promise in deriving high-level requirements for a stress/workload-monitoring and communication tool, several limitations are noteworthy. While focus groups allowed for scaffolding and assessment of saturation, the method is prone to the influence of the team-thinking phenomenon where participants may bias others in the group and several ideas may remain unexplored. In addition, larger groups with a wider variety of backgrounds and inclusive of a more diverse demographic makeup (eg, a better balance of male and female nurses) may reveal additional requirements. Future studies should focus on diversification of participants from various hospitals in terms of location, size, and specialty to evaluate and update the generated requirements. Additional focus groups, individual interviews, and surveys to provide additional viewpoints can be used to complement or evaluate the reported findings. These initial requirement analysis efforts are based on the assumption that the wearable tool will be capable of assessing stress and workload using physiological parameters. Work is in progress to develop

sophisticated machine learning algorithms to infer mental state status from heart rate and accelerometer sensor information.

CONCLUSION

A user-centered process was followed for the derivation of information requirements for a nursing stress- and workload-monitoring system, composed of a wearable smartwatch-based tool worn by nurses and a manager-facing display that provides an overview of the unit's health status. The assessment of needs, based on intended users' feedback, ensures the design of systems that meet users' needs and expectations. Two focus groups were conducted with both delivery care nurses and nurse managers to allow for consideration of multiple stakeholder views in our user-centered design process. The findings provide a foundation for the front-end development of a technology to support nurses in their tasks and to improve their well-being and job satisfaction. Such a tool will also help nurse managers to have access to the "big picture" of the unit's health status and would inform their resource management efforts.

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