Designing Guidelines for Mobile Health Technology: Managing Notification Interruptions in the ICU

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ABSTRACT
Previous research on reducing unwanted interruptions in hospital intensive care units (ICU) have focused on providing context-aware solutions that consider factors such as location and activity of the person receiving the interruption. We seek to broaden an understanding of how to manage interruptions by using the Locales Framework to analyze data collected from a field study on mobile notification interruptions in the ICU. Based on our data along with previous literature on cognitive theories, mental models, strategies for managing interruptions, and principles of human factors, we propose five guidelines to aid in designing mobile technology interventions for the ICU.

Author Keywords: Interruption; interruption management; clinical informatics; human-computer interaction; locales.

ACM Classification Keywords
H.5.m. Information interfaces and presentation.

INTRODUCTION
Ubiquitous information and communication technologies such as smartphones and tablet devices are increasingly being used to support the communication, collaboration, and coordination needs of hospital intensive care units (ICU) [1,3,45]. Although these specific mobile healthcare technology (MHT) applications facilitate collaborative work, research has shown that notifications delivered by text messages have resulted in increased cognitive load and medical errors in the ICU [17,22,31,33, 34,54].

While evidence continues to mount regarding interruptions in the healthcare environment (with an adverse impact on clinical work), other studies acknowledge the overwhelming importance of information that clinical notifications transmit to the clinician [24,41,50,49,51]. For example, research suggests that 11% of all interruptions from notifications contribute to increased safety, improvements in patient comfort, and increased accuracy [50].

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Given this dual view on the impact of interruptions caused by MHT notifications, we argue for the need to embed functionality that supports optimal notification and interruption management. McCrickard et al. [37] define an interruption as any event within a notification system that prompts the transition of attention from a primary task to the notification. In healthcare, Sasangohar and colleagues [50] define interruptions as "*externally or internally generated, unexpected events that may cause a break in the primary task, diverting attention to a related or unrelated secondary task, which can have both negative and positive effect on the interrupter's or the interruptee's main task.* (*p.* 3)"

This study focuses on interruptions caused by MHT as ICU clinicians execute their daily routines. We use the Locales Framework to guide our understanding of the dynamic, situated work in the ICU and the circumstances in which the interruptee experiences interruptions from notifications. We identify design guidelines for MHT notification systems to optimally manage interruptions in the ICU.

METHODS
We conducted a field study in the Eskenazi Health hospital (Indianapolis) using an exploratory sequential mixed methods approach [9], in which the primary author observed an ICU team. Prior literature and 10 hours of initial observation informed some of the practices followed in the complex ICU environment [7] and helped highlight work practices that might otherwise be taken for granted by an expert. Following this initial observation, a different ICU team was then observed for another 10 hours. The observer also conducted ad hoc, opportunistic interviews [44]. Semi-structured interviews were conducted with the clinicians observed.

We then pursued task-centric, role-centric, artefact-centric, and space-centric shadowing of ICU residents and nurses over a period of 60 hours. We shadowed residents and nurses due to their increased information exchange and collaboration in our initial observation sessions. We observed clinical activities such as rounding, hand-off, general patient care and information flow in the ICU. We used contextual inquiry [5] to observe the clinicians in the ICU to understand their collaboration and interruption management practices. With respect to interruption management, we focused specifically on the (i) medium (such as pager, telephone etc.) and nature of information communicated, (ii) practices followed by the clinicians in keeping themselves abreast of the dynamic and changing patient condition and care, and (iii) strategies used by the clinicians to avoid distractions to their ongoing activity when they received a phone call or alert on their pager. We collaborated with two expert ICU physicians who helped validate our data interpretations and consolidate our findings. Notes made during observations and audio-taped interviews were later transcribed. Notes were sometimes shared with the clinicians to communicate the observations thereby gaining their trust [7].

Study context

The ICU is a 16-bed unit, equipped with sophisticated equipment that is used to monitor and treat critically ill patients who are at risk for potentially life-threatening health problems. Patient care is highly collaborative in the ICU, with a team of members performing duties with different roles, such as attending physicians, residents, specialists, sub-specialists, surgeons, nurses, respiratory therapists, lab technicians, etc. To limit the scope of our project, we chose to observe an ICU team comprising of an attending physician (1), fellow (1), residents (1-2), medical student interns (1-2), pharmacist (1), and nurses (2-4). ICUs typically have a hierarchy, where the attending physician leads and advises the team, the fellow and pharmacist act as consultants, residents and interns work together in performing medical procedures or instructing nurses, and nurses carry out the instructions and work closely with the patients. Attending physicians, fellows, and residents are medical doctors, while student interns are trainees for a medical degree. Pharmacists are licensed experts and registered nurses primarily take care of and assist patients.

The study site is comprised of electronic information sources that include a patient electronic medical record (EMR) and computerized order entry system, patient charting and order notification system, bedside physiological monitors and infusion pumps. The clinicians access electronic information through mobile workstations at the nursing station, inside and outside the patient room, and conference rooms. Non-electronic sources provide information on patients, activities and procedures followed in the ICU and include whiteboards, printed copies of patient records placed outside patient rooms, paper checklists, rounding materials, and printed copies of EKG charts. As such, the ICU environment comprises an artifact ecology [59] rich in a heterogeneous mixture of digital and physical artifacts that are interlinked and used for a variety of clinical tasks while supporting the ICU workflow. For instance, a patient's record may be printed, annotated, and the written notes may be used to perform an activity and later input into the patient EMR [55].

The ICU clinicians also serve as information sources for each other. Patients also act as important information resources in helping provide feedback (such as pain level) to the ICU clinicians on their care. The existing technology systems supporting communication between ICU clinicians at the study site included electronic resources such as landline telephones (placed outside patient rooms, at nursing stations and conference rooms), hospital-owned mobile phones, pagers, and secure communication tubes (at nursing stations to send patient samples for lab testing and to receive medication for patients).

LOCALES FRAMEWORK

Fitzpatrick [13] developed the Locales Framework to understand the nature of social activity and how a locale (or place) supports activities. It is comprised of five aspects: Locale foundations, Civic Structures, Interaction Trajectory, Individual views, and Mutuality, detailed here [14]. According to this framework, a social world is comprised of a group of people in a site of collaboration, using some means to communicate, while sharing a common purpose. A locale is the actual site in which a group collaborates, the means by which people communicate, and the means by which the work is achieved. For instance, a resident and a nurse with the goal of advancing a patient out of the ICU would form a social world. If the resident and the nurse met in a conference room while discussing the patient's condition, the room with its artifacts (whiteboard, workstation, notes etc.) forms a physical locale. If the resident and the nurse had a phone conversation, then that would form an audio locale.

The Locales Framework has been validated to understand existing collaborative work practices, and to motivate the design of new systems [21,32,53]. The Locales Framework is concerned with the principled design of CSCW systems, where the framework helps provide a coherent image of system requirements and informs their construction [14]. We view the situated nature of ICU work using the idea of dynamic social worlds, which help us focus on the interaction at hand. We draw on our fieldwork using the five different aspects of the Locales Framework to understand the nature of collaborative work mediated through information exchange using technology.

We describe here from our fieldwork two different locales (L1, L2) in different physical locations. In L1, a nurse (N) at a nursing station documents a task. She notices that her patient's record has a new lab result. Meanwhile, in L2, a resident (R) is in the conference room involved in discussing face-to-face with the fellow (F) about an intervention. The N calls the R using a landline phone while R is using a hospital-owned mobile phone. R is interrupted from his conversation with F since he is not expecting a call from N. Since R cannot determine who is calling (the callerID is unknown), he answers the call. This results in the creation of a new locale with members R and N. We report an extract of this phone conversation.

> N: I am calling about Mr. Smith in room 160 with lactate 4.
> R: What are his current vitals?
> N: He has fever with temperature 101, blood pressure is 90 over 40, heart rate is 95, and blood oxygen is 90% on ventilator. His respiratory rate is 20.
> R: What is his white blood count?

N: 4000.
R: Was there an earlier test?
N: Yes, lactate was 2.3 three hours ago.
R: Ok, let's redraw in 30 minutes and see what's going on. I will sign the order shortly.
N: Ok.

DESIGN IMPLICATIONS

We apply here the five Locales Framework aspects [14], described above, to identify design guidelines for designing a notification system for MHT.

Virtual patient locales. Our example locale is a discontinuous audio space for the duration of the phone call. The conversation thread can persist beyond the end of the phone call – the resident or the nurse can return to it several times (through multiple phone calls) or there can be changes in membership if another clinician is consulted. There is however a lack of shared awareness for all the clinicians in the patient's team–-at the study site, the information is held in memory by the locale members or notes are made on paper [8,35,55]. Information shared during the phone call is not immediately digitally documented to keep the other clinicians informed about the patient's progress. The existing notification system does not inform the nurse automatically when the resident has signed an order for her to process. This lack of knowledge of team members' work in relation to the patient's current condition can potentially impact patient safety [56].

One way to enhance awareness among co-workers is to take advantage of technology solutions that mediate communication [3,27,34,40,57]. For instance, the MHT can allow clinicians to create patient-specific locales and exchange chat messages seen by everyone on the team within each locale to keep everyone abreast of the patient's condition. This guideline (based on Locale foundations, civic structures, and mutuality) creates virtual and persistent patient locales, that allow ICU clinicians and information resources to co-exist, thus keeping others informed through notifications, and improved shared awareness.

Asynchronous notifications. The creation of the locale in our example is dependent on the resident responding to the call initiated by the nurse. The resident cannot avoid the call-- the mobile device at the study site does not include caller information, thus creating a challenge for the resident to identify the significance of the message that will be conveyed and its relation to the patient's treatment plan. Thus, the resident's workflow will be disrupted if he is busy performing an unrelated activity when the phone call is initiated, in turn impacting his performance [56]. If however, the resident is on downtime, the information in the call can allow him to effectively and timely diagnose a patient's abnormal condition.

This potential disruption can be overcome by asynchronous notifications. Means for managing interruptions caused by notifications include: (i) an interruption impact reduction paradigm, in which software-based agents prevent or block a notification for a specific time period [16,38,48], and (ii) an interruption value evaluation paradigm, in which a preview of a notification is provided so the interruptee can decide to either continue or break an ongoing task [19,20].

This guideline (based on Locale foundations and civic structures) uses the interruption value evaluation paradigm, so that the interruptee can evaluate every interruption. This is supported by results that not all ICU notifications are unwanted interruptions [33,50]. As phone calls are more disruptive than text or voice messages [26], notifications may be provided, through a combination of visual [43] or tactile cues [42] that occur at a time determined by the receiver to minimize disruptions to an ongoing activity. For instance, the resident can state that he is "busy" until 11 am and prefers receiving less urgent messages after 11. In this case, the technology will batch notifications for less urgent messages after 11 am. Urgent messages are generated as a visual cue for the resident irrespective of time. Urgency of messages will be computed based on the patient's current vital signs (from EMR) and a priority measure (such as high, medium, low) explicitly stated by the sender.

Locale-specific notifications. In our example locale, both the resident and the nurse can be members of multiple locales, but share a collective goal of managing a patient. This guideline (based on civic structures) proposes the need for a clear distinction and easy movement among multiple locales. Research has identified several task-switching strategies: (i) encoding in the long-term memory of the receiver, (ii) rehearsing information prior to switching between locales, or (iii) depending on environmental cues when resuming a task [4,12,30,42,58]. Similar strategies could be applied while switching between multiple locales. For instance, the system can color-code the different patient locales to encode notifications based on color. When the nurse sends the resident a message about a lab result, the color of the notification can be used as a retrieval cue in reducing the memory demand for the resident, thus allowing him to simply "glance at" the message while determining which patient the message concerns. Notifications can be tailored to each locale. Appropriate content can be presented for the resident to effectively and efficiently understand and interpret information, e.g. a patient room number coupled with the patient's initials can be an accompanying visual cue to differentiate among locales. Others on the team who are not notified directly can still remain updated by visiting the virtual patient locale. The system can also buffer less urgent messages based on the location of the receiver. For instance, a resident walking into a patient's room can receive the buffered notifications specific to the patient to provide a context.

Temporal notifications. In the example, the resident suggests that the nurse perform the lab test again after 30 minutes. Hence the resident expects a phone call from the nurse in 30-40 minutes. From the contextual inquiry sessions, if the resident expects to hear from the nurse, he will more likely interrupt his current activity and respond to any notification (which may not be the nurse's phone call). Thus there is a temporal structure to the resident's workflow. Research identifies ICU work to be temporally organized as clinicians seek, provide, and manage information in their daily work [46,47]. The system should allow clinicians to be aware of activities and interactions evolving over time. This includes control over past, present and future aspects of work; how people coordinate their activities over time; how people learn from past experiences and breakdowns, and how processes are supported.

Providing information about the notification can improve the contextual and situational awareness in the dynamic and temporal nature of clinical work. Research on context-aware computing and interruptibility define interruption context by considering the situation of the interruptee [10,18,28,52] based on social [15,26], cognitive [39,60], and relational factors [15,2]. This guideline (based on interaction trajectory and mutuality) proposes an extra *patient-centric* factor in the context of caring for the critically ill, i.e. factors that have the potential to impact patient safety and long-term care. These factors include, e.g. a patient's past and current condition, recent vital signs, previous and recent intervention results, and time between a medical order creation and execution. If the resident from the example locale had been provided with a visual cue containing the lab result and vital signs before initiating a phone call, then the nurse would have conveyed the information less disruptively. The lab test performed again could contain visual information of previous and recent test results (to compare the patient's progress), when the tests were performed, and vital signs. This will improve the contextual awareness and also provide implicit information on the notification's priority. For instance, seeing an abnormal temperature, heart rate, blood oxygen saturation in addition to the lab results can indicate to the resident that the patient is having an inflammatory sepsis response.

Clinician-tailored empathic notifications. Each clinician can hold a unique perspective reflecting her/his participation in a patient locale [46,55]. In our example, compared with the resident, the nurse has a more detailed knowledge of the patient, e.g. with respect to specific physiological responses to a medicine dosage. The resident has a more detailed knowledge of multiple patients in the ICU. This difference in perspectives influences clinicians to participate differently within shared locales. The nurse will notify the resident of an abnormal lab result based on her knowledge of the patient's current condition and normal limits of results. The nurse might consider even a 0.5 increase above a normal value as important to be communicated to the resident. The resident, on the other hand, might not be aware of the patient's current condition and will prefer responding to this 0.5 increase when he has completed an important conversation with the fellow on another patient who is relatively more ill.

This guideline (based on individual views) proposes tailoring notifications specific to clinicians by considering their responsiveness. This helps tailor empathic and polite notifications based on a clinician's perspective of a locale in a way that reflects their degree of focus and participation. Research identifies that responsiveness to notifications depends on what the interruptee is doing at the time [15], the emotional state of the interruptee [29,36], and the modality of the notification [29]. Bickmore et al. [6] ascertain the need for an appropriate level of politeness while interrupting users in order to maximize long-term effectiveness. Hence, the system can use different modalities of notification (visual, tactile, etc.) based on explicitly identified message importance and clinician participation in the locales so that non-active members in a locale can be notified differently compared to active members. For instance, a resident who is an active member of a patient locale may receive a tactile alert from a wearable device in addition to a visual cue on a message explicitly stated as important by the nurse. A less active attending staff may receive only a visual alert. This guideline is motivated by the human factors principles of Phansalkar et al. [43] concerning placement of information, prioritization, and usage of colour and textual information.

SUMMARY

In this paper, we report on an exploratory ICU field study focusing on the interruptions caused by MHT. We use the Locales Framework to identify design guidelines for notification systems in a MHT in the ICU. Our study had limitations. As we did not obtain formal ethical clearance to observe patients or their family members, the observation was limited to hallways, nursing stations, and conference rooms in the medical ICU. This also limited observation in other locations, e.g. the emergency room (ER), trauma/burn unit, operation theatre, and other medical wards. Hence, there was often a break in the sequence of observational notes. Ad hoc opportunistic interviews were done to fill in gaps where the clinicians were asked to recollect actions outside the ICU.

We acknowledge that the ICU practices at the study site can be different from other ICUs. Our study site, however, is one of the leading providers of health care in the Midwest U.S. We expect our findings to be representative of a typical ICU environment. Future studies at multiple ICU settings will enable wider generalizability of our findings for ICUs. Although there are existing studies investigating interruptions in medical work and proposing technology interventions, there is a lack of design guidelines specific to the ICU environment. We proposed a set of design guidelines for managing notification interruptions effectively in the ICU, motivated through cognitive theories, models relating to attention and memory, and human factors principles for different modalities of notifications.

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