Understanding and Mitigating the Interruptions Experienced by Intensive Care Unit Nurses

by

Farzan Sasangohar

A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy

Department of Mechanical and Industrial Engineering
University of Toronto

Understanding and Mitigating the Interruptions Experienced by Intensive Care Unit Nurses

Farzan Sasangohar

Doctor of Philosophy

Mechanical and Industrial Engineering
University of Toronto

2015

Abstract

Intensive Care Unit (ICU) nurses get interrupted frequently. Although interruptions take cognitive resources from a primary task and may hinder performance, they may also convey critical information. Effective management of interruptions in ICUs requires the understanding of interruption *characteristics*, the *context* in which interruption happens, and interruption *content* (3 Cs of interruption). Using this proposed framework, two observational studies were conducted in a cardiovascular ICU (CVICU) at a Canadian teaching hospital. The focus of the first study was to understand the anatomy of interruptions, whereas the second one evaluated an awareness-display designed to help minimize interruptions that occur at inopportune times. Finally, a laboratory study was conducted to study a phenomenon that was observed during the observational studies, namely, nested interruptions.

The first observational study revealed that the rate of interruptions with personal content observed during low-severity tasks (outcome if an error occurs) was significantly higher compared to medium- and high-severity tasks. This finding suggested that other personnel may tend to regulate their interruptions based on nurses' tasks. However, given that nurses' tasks are not always immediately visible to an interrupter, a task-severity awareness tool (TAT) was

designed and installed in a CVICU room for the second observational study. When a nurse engaged the tool within the room, a "Do Not Disturb Please!" message was displayed outside the room. It was found that the interruption rate during high-severity tasks in the TAT room was significantly lower than in other rooms. In addition, in the TAT room, interruptions with personal content were entirely mitigated during high-severity tasks.

In these two studies, it was also observed that not only do nurses receive frequent interruptions resulting in a switch to a secondary task, these secondary tasks also get interrupted; a phenomenon defined here as *nested interruptions*. It was hypothesized that nested interruptions would tax working memory even further compared to performing serial secondary tasks or no secondary tasks as the nurses would have to resume both the secondary and the primary tasks. Thirty nurses from the same CVICU participated in a simulated ICU study where they were interrupted during an electronic order entry task (primary task). Three conditions were tested during the interruption period: no secondary task; a serial condition where participants performed two secondary tasks back-to-back; and a nested condition where participants performed a secondary task that itself got interrupted. Compared to the other two conditions, nested interruptions resulted in significantly longer resumption lags and less accurate task resumption.

Overall, this dissertation contributes to our understanding of ICU interruptions and ways to mitigate them and also expands the theory of interruptions through experimental findings.

Acknowledgments

First and foremost, I would like to thank my wife, Elmira. This work wouldn't have been possible without her support and love. Elmira: I dedicate this thesis to you. Thank you for being patient. I owe my success mostly to you. I love you with all my heart.

I was very fortunate to have a supervisor as diligent, caring, promotive, and kind as Birsen Donmez. Birsen: Not only you are an excellent advisor and researcher, but also a great human being. I have learned so much from you and I hope I can be as good as you are to my students. I was also lucky to have two other extremely knowledgeable and supportive supervisors. I would like to thank Patricia Trbovich and Tony Easty for their support and excellent mentorship.

I would like to thank my committee members, Mark Chignell and Linda McGillis Hall for their continued support and for being valuable resources for my research.

I would also thank my external examiner Penny Sanderson and my internal examiner Greg Jamieson for their valuable feedback and thoughtful suggestions.

I had a pleasure of working with several bright undergraduate students. I would like to thank Sahar Ameri, Paria Noban, Jaquelyn Monis Rodriguez, Marcus Tan, Areeba Zakir, and Junho Choi for their help in data collection and analysis, and implementation included in this dissertation.

I would like to thank Helen Storey and the rest of CVICU staff at Toronto General Hospital for allowing me to conduct this research in their unit. Thank you for your support and your passion for research.

I would like to thank the members of Human Factors and Applied Statistics Lab (HFASt) at the University of Toronto and Humanera at University Health Network for their help reviewing some of the work included in this dissertation.

I would like to thank Gary Fernandes and the Design Research team at TD for their support.

Finally, I would like to thank my parents, Farah and Parviz for their love and support. I hope I made you proud. I also thank my in-laws Elaheh and Mohammad for their continued support.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1
Introduction

The negative effects of interruptions in safety-critical work environments are well documented. Interruptions cause increased task completion times, error rates and job stress (e.g., Bailey & Konstan, 2006; Bergen, 1968; Cellier & Eyrolle, 1992; Czerwinski, Cutrell, & Horvitz, 2000). Disruption of work in team-based activities can also lead to coordination problems, increased time pressure and increased team member workload (Jett & George, 2003). In a review published by the National Traffic Safety Board (NTSB), interruptions were found to be a contributing factor in almost half of the aviation accidents attributed to crew errors (Dismukes, Young, Sumwalt, & Null, 1998). In the Nuclear Power Plant domain, interruptions of job performance were shown to account for more than 15% of all plant shutdowns (Griffon-Fouco & Ghertman, 1984). Previous research shows that interrupting a life-critical cognitively complex task may result in a tragedy. An example is the crash of the Northwest plane where the flight crew forgot to finish the preflight checklist after they were interrupted by air traffic control (McFarlane, 2002). Failing to resume the preflight checklist caused the crew to skip checking the aircraft's flaps, which were in the wrong position and caused the airplane to crash after takeoff. Life-criticality, a high degree of multi-tasking, and the cognitive load of operations in some domains warrant an investigation of the effects of interruptions on human performance and to mitigate any adverse effects they might have.

In healthcare, interruptions are widespread. The advances in healthcare technologies as well as complex structure, rapid pace, and collaborative nature of tasks in these environments make interruptions a common occurrence. For example, Hymel & Severyn (1999) investigated interruptions in an urban teaching hospital emergency department and found that interruptions happen on average every 12.6 minutes (about 5 per hour). Trbovich et al. (2010) showed that nurses are being interrupted up to 14 times an hour during medication administration through intravenous (IV) infusion. According to this study, nurses were interrupted 22% of their working time. Similar studies showed that interruption comprised, on average, 7% (Potter et al., 2005) to 65.6% (Moss et al., 2008) of nurses' work time.

Several patient safety organizations acknowledge the potential effects of interruptions on medical errors. In the United States, the Agency for Healthcare Research and Quality (AHRQ) and The Joint Commission of the Accreditation Organization (JCAHO) reported that interruptions and distractions affect medical errors (JCAHO, 2001; 2002). According to MEDMARX, the largest adverse drug event database in the United States, hospitals attribute 43% of medication errors to workplace interruptions (Bordon, 2003; Santell et al., 2003). The Institute of Medicine's report called *To Err Is Human*, identified interruptions as a possible factor contributing to medical errors (Kohn, Corrigan, & Donaldson, 2000). Interruptions were also listed as one of the top stressors by community psychiatric nurses (Leary et al., 1995).

1.1 Interruptions in Intensive Care Units

Intensive care units (ICUs) stand out as one of the most complex and demanding healthcare work environments. ICU nurses perform various procedures, document patient care, interact with medical devices, respond to the needs of patients and families, and often multitask (Carayon & Gürses, 2005). Furthermore, ICU nurses are frequently interrupted (e.g., 10/hr in Drews, 2007; 15.3/hr in Grundgeiger et al., 2010; 4.5/hr during documentation in Ballerman et al., 2010). Intensive care units are generally known to be error prone (Rothschild et al., 2005) and given the limitations of human working memory and attentional resources (e.g., Fuster, 2008; Miller, 1956; Shallice, 1988), it is likely that interruptions combined with performing multiple concurrent tasks facilitate errors (Westbrook et al., 2010). In line with this expectation, interruptions observed in ICU settings are generally considered to have negative effects on performance, and some of the current mitigation approaches focus on removing or blocking interruptions by applying a sterile cockpit approach and no interruption zones (e.g., Anthony et al., 2010; Hohenhaus & Powell, 2008; Hughes & Blegen, 2008). These reductionist approaches may result in disrupting the flow of potentially valuable information and events that could positively affect patient safety.

Despite the general negative effects of interruptions, interruptions in healthcare at times are necessary as they can convey critical information (Coiera & Tombs, 1998; Grundgeiger & Sanderson, 2009; Rivera-Rodriguez & Karsh, 2010; Walji et al., 2004). In ICUs, interruptions are actually an integral part of the job and are inevitable: the ICU setting is a highly collaborative work environment where communications are vital in ensuring patient safety. For example, nurses or MDs should interrupt their colleagues to notify them of important patient status, remind them of important tasks (e.g., medication order, lab results), or to help them perform their task (e.g., during a medical procedure). In addition, during low-workload periods (e.g., when patients are stable), interruptions may also improve performance by decreasing boredom or increasing arousal (Speier, Valacich, & Vessey, 1999). It is apparent that mitigating interruptions in the ICU setting is much more complex than merely blocking all external events that may break the continuity of nurses' tasks. Understanding and mitigating interruptions in a complex system such as an ICU requires a holistic approach to provide insight into why and how situation-specific interruptions occur.

1.2 Three C's of Interruptions

As a first step to understanding different ICU interruptions with the ultimate goal of developing situation-specific mitigation approaches, a review of healthcare literature was conducted (partly reported in Sasangohar et al. (2012)). From this review I conclude that there are three main factors influencing the effects of interruptions in ICU: *Characteristics* of interruptions, *Context* in which interruptions happen, and interruptions' *Content*. These 3 Cs of interruptions are discussed below:

(1) Characteristics (e.g., frequency and duration): Previous research on interruptions mainly focuses on interruption characteristics and suggests that both interruption frequency and duration have an impact on performance. Longer interruptions tend to result in a longer period of task resumption (i.e., time taken to resume the primary task once the interruption is over), which can hinder performance for time-critical tasks (Grundgeiger et al., 2010; Monk et al., 2008). Furthermore, more frequent interruptions decrease decision accuracy and increase decision time (Speier et al., 1999). In the ICU context, research so far has mainly focused on the frequency and duration of interruptions to nurses and reported high frequencies (10/hour in Drews (2007); 15.3/hour excluding multitasking in Grundgeiger et al. (2010); 4.5/hour during documentation in Ballermann et al., (2010)) and an increased task resumption time for longer interruptions (Grundgeiger et al., 2010).

(2) Context (e.g., sources of interruption, tasks being interrupted, and conditions interruptions happen under): Context plays a major role in understanding why interruptions happen and informs how they should be handled. For example, it may be necessary to block an interruption if the task at hand can lead to a severe outcome in case of an error. Conversely, an interruption may increase arousal in low workload periods. In this research, I investigate an important variable that

might affect the interruption behavior, namely the severity of the primary task that is facing an interruption (described in Chapter 2). Trbovich et al. (2010) studied interruptions to medication administration tasks in a chemotherapy setting. They categorized the tasks in terms of their potential safety impact (i.e., low, medium, high) and used these categorizations to highlight the interruptions to tasks with high safety impact. To my knowledge, an analysis of interruptions according to primary task severity has not been conducted in ICU settings. Other contextual variables that were studied in ICUs include the sources of interruption and interrupted tasks. These studies report other nurse interruptions to be one of the top sources (24% in pediatric ICU by McGillis Hall et al. (2010); 37.3% in adult ICU by Drews (2007)) and patient care and documentation as the most commonly interrupted primary tasks (34% and 21%, respectively, reported by McGillis Hall et al. (2010) for pediatric ICU).

(3) Content (e.g., information the interruption conveys, purpose of interruption): Interruption content can guide how the interruption should be handled. For example, an interruption should potentially be allowed if it conveys time-critical information about the task at hand or if it is necessary for another time-critical task even if it is unrelated to the task at hand (e.g., another patient having a cardiac arrest). In pediatric care (critical, surgical, and medical care combined), McGillis Hall et al. (2010) reported communications with the nurse related to patient care to be the most frequent cause of interruptions (35%) as well as the existence of potentially non–patient-care-related interruptions (e.g., socializing, 4%; phone calls, 2.7%). These latter types of interruptions may have to be blocked based on a given context. In general, interruption mitigation strategies should consider the urgency of an interruption and its relevance to the task at hand.

1.3 Research Approach

This dissertation documents a multi-phase investigation of interruptions in the ICU settings with the overarching goal of designing context-specific interruption mitigation tools to help ICU personnel to modulate their interruption behavior. First, an observational study (discussed in Chapter 2) was conducted using the 3C's framework to investigate why and how interruptions happen in ICUs. The findings were then used to design a mitigation tool to reduce unnecessary interruptions in ICU (discussed in Chapter 4). A second observational study was conducted to simultaneously address the methodological limitations of the first study and validate its findings (discussed in Chapter 3) and evaluate the effectiveness of the mitigation tool (discussed in Chapter 4).

The observations from these studies revealed that not only do ICU nurses get interrupted during a primary task resulting in a shift of focus to a secondary task, sometimes these secondary tasks also get interrupted resulting in several interrupted tasks (in a nested way) that potentially have to be resumed. Finally, a controlled experiment was conducted to compare the effects of three conditions on task resumption: nested interruptions, serial interruptions (conditions where secondary tasks are performed sequentially), and an interruption where no secondary task is performed (discussed in Chapter 5). Figure 1 provides a visual summary of the research approach.

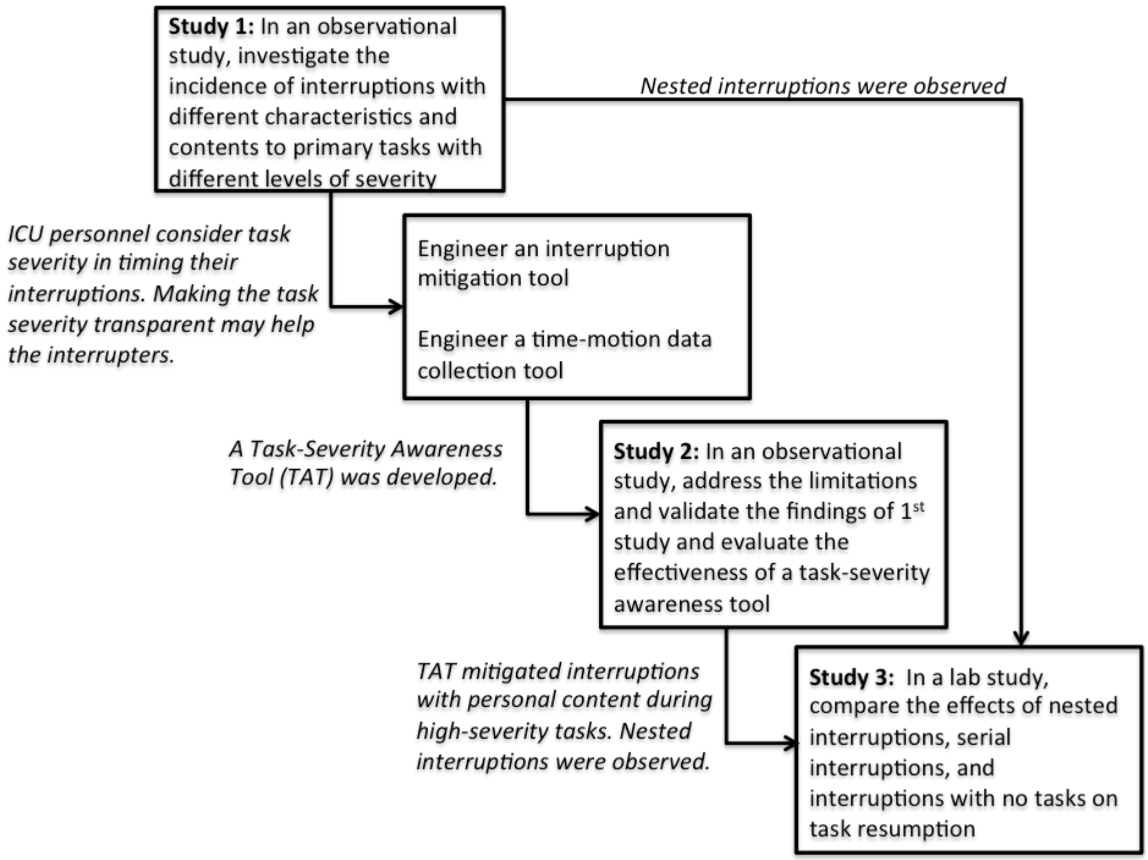


Figure 1. Summary of research approach

1.4 Document Organization

This dissertation is organized into the following chapters:

- *Chapter 2* documents the results of the first phase of the observational studies conducted at a Canadian Cardiovascular ICU (CVICU). Four observers (including myself and 3 of my undergraduate research assistants) trained in human factors research observed 40 nurses, approximately 1 hour each, over a 3-week period. Data were recorded in real time, using touchscreen tablet PCs and the Remote Analysis of Team Environment (RATE) software (Guerlain et al., 2002). The results showed that interruptions are indeed very frequent in this ICU (about 1 per 3 minutes). Although approximately half of the interruptions

(~51%) happened during high-severity tasks (as defined by CVICU nurses), more than half of these interruptions, which happened during high-severity tasks, conveyed either work- or patient-related information, which could potentially be classified as positive interruptions. The rate of interruptions with different content was compared across varying task severity levels. The rate of interruptions with personal content was significantly higher during low-severity tasks compared to medium- and high-severity tasks. This important result suggests that other personnel and in particular nurses (who were the major interrupters) might be considering the severity of the task-at-hand and assessing the importance of their interruptions before interrupting. Despite this interesting result, an important limitation of this study was the lack of an exposure variable. As it was not known what percentage of time nurses spent performing different primary tasks, inferences could not be made connecting primary task characteristics to the occurrence of interruptions. In other words, I could not investigate interruption rate as a function of primary task type and severity while controlling for primary task duration as an exposure variable. This methodological limitation was addressed in the second observational study that evaluated the effectiveness of an interruption mitigation tool. The data from the baseline condition, that is from the CVICU rooms without this tool, were used to validate the findings of the first observational study. The findings from this validation are documented in Chapter 3.

- *Chapter 3* presents the results from the baseline condition of the second observational study. This second observational study was also conducted at the same CVICU. Chapter 3 reports on the rate of interruptions observed during tasks of varying severities (low, medium, high), with a particular focus on comparing different interruption contents. Thirteen nurses participated in the baseline condition (during which the mitigation tool was installed in one of the CVICU rooms that was not used by these nurses). Three observers (including myself and two other observers who were involved in the first study) observed the nurses, about 2 hours each, over a 3-week period. Data were collected in real time, using an Apple iPad application I designed for this purpose (see Appendix A for a detailed description of the tool). The results showed that nurses spent about 50% of their time conducting medium-severity tasks (e.g., documentation), 35% conducting high-severity tasks (e.g., procedure), and 14% conducting low-severity tasks (e.g., general care). The rate of interruptions with personal content observed during low-severity tasks was 1.97 (95% CI: 1.04, 3.74) and 3.23 (95% CI: 1.51, 6.89) times the rate of interruptions with personal content observed during medium- and high-severity tasks, respectively. These results support the results of the first observational study (Chapter 2) and support the finding that interrupters might have evaluated task severity before interrupting.

However, the nurses' tasks may not always be visible to the interrupters. For example, an MD may enter an ICU room and may realize that a high-severity task is in progress (e.g., medication administration). Although the MD may assess the situation and exit the room, the act of entering the room itself may result in an interruption (i.e., nurse may notice the MD and shift his focus away from his primary task). It seems that increasing the transparency of the nature and severity of the task being performed may help others further modulate when and how they interrupt a nurse.

- *Chapter 4* documents the design and evaluation of a task-severity awareness tool (TAT) designed for nurses to inform others when they are performing high-severity tasks. A participatory design approach was used where design requirements of the awareness display (e.g., shape, size, type, and location of buttons; displayed message; color and location of the display) were identified based on interviews with senior CVICU nurses and a group interview consisting of two senior CVICU nurses and two human factors researchers. Appendix B documents the protocol for this group interview and Appendix C presents the transcript of this interview. When a nurse engages the tool within an ICU room (using a set of buttons), a "Do Not Disturb Please!" message is displayed on an LED display outside the room. TAT was installed in a Cardiovascular ICU room at the same Canadian hospital. Fifteen nurses assigned to the TAT room and 13 nurses assigned to 11 other rooms were observed (data reported also in Chapter 3), approximately 2 hours each, over a 3-week period, in non-overlapping time periods. Results showed that interruption rate during high-severity tasks in the TAT room were significantly lower than in other rooms. In addition, interruptions with personal content were entirely mitigated during high-severity tasks. Further, interruptions from nurses and MDs were also entirely mitigated during high-severity tasks but happened more frequently during non-high-severity tasks compared to rooms with no TAT. These findings show that the awareness display proved to be effective in helping ICU personnel moderate their interruption behavior especially during critical tasks. Interruptions to medium- and low-severity tasks were still frequent regardless of this mitigation.

- *Chapter 5* documents the results of a controlled experiment conducted to compare the effects of nested interruptions, sequential secondary tasks (serial interruptions), and no secondary task interruptions on resumption lag and resumption accuracy. Some of the negative effects of interruptions such as longer resumption are associated with limitations of working memory. According to the Memory for Goals Theory (Altmann & Trafton, 2002), goals and cues related to the resumption of an interrupted task are stored in working memory, which has limited space and is prone to decay over time. During the observations conducted at the abovementioned CVICU (Chapters 2, 3, and 4), it was observed that not only do ICU nurses get interrupted during a primary task resulting in a shift of focus to a secondary task, sometimes these secondary tasks also get interrupted resulting in several interrupted tasks (in a nested way) that potentially have to be resumed. It was hypothesized that nested interruptions would tax working memory and result in longer resumption lags and reduced resumption accuracy. A controlled experiment was conducted to investigate the effects of these nested interruptions on resumption lag and resumption accuracy using simulated ICU tasks. Thirty nurses from the same Canadian CVICU participated in a study where they were interrupted during a simulated electronic order entry task. Three conditions were tested (repeated measures, counter-balanced) during the time-controlled (100 seconds) interruption period: a baseline where no task was conducted; a serial condition where participants performed (and completed) two tasks back-to-back; and a nested condition where participants performed two tasks one of which was interrupted by the other and had to be resumed. Nested interruptions resulted in significantly longer resumption lags and less accurate task resumption compared to both the serial and baseline conditions. The training slides used in this study are included in Appendix D, the study protocol is included in Appendix E, and the simulation screenshots are included in Appendix F.

- *Chapter 6* summarizes the main findings and contributions of this research, and identifies the limitations and opportunities for future research.

Chapter 2
First Observational Study: Understanding Interruptions Through Content and Task Severity

Understanding interruptions in a complex system such as an ICU requires a holistic approach to provide insight into why and how interruptions occur. In this chapter, an initial step is taken through an observational study to explore the relations between the 3 Cs of interruptions, in particular, by identifying interruption content and associated primary task severity. The work presented in this chapter has been published in the Journal of Critical Care (Sasangohar et al., 2014).

2.1 Methods

Nurses of the cardiovascular ICU (CVICU) of a Canadian teaching hospital (affiliated with the University of Toronto medical school, in which medical students receive practical training) were asked to participate in an observational study. The unit is a 24-bed closed CVICU that only accepts cardiovascular or vascular (both elective and emergent) surgery patients. The number of patients within the unit varies over the week, with about 12 patients cared for on Sunday, 16 on Monday, 20 on Tuesday, and 22 for the rest of the week. Forty nurses participated in the study (response rate of 90%). Observations were conducted on weekdays between 8:00 and 18:00 during day shifts (07:30-19:30) over a 3-week period. Observers visited the unit each day and in each visit, the available CVICU nurses (~20 rostered per shift) were randomly asked to participate in the study. The study was approved by the research ethics board of this hospital (Toronto, Canada, File #: 12-5572-AE). Four observers (myself and 3 undergraduate engineering students) trained in human factors research conducted 56 observation sessions (1 observer per session), ranging from 26 to 110 minutes, with an average of 56 minutes. The total observation time was 48 hours, a number that is similar to previous ICU interruption studies (34 hours in Drews (2007); 30 hours in Grundgeiger et al (2010); 60 hours in Ballermann et al (2010)). Each working hour from 8:00 to 18:00 was observed at least 3 times. I trained the undergraduate students regarding data collection (5 hours each) and performed 2 pilot studies (2 hours each) with each student. In addition, a codebook was developed to ensure standard adoption of terminology and to homogenize event coding (Table 1). Patient data were not collected; thus patient consent was not required for the study. Other nurses were only observed if they interrupted the participant. Their consent was also not required by the Research Ethics Board.

Inter-rater reliability was analyzed for the coding of events collected in the pilot studies. Cohen's κ was calculated to compare the coding for each data collection category (i.e., interruption source, interrupted task, and interruption content) separately between myself and each undergraduate observer. Results showed substantial to almost perfect agreements between observer pairs for the interruption source (κ ranged from 0.71 to 0.95), moderate to almost perfect for the interrupted task (κ ranged from 0.59 to 0.95), and moderate to almost perfect for the interruption content (κ ranged from 0.56 to 0.88). Overall, only 1 undergraduate observer had moderate agreements with me (i.e., $0.55 < \kappa < 0.6$ for 2 categories). This undergraduate observer participated in 3 hours of additional training within 7 days of the pilot study. In addition, the start time and end time of each event were compared between the 2 coders, allowing for a ± 2 second margin of error. Results showed substantial to perfect agreements between observer pairs for the event start ($0.66 < \kappa < 0.71$) and end times ($0.67 < \kappa < 0.77$). Considering the large number of categories used to establish inter-rater reliability, the results show an adequate level of agreement between observers (Sim & Wright, 2005).

Table 1. Observational study 1: List of sources of interruption, interrupted tasks, and interruption content used in data collection

Interruption Source	Interrupted Task	Interruption Content
Anesthesiologist: CVICU medical anesthesia	***Connecting equipment*:** Connecting medical equipment to patient (e.g., defibrillator, dialysis, ventilator)	***Patient-related*:** Interruptions that convey information about patient the observed nurse was treating (e.g., MD orders a new medication, phone call from the lab to discuss blood test)
Clerk: CVICU staff in charge of documentation and communication	***Discussion*:** Conversations with other healthcare providers about the status of the patient	***Work-related*:** Interruptions that are related to CVICU tasks but not about the patient-in-care (e.g., PCC discusses a new transfer, other nurses request help for their patients)
Equipment: Any noise or alarm related to medical equipment	***Documentation*:** Bedside clinical documentation of patient care such as vital signs, medications, and procedures	***Personal*:** Personal communications that are not about the patient or CVICU tasks (e.g., greetings, personal conversations about vacations)
***MD*:** CVICU medical fellows	***General care*:** Routine ICU tasks such as feeding, bathing, and comforting the patient	***Alarm*:** Medical equipment or emergency alarms
***Nurse*:** Other nurses in the unit	***Infusion setup*:** Setting up the intravenous (IV) infusion such as priming, line insertion, and pump preparation	
***Patient*:** Patient under care	***Line change*:** Process of changing the IV tubing	
***PCA*:** Patient-care assistants are in charge of helping the medical team in tasks such as moving the patient, bed setup, walking the patients.	***Medication administration*:** Process of administering medication orally, through infusion, or injection (e.g., connecting syringe to the IV access device and injecting the medication directly into the vein)	
PCC: Patient-care coordinator works directly with CVICU Manager and entire healthcare team facilitating flow of patients while ensuring all patients and family needs are met.	***Medication order*:** Process of ordering medication for the patient using the medication electronic system	
***Pharmacist*:** Hospital personnel in charge of supply of medications to CVICU staff	***Medication preparation*:** Preparing medication for injection, infusion, or oral administration (e.g., priming IV lines or syringe, preparing the medication cup, connecting IV lines to patients)	
***Phone*:** Any phone that is answered	***Patient assessment*:** Assessing patient status by manual measurement of vital signs, etc.	
***Physiologist*:** Hospital personnel in charge of post-surgical patient rehabilitation	***Procedure*:** Medical procedures performed on the patient (e.g., taking blood sample, intubation)	
***Psychologist*:** Hospital personnel in charge of providing psychological consultation to patients and family members	***Pump programming*:** Setting the IV medication dosage and volume to be infused by the pump	
***Surgeon*:** Hospital personnel who performed the surgery	***Using the computer station*:** Using the in-room computer station for any reason other than medication order (e.g., research, email)	
***Visitor*:** Visitors or family members	***Vitals monitoring*:** Acquiring patient vital signs visually from the displays of the various monitoring devices to which the patient is connected	
***X-ray technician*:** Hospital personnel who perform in-room x-ray imaging	***Other*:** Any other task not categorized above	

2.1.1 Apparatus

An observational tool called the Remote Analysis of Team Environments (RATE) was used on 2 Motion C5t and 2 Fujitsu Lifebook U810 ultraportable touchscreen tablets. RATE, developed by University of Virginia researchers (Guerlain et al., 2002), was modified for the purposes of this study to include lists of interruption sources, interrupted tasks, and interruption content (Table 1). These lists were based on a review of the literature (Sasangohar et al., 2012) and interviews conducted with 3 experienced CVICU nurses before the observational study was undertaken. To document an interruption, the observer interacted with the RATE interface to select the proper categories from the lists of interruption source, interrupted task, and interruption content, which created a time-stamped interruption event in a database. These lists were entirely visible at any point in time (i.e., no drop-down menus were used). Furthermore, 10 most recent events were visible on the right side of the screen to facilitate the recording of when an interruption ended. When the observer clicked an event, the event's end time was recorded and the event was removed from the list. On the interface, there was a "comments" text box, which was used by the observer to take opportunistic notes using a digital keyboard or a stylus. When the observer finished taking a note by clicking the "enter" button, the note was time stamped and saved. It should be noted that although an attempt to collect data on interruption length was made, these data are not reported due to data collection limitations.

2.1.2 Cardiovascular ICU staff

The unit has approximately 20 registered nurses (RNs) present during the day shifts, including 1 clinical resource RN and 1 nurse manager. Overall, there are about 100 nurses working in this CVICU. Other personnel generally available during day shifts on weekdays are 1 patient care coordinator (PCC), 2 staff medical doctors (MDs), 2 vascular fellows, 2 unit clerks, 3 patient care assistants, and 3 to 4 cardiovascular surgeons. Each day, there are 2 rounds (at 07:30 and 15:00) in which the CVICU team including 1 to 2 staff anesthesiologists, 1 cardiovascular surgeon, 2 to 3 cardiovascular and anesthesia fellows, 1 in-charge nurse, and primary and neighboring nurses participate. There are also vascular team rounds at 08:00 in which 1 vascular surgeon, 2 fellows, 3 residents, 1 PCC, and primary and neighboring nurses participate.

2.1.3 Procedure

At the beginning of the study, the observer explained the study procedures and told the participants that the focus of the study was not to collect data on their performance but to collect data on the events that resulted in an interruption to their tasks. After obtaining participant consent, one observer observed one registered nurse inside the ICU room while providing patient care for about an hour. To obtain a more representative sample, a large number of nurses were observed for an hour each rather than fewer nurses for longer periods. Furthermore, the observation period was reduced to minimize observer fatigue. When an interruption occurred, the observer marked the relevant information on the RATE software. If time allowed, he also typed in additional comments (e.g., MD entered the room to discuss laboratory results).

The definition of interruption adopted for this research is *an external intrusion of a secondary task, which leads to a discontinuity in primary task*. This definition is similar to the one given by Grundgeiger et al. (2008) but does not consider the secondary task to be unplanned or unexpected as these two stipulations were hard to assess during observation. Furthermore, the definition that we adopted also does not consider a “discontinuity in task performance” as suggested by Grundgeiger et al. (2008) because we were not able to assess primary task performance. Instead, this definition was operationalized as instances where the participant’s visual focus was turned to a secondary task (i.e., the participant looked away from the primary task) due to an external interruption event. Although the observers attempted to record data on potential distractions (external events that do not result in break-in-task but may use cognitive resources; e.g., noise from the hallway) as well, due to reliability issues associated with the identification of distractions (e.g., coders subjectively inferred that an external event was a distraction to the observed nurse if the event was perceived as distracting by the coder), this research focuses only on interruptions as defined above. Multitasking instances where nurses continued performing their task in the presence of an interruption (e.g., nurse answers the patient's question while setting up the pump and not looking away from the pump) were not the focus of this study and were excluded.

2.2 Results

2.2.1 Interruption Characteristics

In 48 hours of total observation time, 1007 interruptions were observed. That is, on average, 1 interruption occurred per about 3 minutes of observation.

2.2.2 Interruption Context

Of the 1007 interruptions observed, other nurses were the most common source (43.38%), followed by equipment (12.04%) and MDs (12.04%), and then patients (8.46%), visitors (6.47%), and phone (4.38%). The rest of interruption sources accounted for less than 15% of all interruptions.

Almost half of all interruptions happened during documentation (26.91%) and procedures (21.45%) (Table 2). Once the observations were complete, 4 experienced nurses were asked to categorize CVICU tasks as having high-, medium-, or low-severity outcomes in case of an error. The nurses responded individually, and the mode response was chosen for task severity. Based on this breakdown, approximately half of the interruptions (50.65%) were found to have happened during high-severity tasks (Table 2). It should be noted that approximately 6% of the interruptions could not be assigned a task severity category due to missing information.

Table 2. Observational study 1: Frequency of interrupted tasks grouped by severity

Severity	Task	Frequency	Percentage of all interruptions
High	Procedure	**216**	21.45%
	Vitals monitoring	**122**	12.12%
	Medication order	**51**	5.06%
	Medication preparation	**48**	4.77%
	Medication administration	**36**	3.57%
	Infusion setup	**19**	1.89%
	Pump programming	**12**	1.19%
	Patient assessment	**6**	0.60%
Medium	Documentation	**271**	26.91%
	Discussion	**64**	6.36%
	Connecting equipment	**5**	0.50%
	Line change	**0**	0.00%
Low	General care	**96**	9.54%
	Using the computer station	**1**	0.10%
Other: context data unavailable		**60**	5.96%
		Total: **1007**	100%

Table 3 reports the frequency percentage (mean and SD) of different interruption sources and contents within the three task severities. To obtain this table, first the frequency percentages within each task severity for each participant were calculated; and then the means and SDs of these values were calculated. When there were no interruptions recorded for a specific task severity level, the datum for that task severity level was treated as a missing value. For low-severity tasks, there were 17 participants whose data were treated as missing as opposed to 1 participant each for high and medium-severity tasks.

Table 3. Observational study 1: Overall statistics of context, characteristics, and content of interruptions

Context		Characteristics	Content
Severity for task-at-hand	Top 4 interruption sources: mean % within severity group (standard deviation)	Interruption frequency (% of all interruptions)	Interruption content ranking: mean % within severity group (standard deviation)
High	1) Nurse: 46.90% (30.91) 2) MD: 15.72% (23.14) 3) Equipment: 14.41% (20.55) 4) Patient: 7.03% (12.40)	510 (53.85%)	1) Work-related: 34.65% (23.55) 2) Patient-related: 29.25% (23.79) 3) Personal: 21.03% (21.51) 4) Alarm: 15.07% (21.23)
Medium	1) Nurse: 40.05% (29.55) 2) MD: 14.87% (24.69) 3) Equipment: 12.03% (18.68) 4) Patient: 6.51% (12.33)	340 (35.80%)	1) Work-related: 41.85% (24.63) 2) Patient-related: 30.78% (28.22) 3) Personal: 14.32% (16.38) 4) Alarm: 13.05% (19.92)
Low	1) Nurse: 40.50% (35.81) 2) MD: 14.92% (31.09) 3) Patient: 13.04% (22.68) 4) Equipment: 12.08% (24.01)	97 (10.24%)	1) Personal: 65.25% (24.97) 2) Patient-related: 20.02% (24.57) 3) Work-related: 8.71% (13.75) 4) Alarm: 6.02% (11.80)

A 3 (task severity: high, medium, or low) x 4 (source: nurse, MD, equipment, or patient) mixed linear model was built with participant included as a random factor to compare the effects of different sources and task severities on interruption rates. Residuals were checked to ensure that the model assumptions were met. The main effect of source was significant ($F(3,357) = 43.30$; $p < .0001$). In particular, rate of nurse interruptions was significantly higher than that of MDs ($t(357) = 8.35$; $p < .0001$), patients ($t(357) = 10.17$; $p < .0001$), and equipment ($t(357) = 9.03$; $p < .0001$). The main effect of task severity ($F(2,357) = 0.13$; $p = .88$) and its interaction with source were not significant ($F(6,357) = 0.38$; $p = .89$).

2.2.3 Interruption Content

Most interruptions were either work related (but not about the patient in care, 34.79%) or patient related (33.26%). Interruptions with personal content constituted 17.88%; and 20.18% of interruptions by other nurses were about personal matters. Furthermore, alarms constituted 14.07% of all interruptions. Table 4 presents a list of interruption contents that were recorded through opportunistic notes. Although it may not be a comprehensive list of contents, it informed the coding for the next observational study discussed in Chapters 3 and 4.

Table 4. List of interruption content categories based on observation notes

Patient-related
Question/conversation about the patient status – Healthcare provider
Question/conversation about the patient status – Visitors
Patient arrival
Patient care
Rounds
Work-related
Breaks
Looking for a colleague
Missing tools (other nurses)
Nurse helping/asking for help
Other nurses talking to the nurse
Patient asking for something/needing help with something
Patient transfer
Phone call
Searching/asking for information
Shift hand-over
Updating Critical Care Information System (CCIS)
X-ray/asking about X-ray
Personal
Non-staff person talking to the nurse
Nurse talking to visitor
Other nurses talking to the nurse
Patient talking to the nurse

A 3 (task severity: high, medium, or low) x 4 (content: patient related, work related, personal, or alarm) mixed linear model on interruption rate with participant included as a random factor revealed significant effects for content (F(3,349) = 17.40; $p < .0001$) and its interaction with task severity (F(6,349) = 20.12; $p < .0001$). Follow-up comparisons of content across different task severity levels revealed that the rate of interruptions with personal content observed during low-severity tasks was higher than that observed during both medium- (t(349) = 8.67; $p < .0001$) and high-severity tasks (t(349) = 7.52; $p < .0001$). Furthermore, the rate of work-related interruptions to low-severity tasks was smaller than that to both medium- (t(349) = −5.64; $p < .0001$) and high-severity tasks (t(349) = −4.41; $p < .0001$). Other comparisons were not significant ($p > .05$).

Comparisons of task severity level across different contents were also conducted. During low-severity tasks, the rate of personal interruptions was higher than the rate of alarms (t(349) = 8.91; $p < .0001$),work-related interruptions (t(349) = 8.51; $p < .0001$), and patient-related interruptions (t(349) = 6.80; $p < .0001$). During high-severity tasks, the rate of alarms was lower than the rate of interruptions with patient-related content (t(349) = −2.84; $p = .005$) as well as work-related-content (t(349) = −3.92; $p < .0001$). In addition, interruptions with work-related content were observed to have a significantly higher rate than personal interruptions (t(349) = 2.73; $p = .007$).

Same differences were observed during medium-severity tasks, where the rate of alarms was lower than the rate of interruptions with patient-related content (t(349) = −3.55; $p = .0004$) as well as work-related content (t(349) = −5.77; $p < .0001$). Furthermore, again for medium-severity tasks, interruptions with work-related content had a significantly higher rate than personal interruptions (t(349) = 5.52; $p < .0001$). Other comparisons were not significant (p > .05).

2.3 Discussion

The ICU nurses got interrupted frequently (~20/hour). Other nurses (~43%) accounted for almost half of all interruptions, followed by equipment (~12%) and MDs (~12%). Almost half of all interruptions (~51%) happened during high-severity tasks and, in particular, during procedures (~21%). Although most interruptions were either work or patient related, approximately 18% of interruptions were due to personal reasons. Moreover, based on opportunistic notes, it was found that some of the work-related interruptions were initiated by nurses who were missing medical supplies or equipment. Finally, looking across task-severity levels, the rate of work-related interruptions were significantly higher during medium- and high-severity tasks compared with low-severity tasks, whereas rate of interruptions with personal content was significantly higher for low-severity tasks compared with medium- and high-severity tasks.

We observed 19.7 interruptions per hour, slightly larger than other observational studies in ICU settings, that reported 4.5 to 15.3 per hour, a range that itself represents large variability (Ballermann et al., 2010; Drews, 2007; Grundgeiger et al., 2010). The differences among these numbers might be due to differences in interruption definitions adopted or due to the characteristics of the specific ICUs observed. Also in line with other studies (24% in a pediatric ICU in McGillis Hall et al. (2010); 37.3% in adult ICU in Drews (2007)), we observed other nurses to be the most common source of interruption (~43%).

Similar to Trbovich et al. (2010) who investigated interruptions in chemotherapy settings, interrupted ICU tasks were categorized in terms of potential severity in case of an error. Although most observed ICU tasks were categorized as high-severity tasks, the fact that more than half of the interruptions happened during high-severity tasks might be of concern. However, a large percentage of interruptions were found to be either work or patient related, which can convey information that is necessary for the completion of the task at hand.

Ideally, the non-urgent, non-task-relevant interruptions should be delayed or blocked during high-severity tasks. It should be noted that such mitigation techniques would depend on the awareness of the task at hand, which may sometimes be difficult to achieve. For example, a clinician may enter a room without knowing the tasks that are being performed, and the mere act of entering a room may cause an interruption. Conversely, interruptions with personal content ranked highest during low-severity tasks, which may indicate that interrupters might have evaluated the task severity before interrupting. Although not statistically significant, higher average rate of interruptions by patients during low-severity tasks (Table 3) may also support this argument. Therefore, making task severity more transparent may help others modulate when and how they interrupt a nurse. Chapter 4 presents an evaluation of a technological intervention to improve task severity awareness by enabling nurses to inform other personnel of the severity of their task at hand.

An important limitation of this study was the lack of an exposure variable. As it is not known what percentage of time nurses spend performing different primary tasks, inferences cannot be made connecting primary task characteristics to the occurrence of interruptions. Furthermore, as pointed out in the results section, when there were no interruptions recorded for a specific task severity level, the data for that task severity level were treated as a missing value. However, when we did not record interruptions for a certain task severity level, there could have been two underlying reasons: (1) the participant did not perform tasks at that severity level during the observation period and (2) the participant did perform tasks at that severity level, but no interruptions happened during these tasks. These limitations were addressed in the second observational study described in the next few chapters (Chapters 3 and 4).

Chapter 3
Second Observational Study: Methodological Fixes and Confirmation of the First Observational Study Findings

In the first observational study described in Chapter 2, we observed that the proportion of interruptions with personal content was higher during low-severity tasks, compared to medium- and high-severity tasks. These results suggest a certain level of intuitive task-severity awareness among the interrupters, suggesting that a deliberate attempt at making task severity more transparent may help others modulate when and how they interrupt a nurse. This finding informed the design of an interruption mitigation tool discussed in detail in Chapter 4. A second observational study was conducted to evaluate the effectiveness of this mitigation tool (overall results presented in Chapter 4). The tool was installed in one room in the same CVICU that was observed in the first observational study and the study was designed such that the room with the mitigation tool as well as 11 other ICU rooms was observed. This second observational study provided us with data (collected from rooms which did not have the mitigation tool) to address the methodological limitations of the first study.

As discussed in the previous chapter, the first observational study had a significant limitation in that the task-at-hand (or the primary task) was only observed when an interruption happened and thus did not capture the prevalence of non-interrupted tasks. Previous studies have shown variation in the percentage of nurse time spent performing different ICU tasks. For example, Keohane et al. (2008) reported that about 10% of ICU tasks they observed were documentation whereas Wong et al. (2003) reported documentation to be around 35%. The second observational study addressed this methodological limitation and the baseline data collected during this second study (i.e., from ICU rooms that did not have the mitigation tool) were used to assess whether occurrence of interruptions varies as a function of primary task severity and interruption content. This chapter presents my findings from these observations and also reports the make-up of different ICU tasks. The work presented in this chapter has been accepted for publication in the International Journal of Nursing Studies (Sasangohar et al., in press).

3.1 Methods

To collect the baseline data (from rooms without the technological intervention), the observers visited the CVICU every weekday between 10:00 and 18:00 during day shifts (07:30 to 19:30) for about 3-weeks. Similar to the first study, in each visit, the available CVICU Nurses (~20 rostered per shift) were randomly asked to participate in the study. The first nurse who agreed to participate was observed. Overall, thirteen nurses participated in the baseline data collection (response rate of ~80%). Each nurse was observed only once. The study (including the mitigation tool component) was approved by the Research Ethics Board of this hospital (Toronto, Canada, File #: 13-7147-AE). Three observers (myself and 2 undergraduate engineering students) who were also involved in the first study conducted thirteen observation sessions (1 observer per session), ranging from 46 to 120 minutes, with an average of 89 minutes. The total observation time was 19 hours. Each 2-hour block from 10:00 to 18:00 was observed at least two times. Similar to the first study, patient data were not collected; thus patient consent was not required for the study. Other nurses were only observed if they interrupted the participant. Their consent was also not required by the Research Ethics Board.

Undergraduate students received further training before data collection. In addition, they performed two pilot studies (2 hours each) along with me. Furthermore, a codebook was developed to ensure standard adoption of terminology and to homogenize event coding (Table 5). This codebook was improved from the one used in the first study (Table 1) based on lessons learned from this earlier study. The top three lists in Table 5 (i.e., interruption source, interrupted task, interruption content) were similar to the first observational study and were based on a review of the literature (Sasangohar et al., 2012) and interviews conducted with three experienced CVICU nurses before the first observational study was undertaken. The final list (specific content) was based on opportunistic notes taken during the previous study and was added to minimize the need for note-taking for some recurring events (e.g., asking for help).

An inter-rater reliability analysis was conducted for the coding of events observed in the pilot studies. Cohen's κ (Landis & Koch, 1977) was calculated to compare the coding of the three major data collection categories (i.e., interruption source, interrupted task, and interruption content) of me (benchmark) with each undergraduate observer. Results showed perfect agreements between observer pairs for the interruption source ($\kappa = 1.00$), substantial to perfect for the interrupted task ($0.72 < \kappa < 1.00$), and almost perfect for the interruption content ($0.87 < \kappa < 1.00$). In addition, the start time and end time of each event were compared between the 2 coders, allowing for a $\pm$ 2 second margin of error. Results showed substantial to perfect agreements between observer pairs for the event start ($0.66 < \kappa < 0.71$) and end times ($0.67 < \kappa < 0.77$).

Table 5. Observational Study 2: Description of data collection categories: Lists of sources of interruption, interrupted tasks, and interruption content

Interruption Source	Interrupted Task	Interruption Content
Anesthesiologist: CVICU medical anesthesia ***Clerk:*** CVICU staff in charge of documentation and communication ***Equipment:*** Any noise or alarm related to medical equipment ***MD*:** CVICU medical fellows ***Nurse*:** Other nurses in the unit ***Patient*:** Patient under care ***PCA*:** Patient-care assistants are in charge of helping the medical team in tasks such as moving the patient, bed setup, walking the patients. ***PCC:*** Patient-care coordinator works directly with CVICU Manager and entire healthcare team facilitating flow of patients while ensuring all patients and family needs are met. ***Pharmacist*:** Hospital personnel in charge of supply of medications to CVICU staff ***Phone*:** Any phone that is answered ***Physiologist*:** Hospital personnel in charge of post-surgical patient rehabilitation ***Psychologist*:** Hospital personnel in charge of providing psychological consultation to patients and family members ***Surgeon*:** Hospital personnel who performed the surgery ***Visitor*:** Visitors or family members ***X-ray technician*:** Hospital personnel who perform in-room x-ray imaging ***Other:*** Any other personnel or source that the observer is not familiar with	***Connecting equipment*:** Connecting medical equipment to patient (e.g., defibrillator, dialysis, ventilator) ***Discussion*:** Conversations with other healthcare providers about the status of the patient ***Documentation*:** Bedside clinical (paper) documentation of patient care such as vital signs, medications, and procedures ***General care*:** Routine ICU tasks such as feeding, bathing, and comforting the patient ***Infusion setup*:** Setting up the intravenous (IV) infusion such as priming, line insertion, and pump preparation ***Medication administration*:** Process of administering medication orally, through infusion, or injection (e.g., connecting syringe to the IV access device and injecting the medication directly into the vein) ***Medication order*:** Process of ordering medication for the patient using the medication electronic system ***Medication preparation*:** Preparing medication for injection, infusion, or oral administration (e.g., priming IV lines or syringe, preparing the medication cup, connecting IV lines to patients) ***Procedure*:** Medical procedures performed on the patient (e.g., taking blood sample, intubation) ***Pump programming*:** Setting the IV medication dosage and volume to be infused by the pump ***Using the computer station*:** Using the in-room computer station for any reason other than medication order (e.g., research, email) ***Vitals monitoring*:** Acquiring patient vital signs visually from the displays of the various monitoring devices to which the patient is connected ***Other*:** Any other task not categorized above	***Alarm*:** Medical equipment or emergency alarms ***Patient-related*:** Interruptions that convey information about patient the observed nurse was treating (e.g., MD orders a new medication, phone call from the lab to discuss blood test) ***Personal*:** Personal communications that are not about the patient or CVICU tasks (e.g., greetings, personal conversations about vacations) ***Work-related*:** Interruptions that are related to CVICU tasks but not about the patient-in-care (e.g., PCC discusses a new transfer, other nurses request help for their patients) **Specific Content** Asking help Helping others Patient question visitor question Patient-visitor conversation Patient arrival Missing tools Looking for colleague Shift hand-over/breaks Patient transfer CCIS (Critical Care Info. System) Patient talking Nurse talking MD talking

3.1.1 Instrument

To facilitate more efficient data collection and longer observation periods, a software tool inspired by Remote Analysis of Team Environments (RATE) (Guerlain et al., 2002) was developed and was used on Apple iPad (with retina display) tablets. As shown in Figure 2, the tool includes 4 clickable and scrollable lists: interruption source, interrupted task, interruption content, and specific content (described in Table 5). To code the start of an event (task-at-hand or interruption) the observer interacted with the tool to select the proper categories from these four lists. Double-tapping anywhere on the screen meant that the event has started and this action created a time-stamped event in a database. The four most recent events were visible at the bottom of the screen to facilitate the recording of when an event ended. When the observer clicked an event, it was time-stamped and removed from the list. The timer on the top left of the display kept a running time of the entire observation that could be stopped by clicking on 'STOP'. There was also a 'NOTE' button, which was used by the observer to take opportunistic notes using iPad's digital keyboard. When the observer finished taking a note by clicking the 'ENTER' button, the note was time-stamped and saved in the database. The interface also allowed for indication of non-task times through the 'NTT' option whenever an observation was not possible (e.g., breaks, curtains on). A more detailed description of the tool can be found in Appendix A.

3.1.2 Procedure

Similar to the first study, at the beginning of the study, the observer explained the study procedures and told the participants that the focus of the study was not to collect data on their performance but to collect data on the events that resulted in an interruption to their tasks. After obtaining participant consent, one observer observed one registered nurse inside the ICU room while providing patient care between 46 to 120 minutes (depending on the length of unobservable periods such as breaks). Other nurses were only observed only if they interrupted the nurse being observed. The observer marked the start and end of each task conducted by the nurse (primary task). The start and end of the task were operationalized as the shift of observable visual focus (i.e., when nurses looked away from the task) from one ICU task (listed in Table 5) to another. When an interruption occurred, the observer entered the relevant information on the tool. If time allowed, the observer also typed in additional comments (e.g., lab called to discuss results). The observer did not speak to the nurse and did not ask any questions during the observation period.

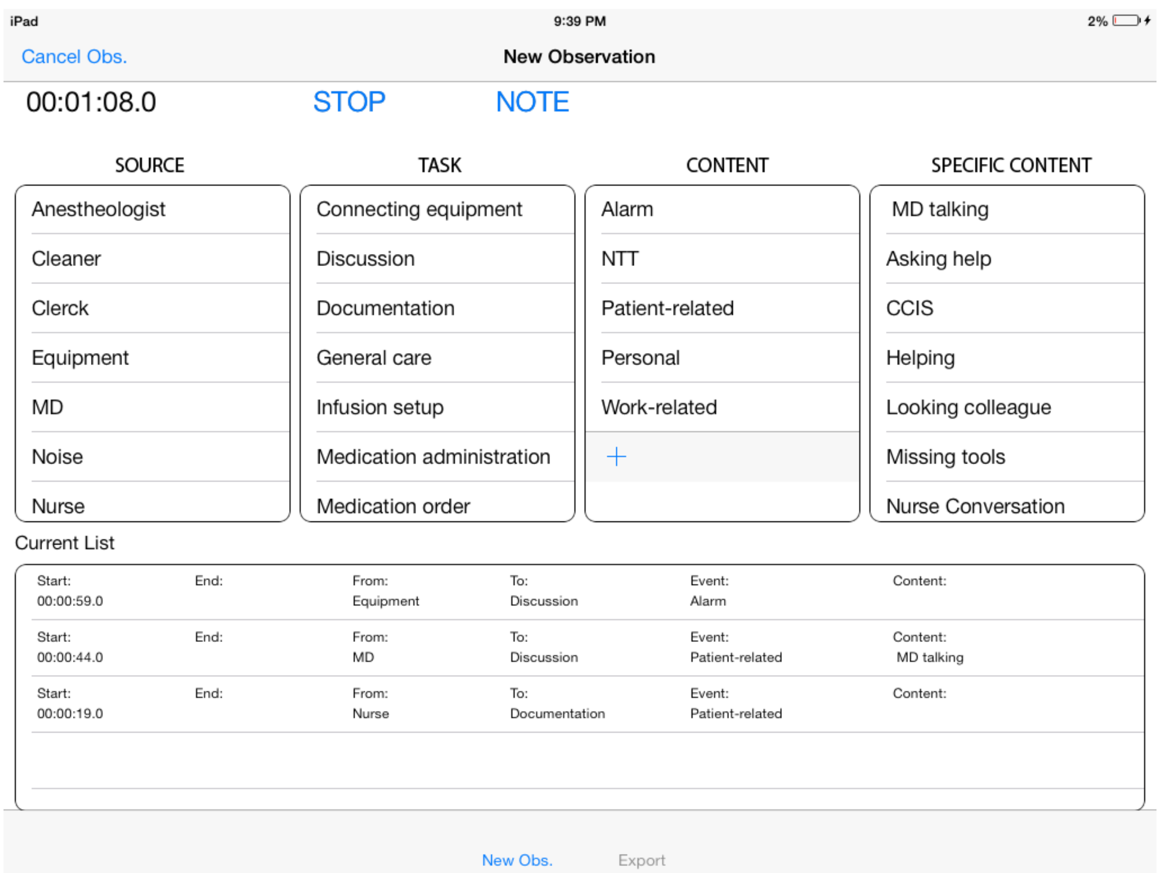


Figure 2. The iPad data collection instrument

The definition of interruption adopted was kept the same as the first study for consistency. To operationalize this definition, the interruption data were collected only when it was possible to observe a break in the primary task due to an interruption (e.g., nurse stopping documentation while discussing the patient with an MD). Similar to the first study, multitasking instances where nurses continued performing their task in the presence of an interruption were excluded.

3.2 Results

3.2.1 Primary Tasks

Overall, 827 primary task activities were observed. Of these activities, 256 (31%) involved discussion with other personnel, 166 (20%) were documentation, 81 (10%) involved general care, and 64 (8%) were procedures (Figure 3 - top). Nurses spent almost half of their time communicating with other personnel (26%) and documenting (23%) (Figure 3 - bottom). They spent 15% of their time conducting procedures and 10% providing general care. Both figures categorize these different task types in terms of having high-, medium-, or low-severity outcomes in case of an error. This categorization followed the methods used in the first observational study discussed in Chapter 2: four experienced CVICU nurses categorized their primary tasks as low-, medium-, or high-severity and the mode response was chosen. Based on this categorization, nurses spent about 50% of their time conducting medium-severity tasks, ~36% performing high-severity tasks, and 14% on low-severity tasks (Figure 3 - bottom).

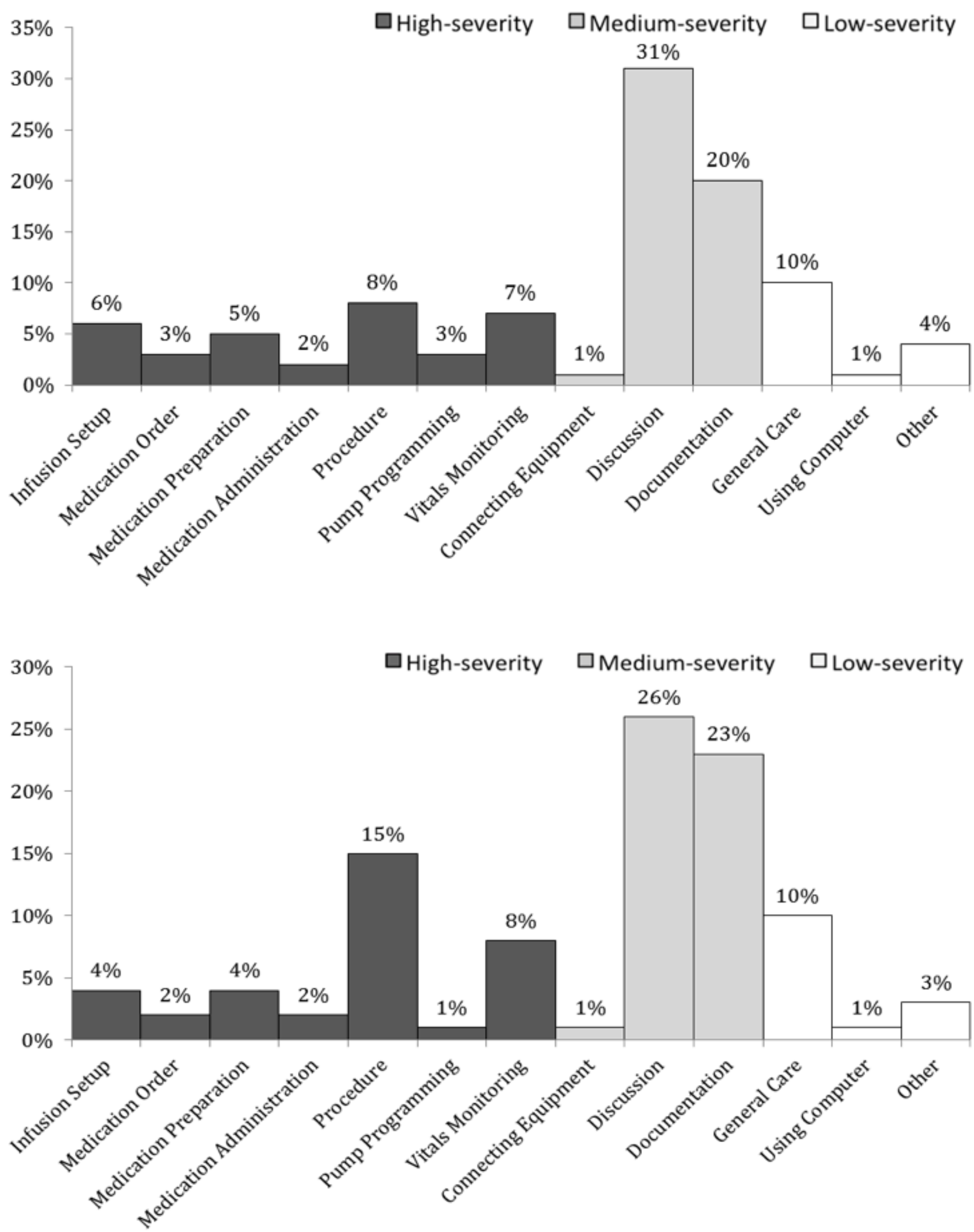


Figure 3. Percentage of different primary tasks observed: (top) percent frequency (n=827), (bottom) percent duration (total duration = 19 hours)

3.2.2 Interruption Characteristics

In 19 hours of total observation time, 254 interruptions were observed. That is, on average, one interruption occurred per about 5 minutes of observation.

3.2.3 Interruption Context

Of the 254 interruptions observed, other nurses were the most common source (51.57%), followed by MDs (12.99%), visitors (7.87%), equipment (6.69%), patients (4.72%), and phone (4.33%). The rest of interruption sources accounted for less than 15% of all interruptions.

As shown in Figure 4, the majority of interruptions happened during documentation (40.68%), general care (11.86%), discussion (10.17%), and procedures (9.32%). 52% of interruptions happened during medium-severity tasks, followed by high-severity (36%), and then low-severity (12%) tasks. Figure 5 ties Figure 3 and 4 by presenting the average number of interruptions per task occurrence. High-severity tasks such as medication administration (0.26), medication order (0.23), and pump programming (0.2) were revealed in this figure to have high rates of interruptions per task occurrence following documentation (0.29) which had the highest rate.

3.2.4 Interruption Content

The majority of interruptions were either work-related but not about the patient-in-care (40%) or patient-related (29%). Interruptions with personal content and alarms constituted 24% and 7% of all interruptions, respectively.

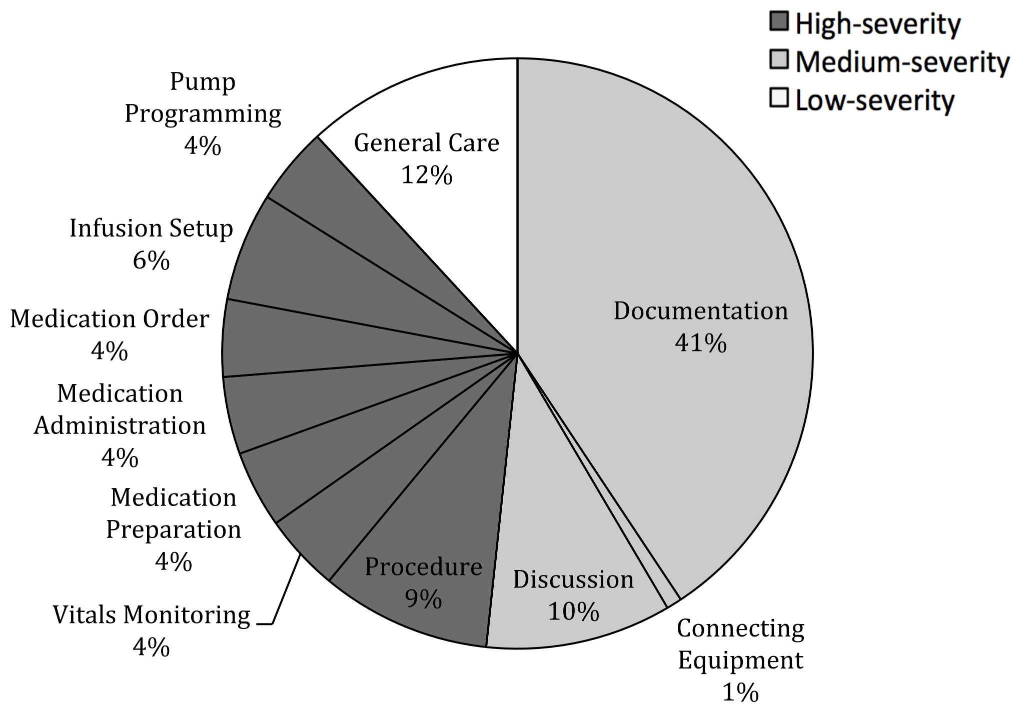


Figure 4. Percent frequency of interruptions by primary task type (n = 254; primary tasks during which no interruptions were observed are excluded)

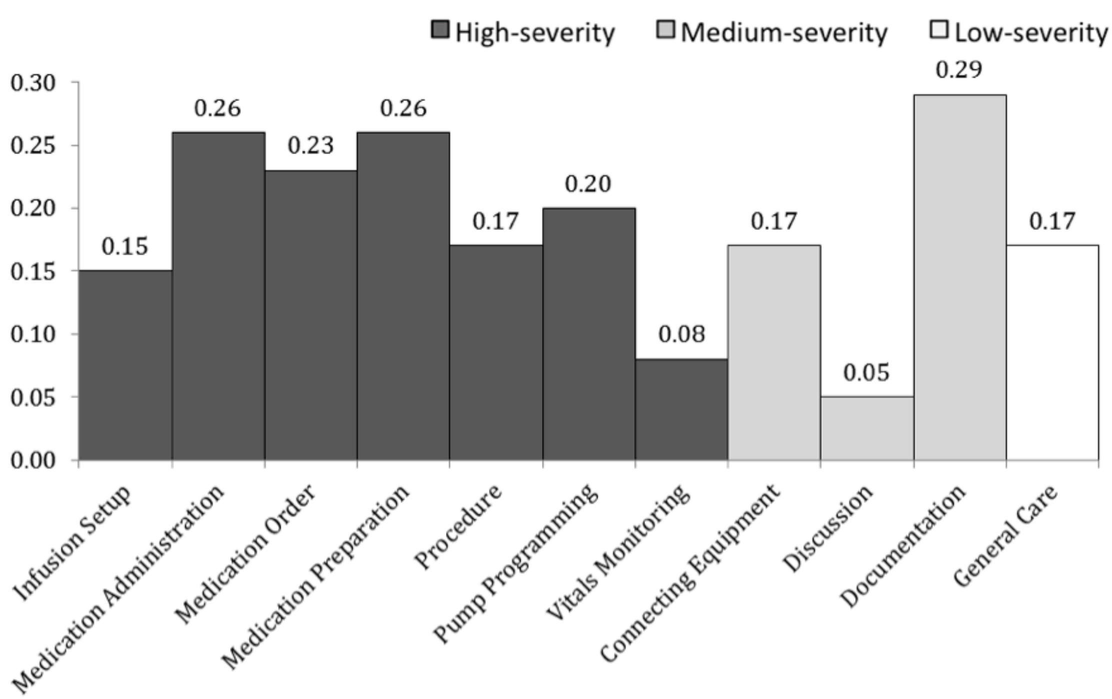


Figure 5. Average number of interruptions per primary task occurrence (primary tasks during which no interruptions were observed are excluded)

Table 6 reports the average rate of interruptions per hour (and standard deviation, SD) from different sources and with different contents observed during the three primary task severities. Unlike the results of the first observational study reported in Table 3, the availability of information about the primary task duration enabled the rate/hr calculations. To obtain Table 6, we first calculated the rates for each participant; the table presents the averages (and SDs) which were obtained across participants. Overall, nurses were the most prevalent source of interruption regardless of task severity, but their rate of interruptions was highest during low-severity tasks (high-severity: 8.66/h; medium-severity: 6.14/h; low-severity: 21.66/h). MDs were the second most frequent source of interruption during high (2.58/h) and low-severity tasks (6.17/h), whereas visitors were the second most frequent source observed during medium severity tasks (2.09/h). There were a few observation sessions where the low task severity periods were quite short (e.g., 48 seconds for one nurse). Interruptions happened during these periods, leading to large interruption rates calculated for these nurses. These extreme values, which are realistic, are reflected in the large standard deviations as well as averages reported in Table 6 for the low severity tasks. However, the statistical models presented in the following sections adjust for such extreme values.

3.2.5 Statistical Analysis

Generalized linear models were built to compare rate of interruptions with different contents observed during different levels of task severity. The models were fitted using PROC GENMOD in SAS 9.2, with the specifications of a log link function and Poisson distribution. Repeated measures were accounted for by using Generalized Estimating Equations (GEE). The logarithm of the total duration of different task severities observed for each participant was used as an offset variable.

Table 6. Observational study 2: Rate of interruptions (frequency per hour) by source and content during different task severities

	Source	Content
Severity of task-at-hand	Top 4 interruption sources: Rate per hour (standard deviation)	Interruption content ranking: Rate per hour (standard deviation)
High	1) Nurse: 8.66 (4.01) 2) MD: 2.58 (2.33) 3) Equipment: 2.10 (1.73) 4) Alarm: 1.03 (3.73)	1) Work-related: 6.21 (3.31) 2) Patient-related: 5.03 (2.45) 3) Personal: 3.29 (2.03) 4) Alarm: 3.26 (3.40)
Medium	1) Nurse: 6.14 (2.16) 2) Visitor: 2.09 (2.09) 3) MD: 1.30 (1.66) 4) Patient: 0.54 (0.77)	1) Work-related: 5.47 (3.37) 2) Patient-related: 4.02 (3.32) 3) Personal: 2.12 (1.64) 4) Alarm: 0 (0)
Low	1) Nurse: 21.66 (42.86) 2) MD: 6.17 (19.40) 3) PCC: 5.77 (20.80) 4) Patient: 2.92 (9.75)	1) Personal: 21.22 (43.04) 2) Patient-related: 9.70 (21.84) 3) Work-related: 5.16 (9.76) 4) Alarm: 3.20 (9.72)

Two separate generalized linear models were built since no alarms were observed during medium-severity tasks. The first model was a 3 (task severity: high, medium, or low) x 3 (content: patient-related, work-related, or personal) and excluded alarms. The second model, which excluded the medium task severity level, was a 2 (task severity: high or low) x 4 (content: patient-related, work-related, personal, or alarm) and informed the results about alarms.

Model 1 results revealed significant effects for content ($\chi^2(2) = 18.51$; $p < .0001$) and its interaction with task severity ($\chi^2(4) = 207.71$; $p < .0001$). Follow-up comparisons of content across different task severity levels revealed that the rate of interruptions with personal content observed during low-severity tasks was 1.97 (95% CI: 1.04, 3.74; z = 2.08; $p = .04$) and 3.23 (95% CI: 1.51, 6.89; z = 3.03; $p = .003$) times the rate of interruptions with personal content observed during high and medium-severity tasks, respectively. Further, the rate of patient-related interruptions during high-severity tasks was 2.39 times that of low-severity tasks (95% CI: 1.03, 5.54; z = 2.03; $p = .04$). Other comparisons were not significant ($p > .05$), except there was a marginally significant difference between patient-related interruptions during high-severity tasks and during medium-severity tasks. More specifically, the rate of patient-related interruptions during high-severity tasks was 1.3 times the rate of patient-related interruptions during medium-severity tasks (95% CI: 0.98, 1.88; z = 1.86; $p = .06$).

Follow-up comparisons of task-severity level across different contents were also conducted. During low-severity tasks, the rate of personal interruptions was 1.91 times the rate of work-related interruptions (95% CI: 1.43, 2.54; z = 4.44; $p < .0001$), 3 times the rate of patient-related interruptions (95% CI: 2.17, 4.15; z = 6.66; $p < .0001$), and 7 times the rate of alarms (95% CI: 2.78, 17.63; z = 4.13; $p < .0001$). In addition, during high-severity tasks, the rate of work-related interruptions was 1.9 times the rate of personal interruptions (95% CI: 1.34, 2.72; z = 3.56; $p < .0001$) and 2.5 times the rate of alarms (95% CI: 1.77, 3.53; z = 5.21; $p < .0001$). Similarly, again during high-severity tasks, the rate of patient-related interruptions was 1.57 times the rate of personal interruptions (95% CI: 1.16, 2.13; z = 2.9; $p < .0001$) and 2.06 times the rate of alarms (95% CI: 1.44, 2.98; z = 3.98; $p < .0001$). During medium-severity tasks, the rate of work-related interruptions was 1.47 times the rate of patient-related interruptions (95% CI: 1.02, 2.11; z = 2.08; $p = .037$) and 2.78 times the rate of personal interruptions (95% CI: 1.91, 4.03; z = 5.37; $p < .0001$). Furthermore, again for medium-severity tasks, the rate of patient-related interruptions was 1.89 times the rate of personal interruptions (95% CI: 1.34, 2.67; z = 3.61; $p < .001$). Other comparisons were not significant ($p > .05$).

3.3 Discussion

To address the methodological limitation of the first study a second observational study was conducted which also evaluated the effectiveness of an interruption mitigation tool (see Chapter 4 for the evaluation of the tool). The 19 hours of observation from the baseline condition of this study (i.e., from rooms with no tool) was used to validate the findings of the first observational study. The primary tasks performed by the nurses as well as the interruptions that they experienced were recorded. The results showed that nurses spent most of their time communicating with other staff (26%) and doing documentation (23%). These findings are in line with the results of the first observational study and previous research; Keohane et al. (2008) reported 22.6% for the former and previous findings on the latter ranged between 12.84% and 35.1% (Keohane et al., 2008; Wong et al., 2003).

Similar to previous studies, we observed frequent interruptions to ICU nurses. We observed 12 interruptions per hour, slightly smaller than the first observational study (Sasangohar et al., 2014) but in line with other observational studies in ICU settings that reported 4.5 to 15.3 per hour (Ballermann et al., 2010; Drews, 2007; Grundgeiger et al., 2010). Consistent with the first study, other nurses (~52%) accounted for almost half of all interruptions, followed by MDs (~13%), and visitors (~8%). Previous research also found nurses to be the most frequent interruption source (Drews, 2007; McGillis Hall et al., 2010; Sasangohar et al., 2014).

Observation of nurses' task-at-hand showed that nurses spent half of their time (50% of observation time) performing medium-severity tasks and almost one-third of their time (35%) conducting high-severity tasks. A very similar pattern was observed with respect to percentage of interruptions, where most interruptions happened during medium- (52%) and high-severity tasks (36%). This evidence suggests that not only medium and high-risk tasks are conducted frequently in ICU, but they may also be interrupted as frequently as low-severity tasks. Thus, efforts should be made to minimize interruptions that could lead to errors, especially for high-risk tasks.

Similar to the first observational study, a large percentage of interruptions were found to be either work- (40%) or patient-related (29%) that may have positive effects on patient safety. These types of interruptions potentially have positive effects but might be delayed if they are non-urgent. There were also potentially negative interruptions observed in this study. For example, personal interruptions were observed at a rate of 3.29/h during high-severity tasks. Arguably, these interruptions should be blocked during high-severity tasks but can help relieve boredom and have a positive effect during low-severity tasks. The majority of previous interruption mitigation approaches in healthcare such as no interruption-zones (e.g., Anthony et al., 2010) or 'Do Not Disturb' vests (Craig et al., 2013) try to block all interruptions and do not consider important contextual information. Overall, there is a need for developing situation-specific mitigation approaches by considering the relevance of an interruption (to patient and/or task) as well as its urgency. Moreover, although we captured exposure through task durations, some tasks may require more personnel to be present (e.g., procedures) and therefore might be more likely to be interrupted. This variation might explain the higher rate of MD interruptions observed during high-severity tasks compared to medium-severity tasks.

In conclusion, the results reported in this chapter support the findings of the first study. The CVICU personnel appear to take context into account before interrupting nurses. It was found that the rate of interruptions with personal content was significantly higher during low-severity tasks compared to medium- and high-severity tasks. This finding provides support for the efficacy of tools or methods that can improve the awareness of other personnel on the tasks performed by nurses. While this chapter presented only part of the data collected as part of the second observational study, the next chapter (Chapter 4) presents the overall data including the data collected in the room in which the mitigation tool was installed.

Chapter 4
Second Observational Study: Design and Evaluation of a Task-Severity Awareness Tool

The observational study described in Chapter 2 showed that the majority of interruptions experienced by nurses can be categorized as positive interruptions that convey information about the patient or other work-related information indirectly affecting the patient. The study also showed that interruptions that can be categorized as negative such as those with personal content (i.e., interruptions that are not patient or work-related), were significantly more frequent during low-severity tasks compared to medium- and high-severity tasks (in terms of consequence to patient in case of an error), suggesting that interrupters may have regulated their interruptions according to nurses' tasks. However, interruptions with personal content still happened during high-severity tasks. Hence, some of these unnecessary or non-urgent interruptions may have happened due to the interrupter's lack of information about the availability of the nurses or their primary tasks.

Although interruption mitigation methods have not been evaluated in ICUs, interruption mitigation has been studied in other healthcare settings. No-interruption zones (Anthony et al., 2010) and physical barriers such as medication preparation booths (Colligan et al., 2012), "do not disturb" vests (Craig et al., 2013), and signage (Pape et al., 2005; Prakash et al., 2014) have all shown promise in reducing interruptions. In addition to these methods not being studied in an ICU setting, these methods have been specific to a certain area or task and may not be practical to implement for a wider variety of areas and tasks that are of concern. These methods also aim to block interruptions without making a distinction for context and interruption content. As suggested by the first observational study (Chapter 2), ICU personnel appear to regulate their interruptions based on nurses' tasks. Follow-up interviews with nurses who participated in this earlier observational study revealed a general perception that many of the unnecessary or non-urgent interruptions in their environment happened when the interrupters were not aware of the criticality of the nurses' tasks. Thus, tools or methods that improve the awareness of the ICU personnel on the criticality of the tasks performed by nurses may empower them to further modulate their behavior.

The term awareness display has been used in previous interruptions research (Bardram et al., 2006; Dabbish & Kraut, 2008; Fogarty, Lai, & Christensen, 2004) to refer to displays that provide information about other collaborators' cognitive or work status (e.g., workload, task, availability, etc.). These displays have been widely studied in office settings with positive results (Cadiz et al., 2002; Van Dantzich et al., 2002) and have also been applied to some extent to healthcare settings. For example, Prakash et al. (2013) used a motion-activated "busy" indicator for pump programming in chemotherapy and found a significant reduction in pump programming errors. Their intervention was a combination of an awareness display, "No-interruption" zone, a speak-aloud protocol, and signage. Thus, it is not clear how much of the total effect can be attributed to the awareness display. Further, I am not aware of any application of awareness displays in the ICU setting.

4.1 Objective and Hypothesis

This chapter introduces an awareness display, called the Task-Severity Awareness Tool (TAT), which was designed for the same CVICU observed in the first observational study (Chapter 2). The tool, described in detail in the following section, is designed for nurses to inform others when they are performing high-severity tasks. It was hypothesized that with the tool, interruptions with personal content would be reduced during high-severity tasks. To test this hypothesis, an observational study was conducted at this CVICU. The work presented in this chapter has been accepted for publication in the Journal of Critical Care (Sasangohar et al., in press).

4.2 Task-Severity Awareness Tool (TAT)

A participatory design approach was used where design requirements of the awareness display (e.g., shape, size, type, and location of buttons, displayed message, color, and location of the display) were identified based on interviews with senior CVICU nurses and a group interview consisting of two senior CVICU nurses and two human factors researchers. The protocol and transcript of this interview can be found in Appendices B and C, respectively. Appendix C also includes a high-level summary of the requirements generated from the interview.

The resulting intervention was a display I built comprising of one Tri-Color Red-Green Type Programmable Scrolling Light Emitting Diode (LED) sign[1] that was hung on top of an ICU room entrance, two big dome LED buttons, and a foot pedal, controlled by an Arduino Uno microcontroller[2] (Figure 6). Pressing any of the two buttons or the foot pedal turned the display on or off, which displayed the scrolling message "Do Not Disturb Please!". In addition, when the display was on, this status was confirmed for the nurses by the flashing of the two LED buttons at a rate of 1 Hz. The light was dimmed by 50% to minimize the distractions that the flashing light might cause.

---

[1] Shenzhen Jingzhi Electronic Technology Co., Ltd., Shenzhen, China

[2] Smart Projects, Ivrea, Italy

4.3 Methods

4.3.1 Setting and Participants

The same CVICU described in previous chapters was observed during weekdays over a 3-week period. On a given day, the CVICU nurses who were rostered for that shift (approximately 20) were randomly approached and asked to participate in the study. Nurses who had not participated in the study before, was selected to participate. Overall, 28 (75%) of the nurses who were approached participated in the study.

Figure 6. The installed LED sign (left), wall LED button and foot pedal (center), and the desktop LED button (right)

4.3.2 TAT Intervention and Study Design

TAT was installed in one CVICU room that was close to the nursing station and was considered by the nurses to be in a busy section of the unit. The tool was installed two weeks prior to the start of observations and was operational outside of the data collection periods. The LED buttons and the floor pedal were positioned for ease of access during high-severity tasks. One of the LED buttons was installed on a wall close to the patient bedside and the other button was installed on the medication preparation desk, while the floor pedal was also installed close to the patient bed (Figure 6). The nurses who were observed were instructed to use TAT for high-severity tasks. As mentioned in Chapter 3, the study was conducted on weekdays between 10:00 and 18:00 during day shifts (07:30 to 19:30) over a 3-week period. The study was approved by the University Health Network Research Ethics Board (Toronto, Canada, File #: 13-7147-AE), which oversees research activities for the hospital studied. The nurses, who agreed to participate, signed an informed consent document. The observations were conducted in a specific ICU room that was under the care of the participant. The observer was stationed in this room and recorded interruptions experienced by the participant throughout the session. Patient data were not collected; thus patient consent was not required for the study. Other nurses were only observed if they interrupted the participant. Their consent was also not required by the Research Ethics Board.

Three observers (including myself and 2 undergraduate engineering students) who were also involved in the first observational study conducted 28 observation sessions (1 observer per session): 15 in the room with TAT and 13 in the other eleven CVICU rooms (as described in Chapter 3, these 13 observations were used to validate the results of the first observational study). Observations of nurses ranged from 46 to 120 minutes, with an average of 104 minutes. The total observation time was approximately 40 hours. Each 2-hour block from 10:00 to 18:00 was observed at least five times. As mentioned previously in Chapter 3, the undergraduate students performed two pilot studies (2 hours each) along with myself. The first pilot study was used to review and discuss event coding and scenarios and the second pilot study was used to conduct inter-rater reliability (described in Chapter 3).

4.3.3 Data Collection

To facilitate real-time time-motion data collection, the same iPad tool described in the previous chapter was used (see Appendix A for more details). In addition, the code 'TAT' was used under the "Content" category to document when nurses turned the display on or off.

4.3.4 Procedure

As discussed in Chapter 3, at the beginning of the study, the observer explained the study procedures and told the participants that the focus of the study was not to collect data on their performance but to collect data on the events that resulted in an interruption to their tasks. Whenever the room with TAT was observed, the nurse was asked to use the device for all high-severity tasks. A list of high-severity tasks (defined in Table 5) was emailed to all CVICU staff by the CVICU manager two weeks before the observations started and a printed list was attached to the TAT room door. A reminder email was sent a week before the observations started. Prior to the start of an observation, nurses were briefly introduced to the list of tasks. The observers marked the start and end of each task conducted by nurses observed. When the nurses pressed the buttons or foot pedal to turn on TAT, the observers started a TAT event. In the case of non-compliance, the observers reminded the nurses to use TAT (68% of high-severity tasks). When an interruption occurred, the observer entered the relevant information on the data collection instrument.

As discussed in Chapter 3, to operationalize the definition of interruption, the interruption data were collected only when it was possible to observe a break in the primary task due to an interruption (e.g., nurse stopping documentation while discussing the patient with an MD). Consistent with the first study, multitasking instances where nurses continued performing their task in the presence of an interruption were excluded.

Van der Laan's Technology Acceptance Questionnaire (Van Der Laan et al., 1997) was administered a week after the completion of the study to collect nurses' opinion on perceived usefulness of TAT and their level of satisfaction with it. This questionnaire includes nine Likert items that ask the participants to rate technology on nine different adjectives (e.g., usefulness, pleasantness). The responses are then translated into numerical values ranging from -2 (negative evaluation) to +2 (positive evaluation). Out of the twenty nurses who participated in the study, only twelve nurses were available to complete the questionnaire a week after the study due to work schedule conflicts. The nurses who completed the questionnaire were also asked if they had any other comments about the tool, its applicability to their work settings, and potential adoption issues.

4.4 Results

In 40 hours of total observation time, 406 interruptions were observed (189 in the TAT room with a total observation time of about 21 hours; 217 in the no-TAT rooms with a total observation time of about 19 hours). Figure 7 presents average interruption rates recorded during high and non-high-severity tasks. During high-severity tasks, the nurses in the TAT room received a significantly lower rate of interruptions compared to the nurses in no-TAT rooms (mean difference: -13.9/h; 95% CI: -17.72, -10.09). There was no difference in interruption rates for non-high-severity tasks between TAT and no-TAT rooms (mean difference: 1.58/h; 95% CI: -3.86, 7.03) (Figure 7).

4.4.1 Interruption Content

Table 7 breaks down interruption rate data for TAT and no-TAT rooms by interruption content and task severity. To obtain this table, we first calculated the rates for each participant; the table presents the averages (and standard deviations) that were obtained across participants. We had hypothesized that with TAT, interruptions with personal content would be reduced during high-severity tasks. The results support this hypothesis. During high-severity tasks, the no-TAT rooms had an average rate of 3.29/h (95% CI: 2.07, 4.52) for personal interruptions, whereas no personal interruptions were recorded for the TAT room.

It was also found that there were no work-related interruptions observed during high-severity tasks in the TAT room, whereas the no-TAT rooms had an average work-related interruption rate of 6.21/h (95% CI: 4.21, 8.20). Thus, it appears that when TAT was in use, the interrupters may have considered these work-related interruptions to be non-urgent and may have delayed them to a more opportune time.

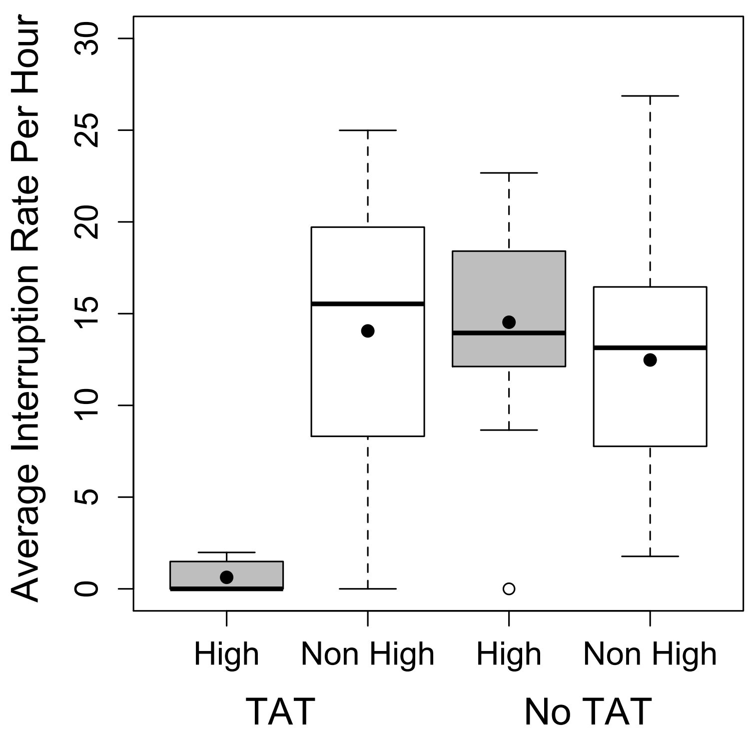


Figure 7. Average interruption rate per hour across TAT and no TAT conditions for different task severities; boxplots represent the five-number summary (minimum, first quartile, median, third quartile, and maximum) as well as potential outliers as indicated with hollow circles and means indicated with solid circles

Table 7. Observational study 2: Rate of interruptions (frequency per hour) by content during different task severities

Severity of interrupted task	Interruption content	No TAT	TAT
		Rate per hour average across nurses (standard deviation)	
High	Work-related	6.21 (3.31)	0 (0)
	Patient-related	5.03 (2.45)	0.63 (0.11)
	Personal	3.29 (2.03)	0 (0)
Non-high	Work-related	5.1 (3.11)	4.61 (4.66)
	Patient-related	4.06 (2.49)	4.61 (6.73)
	Personal	4.08 (4.14)	3.23 (3.15)

The rate of patient-related interruptions also appeared to decrease as reported in Table 7, but not to 0 as was the case for personal and work-related interruptions. A generalized linear model was built to compare rate of patient-related interruptions observed during different levels of task severity (i.e., high vs. non-high) for the two conditions (i.e., TAT and no TAT). The model was fitted using PROC GENMOD in SAS 9.2, with the specifications of log link function and Poisson distribution. Repeated measures were accounted for by using Generalized Estimating Equations. The logarithm of the total duration of different task severities observed for each participant was used as an offset variable.

The results revealed that in the room with TAT, the rate of patient-related interruptions observed during non-high-severity tasks was 5.67 (95% CI: 2.62, 12.25) times the rate of patient-related interruptions observed during high-severity tasks. Further, for patient-related interruptions during high-severity tasks, the interruption rate in rooms with no TAT was 7.18 times the interruption rate in the room with TAT (95% CI: 3.88, 13.3). In the rooms with no TAT, the rate of patient-related interruptions observed during high-severity tasks was 1.5 (95% CI: 1.06, 2.13) times the rate of patient-related interruptions observed during non-high-severity tasks. Overall, it appears that the interrupters delayed their patient-related interruptions to a more opportune time when TAT was in use and that these patient-related interruptions were potentially non-urgent.

4.4.2 Interruption Source

The data were further explored to assess whether the interruption behaviors of different people, in particular nurses and MDs, were affected differently by the tool. Table 8 reports the average rate of interruptions observed in TAT and no TAT rooms, from common sources, broken down by task severity. To obtain this table, we first calculated the rates for each participant; the table presents the averages (and standard deviations) that were obtained across participants. Nurses and MDs, who were the most frequent interrupters during high-severity tasks in rooms with no TAT did not interrupt at all when TAT was in use. Thus, they appeared to be affected similarly by the tool. Instead, it appears that these interruptions may have been delayed to non-high-severity tasks as evident by the higher rate of interruptions observed during non-high-severity tasks in the TAT room.

Table 8. Observational study 2: Rate of interruptions (frequency per hour) by common sources during different interrupted-task severities

		No TAT	**TAT**
Severity of interrupted task	**Common interruption sources**	**Rate per hour average across nurses (standard deviation)**	
High	Nurse	8.66 (4.01)	0 (0)
	MD	2.58 (2.33)	0 (0)
	Visitors	1.03 (3.73)	3.15 (2.5)
	Patient	0.46 (0.67)	0.61 (0.43)
Non-high	Nurse	6.21 (3.2)	11.51 (11.25)
	MD	1.26 (1.47)	3.05 (4.61)
	Visitors	1.31 (1.4)	0.37 (0.73)
	Patient	0.53 (0.69)	0.6 (0.85)

4.4.3 Technology Acceptance Questionnaire

A reliability analysis conducted between the usefulness (Cronbach's $\alpha = 0.78$) and satisfaction (Cronbach's $\alpha = 0.82$) scores between subjects was sufficiently high. Participants generally found the system to be useful (mode: +1), pleasant (mode: +1), good (mode: +1), nice (mode: +1), assisting (mode: +1), desirable (mode: +1), and alerting (mode: +1), but were unsure about its effectiveness (modes: -1 and +1), likability/irritability (mode: 0). The overall usefulness score averaged across participants was 1.08 (95% CI: 0.42, 1.74) whereas the overall average satisfaction score was 0.68 (95% CI: 0.07, 1.23); as stated earlier, the range for these constructs were -2 to 2.

As mentioned earlier in the procedure section, the twelve nurses who completed the questionnaire were also asked if they had any other comments about the tool. Several of these nurses mentioned that although the tool was useful in reducing unnecessary interruptions, using the device involved an extra inconvenient step of pushing the button/foot pedal. Some nurses mentioned that they often forgot to use the device when they were not being observed but they mentioned that if the tool got adopted in the unit they would eventually get used to it.

4.5 Discussion

ICU nurses receive frequent interruptions from other personnel, tools and equipment, patients, and visitors. These interruptions are at times necessary to convey important information for ensuring overall patient safety; however, they can also have negative effects on task resumption, memory, and performance. It was found that other personnel tend to regulate their interruption behavior based on the tasks performed by nurses. However, these tasks are not always immediately visible to an interrupter. A task-severity awareness tool was designed to facilitate better visibility of periods when a nurse is engaged in highly critical tasks. The tool was evaluated in a quasi-controlled observational study in a CVICU.

The results showed that the tool significantly reduced interruptions during high-severity tasks. In particular, we observed no interruptions with personal or work-related content during high-severity tasks in the room that had TAT. This result suggests that the personnel used the information presented by TAT to delay some of the unnecessary or non-urgent interruptions until a more opportune time. Nurses and MDs were observed to be the top two most frequent sources of interruptions in rooms with no TAT, but they did not interrupt at all when TAT was used. This result provides further evidence that the ICU personnel consider the severity of primary tasks in assessing nurses' interruptability once it is made explicit. Although the tool showed promise, it should be tested in other ICU environments where the effectiveness may be different due to variations in workflow, culture, and collaboration demands. In addition, the tool did not appear to reduce interruptions from visitors. While the CVICU personnel were informed about the tool and the objective of the study, visitors were not. Future work should investigate further requirements oriented towards the visitors.

In addition to interruptions with personal content, when TAT was used, work-related interruptions were also eliminated. While some of these interruptions might have been perceived as non-urgent and were delayed to a more opportune time, some important interruptions that should have happened might have been delayed as well. It appears that other personnel may have misperceived the display message as an absolute warning for no entry. Future work should investigate this important limitation by observing and investigating the interrupter's perspective to understand the net effectiveness of awareness displays.

Nurses were generally in favor of technological interventions such as TAT to mitigate interruptions, but several nurses discussed the difficulty of getting accustomed to the extra step involved in engaging the display. In fact, the compliance rate was low; nurses engaged TAT without being prompted in only ~31% of all high-severity tasks. Future research should investigate methods to support ease of use. There were also a few cases where nurses used TAT for non-high-severity tasks (2% of all LED usage cases). The categorization of high vs. non-high-severity tasks was done by a limited number of nurses and we were not able to assess if there was a consensus among the entire unit regarding when the tool should be engaged. When such a tool is implemented in a unit, a general consensus may have to be reached to ensure that the tool is not over-used (more frequently than is required) or under-used (not used to its potential). Future work is needed to investigate the long-term adoption and compliance rates for such an awareness tool. In addition, in 49% of all LED usage cases, nurses turned off the LED either at least a minute before the end of their high-severity task (max = 164 s) or more than a minute after the end of their high-severity task (max = 1187 s). These post-completion errors may relate to prospective memory failures as well as a lack of consensus on the task severity categorization (e.g., nurses might have perceived the follow up tasks as a continuation of their high-severity task). These results may also support the claim that such mitigation tools may be under or overused. Future studies should investigate methods to address such prospective memory failures.

In conclusion, the task-severity awareness tool was found to be effective in mitigating unnecessary or non-urgent interruptions experienced by ICU nurses while they are performing highly critical tasks. The personnel appear to use task-severity cues to regulate their interruption behavior by delaying their non-urgent interruptions.

The observation documented in Chapter 2 and validated in Chapter 3 revealed that not only ICU nurses get interrupted during a primary task resulting in a shift of focus to a secondary task, sometimes these secondary tasks may also get interrupted resulting in nested interruptions. Chapter 5 presents a controlled experiment that was conducted to evaluate the effects of nested interruptions on the time it takes nurses to resume their task after the interruptions (resumption lag) and resumption performance.

Chapter 5
Controlled Experiment: Comparing the Effects of Nested Interruptions, Serial Interruptions, and No Secondary Task Interruptions

As mentioned in Chapter 1, the negative effects of interruptions in Intensive Care Units (ICUs) are associated with potential post-interruption performance decrements. In particular, interruptions may result in healthcare personnel forgetting to resume a task (also known as non-resumptions) (Grundgeiger et al., 2008), longer task resumptions (Grundgeiger et al., 2010; Monk et al., 2008), or erroneous task resumptions (Westbrook et al., 2010) upon returning to the primary task. In addition, in an ICU environment, nurses may receive several interruptions at the same time or sequentially that may intensify the effects on the resumption of the primary task. Although previous research investigates the effects of a single interruption on task resumption (e.g., Grundgeiger et al., 2010; Monk et al., 2008), the effects of receiving more than one interruption on task resumption is largely absent from the literature. In this chapter, a phenomenon I label as *nested interruptions* is introduced where the secondary tasks also get interrupted resulting in more than one task to resume. I draw upon two cognitive models of interruption, memory for goals (Altmann & Trafton, 2002) and prospective memory (Dodhia & Dismukes, 2009), to hypothesize about the effects of nested interruptions on working memory and task resumption. Next, a study is presented to compare the effects of nested interruptions on task resumption lag and task resumption accuracy to the effects of two other types of interruptions: interruptions where multiple secondary tasks are performed but one after the other (i.e., *serial interruptions*) and interruptions that do not involve performing a secondary task.

5.1 Working Memory and Interruptions

Resumption-related effects of interruptions are often associated with limitations in working memory retrieval. Working memory refers to the temporary storage and processing of information during cognitive activities (Baddeley, 1992). Working memory is generally assumed to have limited capacity (also known as limited working memory span) (Miller, 1956; Cowan 2001). The “interference theory” of working memory posits that the new information stored in working memory competes with old information and make the old information more difficult to retrieve (Oberauer et al., 2006; Bancroft and Servos, 2011). Although there are various models of working memory, Altmann and Trafton’s (2002) memory for goals model has been used in the interruption literature to explore the working memory retrieval mechanisms involved in post-interruption task resumption. According to the memory for goals model, the interruptee encodes mental representations of steps in a task as goals for completion in working memory. Borrowing from the ACT-R cognitive theory (Anderson & Lebiere, 2014), Altman and Trafton (2002) argue that initial goals decay gradually or are masked by new goals in working memory unless activated (i.e., retrieved). According to this model, interruptions result in suspended goals while task resumption is the process of accessing the most active goal from the “goal stack” housed in working memory after the interruption ends. The memory for goals model predicts that while interrupted, newer goals may interfere with the old goals affecting task resumption. In line with this model, previous research also shows that interruption length has a positive correlation with the time it takes to resume a primary task after an interruption ends, also known as the resumption lag (Altmann & Trafton, 2002; Grundgeiger et al., 2010).

Similar to the memory for goals model that describes task resumption as the act of retrieving the most active goal from a goal stack (Diez et al., 2002), prospective memory is another working memory model (Dodhia & Dismukes, 2009) that describes task resumption as the act of retrieving the intentions to resume (formed at the time of interruption) from what is known as the prospective memory cue. According to this model, the interruptee forms an intention to act in the future and encodes episodic cues about the state of the primary task to help remember to resume the primary task. Thus, in situations with more than one interruption while away from the primary task, both memory for goals and prospective memory models posit that the contents of the working memory of the primary task will be replaced by the newer goals or intentions to resume, which may affect the resumption performance.

5.2 Nested and Serial Interruptions

The observational study presented in Chapter 2 revealed that nurses not only experience frequent interruptions causing a switch to a secondary task, but the secondary tasks may also get interrupted resulting in a switch to a tertiary task. For example, an ICU nurse may get interrupted by a physician during medication preparation (1st or primary task) asking her to order a medication using the computerized medication order system (2nd or secondary task), and while performing the medication ordering, the nurse may get interrupted by a pump alarm that needs immediate attention (3rd or tertiary task). Hypothetically, nested interruptions may go beyond the tertiary task and may result in deeper levels of interruptions and several interrupted tasks that may need to be resumed (Figure 8). In fact, the first observational study revealed 107 instances of nested interruptions (92 instances resulted in a switch to a tertiary task, 13 resulted in a switch to a fourth task, and 2 resulted in switches to a fifth task). Performing multiple serial tasks may generally result in decay of the working memory (e.g., a primary task is interrupted, and secondary and tertiary tasks are completed, prior to resumption of the primary task) because the primary task goals must be held in working memory during the completion of the secondary and tertiary tasks. Nested interruptions, however, may result in greater working memory decay (e.g., a primary task is interrupted to commence a secondary task that also gets interrupted, during completion of a tertiary task) because both the primary and secondary task goals must be held in working memory during completion of a tertiary task. Consequently, I make a distinction between serial interruptions and nested interruptions.

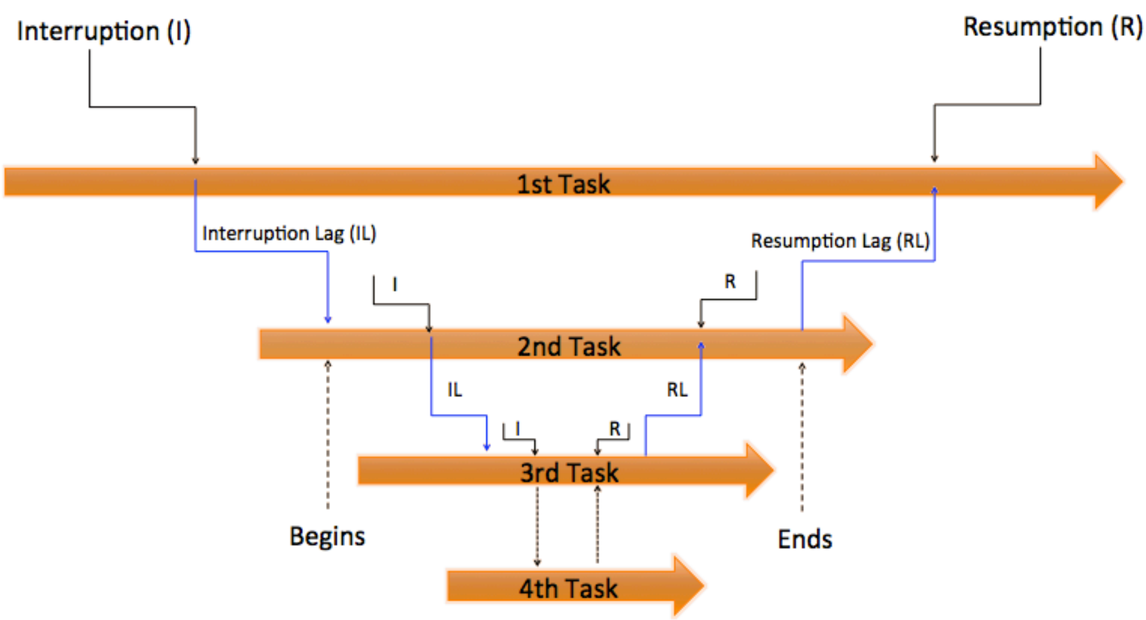


Figure 8. Anatomy of nested interruptions (visualization was inspired by Boehm-Davis et al., 2011)

5.3 Study Goals and Hypotheses

Both memory for goals and prospective memory models posit that when a task is interrupted, goals and intentions to resume related to the primary task are stored in working memory for future resumption. Since nested interruptions involve additional interruptions while away from the first task (hence more incomplete tasks), the additional resumption goals and intentions may overload working memory capacity and compete with the goals and intentions associated with the primary task. Nested interruptions may in turn result in faster decay of working memory of the primary task and a more difficult task resumption compared to serial interruptions and interruptions with no secondary tasks to perform.

It was hypothesized that resumption lag will be longer and resumption will be less accurate for nested interruptions compared to serial interruptions and interruptions with no secondary tasks. A controlled experiment was conducted to investigate these hypotheses using simulated ICU tasks as documented in the following sections.

5.4 Methods

5.4.1 Participants

30 Cardiovascular ICU nurses (27 females, 3 males) from the previously observed CVICU were recruited to participate in the experiment. Participants' age ranged from 26 to 56 years (M = 39, SD = 9.8) and their ICU experience ranged from 4 to 31 years (M = 13, SD = 9.27). Participants received $50 compensation for their participation and one participant received an Apple iPad 3 in a random draw after the completion of the study. Study received approval from the ethics board of the hospital (Toronto, Canada, File #: 6452325) and the University of Toronto (REB#: 29711).

5.4.2 Experimental Design

A repeated measures design was used where each participant completed three experimental conditions (counter-balanced): 1) Baseline in which participants were interrupted during a primary task and did not conduct any task during the interruption period but were asked to wait quietly; 2) Serial interruptions where participants were interrupted during a primary task and had to complete two consecutive tasks during the interruption period before resuming the primary task; and 3) Nested interruptions where participants were interrupted during a primary task and had to conduct a second task that was later interrupted by a third task. Nurses had to resume the second task after completing the third task before being able to resume the primary task.

5.4.3 Data collection Instrument and Experimental Tasks

Nurses interacted with a mock computerized prescriber order entry (CPOE) system used in Pinkney et al. (2014) that emulated the participating institution's medication order entry system. The interface was coded in *Microsoft Visual Basic*[3] and was used in full screen on a *Lenovo*[4] laptop with a 15" display.

5.4.3.1 Primary Task

The primary task was an ICU medication order entry task. Nurses viewed a list of five ICU medications and were given 20 seconds (derived from pilot testing and was deemed to be sufficient time to memorize the medications) to memorize the list and enter the medications in a medication order system (Figure 9). Three versions of the medication list were created and were counter-balanced for each of the three conditions. Previous research shows that frequency of use (Tamayo, 1987) as well as word length and number of syllables (Baddeley et al., 1975) contribute to the difficulty of memorizing words. The three medication lists were carefully generated to have the same length, number of syllables, and number of words. For example the first medication was Dopamine, Atropine, and Propofol for lists 1-3 respectively each of which had 3 syllables, 8 characters, and 1 word. The nurse educator and nurse manager at the participating institution were consulted to ensure that only medications used in the unit were included, and to confirm the similar frequency of medication use between the three lists.

---

[3] Microsoft Corporation, Redmond, WA, USA

[4] Lenovo Group Ltd., Beijing, China

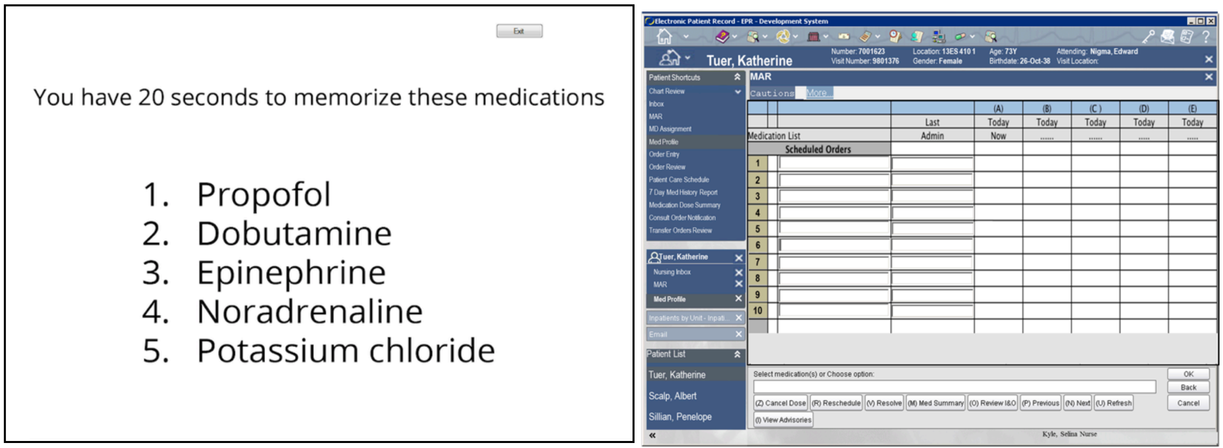


Figure 9. Medication order task: list of medications to memorize (left), medication order entry interface (right)

5.4.3.2 Interruption Period

Primary tasks were interrupted for 100 seconds (regardless of experimental condition) during which participants had to complete one of the three experimental conditions before being asked to resume the primary task. The interruption period (i.e., 100 seconds) was chosen based on the first observational study (Chapter 2) that showed interruptions having an average length of about 50 seconds (x2 for two interruptions). For all three of the experimental conditions, interruptions to the primary task happened after the 3rd medication was entered in the system. The timing of interruptions was pilot-tested to ensure that the number of medications to recall was reasonable. An interface with the text “Interruption: Please wait!” was displayed for 2 seconds after which participants completed one of the three conditions before resuming the entry of the remaining two medications.

5.4.3.3 Interruption Tasks

Participants in the baseline condition viewed a display showing the text “Interruption! Please wait quietly!" and were asked to not speak to the experimenter and remain seated quietly. Participants in the serial and nested conditions performed two tasks: a medication dose entry task, and a head-to-toe patient review task as described below.

Medication dose entry: Similar to the primary task, the medication dose entry task was a memory task where participants were shown a list of four medications along with their recommended dose (Figure 10, left) and were given 20 seconds to memorize the dosage information only. Next, participants were shown the list of medications and were asked to enter the dose and their associated units in the order entry system (Figure 10, right). Two versions of the medication/dosage lists were created and were counter-balanced for the two conditions. The length of both dose and units were chosen to be similar between the two versions.

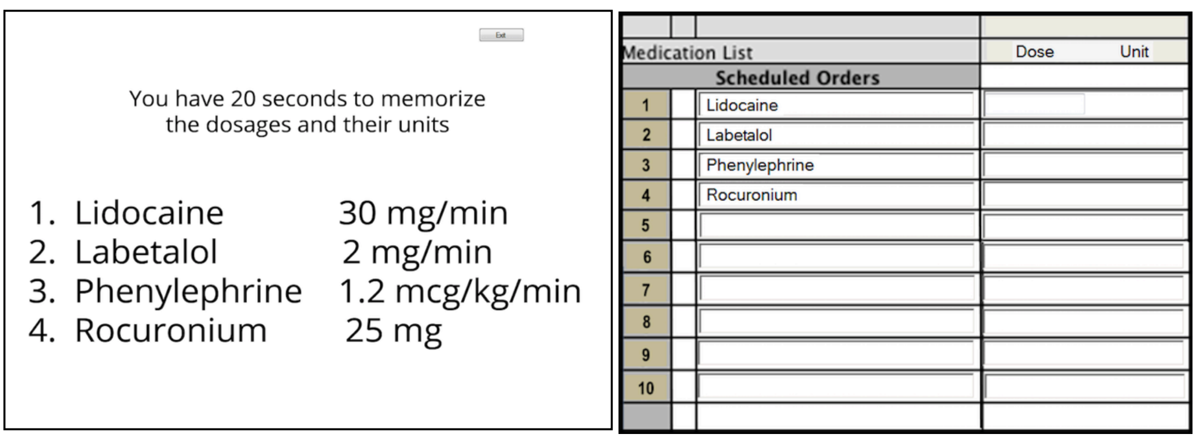


Figure 10. The dosage entry task: list of medications and their dosages (left); the dosage entry system (right)

Head-to-toe: The head-to-toe task involved answering a series of questions about an ICU patient by locating the information on an ICU patient information sheet. The information sheet was adopted from Southeast Medical Associates (SETMA) daily progress templates[5] and included information such as patient's vital signs, diet, diagnoses, etc. Participants were asked questions such as "What is the patient's blood pressure?" or "What is the patient's discharge date?" and had to visually search the ICU patient information sheet for the requested information. The head-to-toe task took 40 seconds (time-controlled). Figure 11 summarizes the experimental conditions and interfaces.

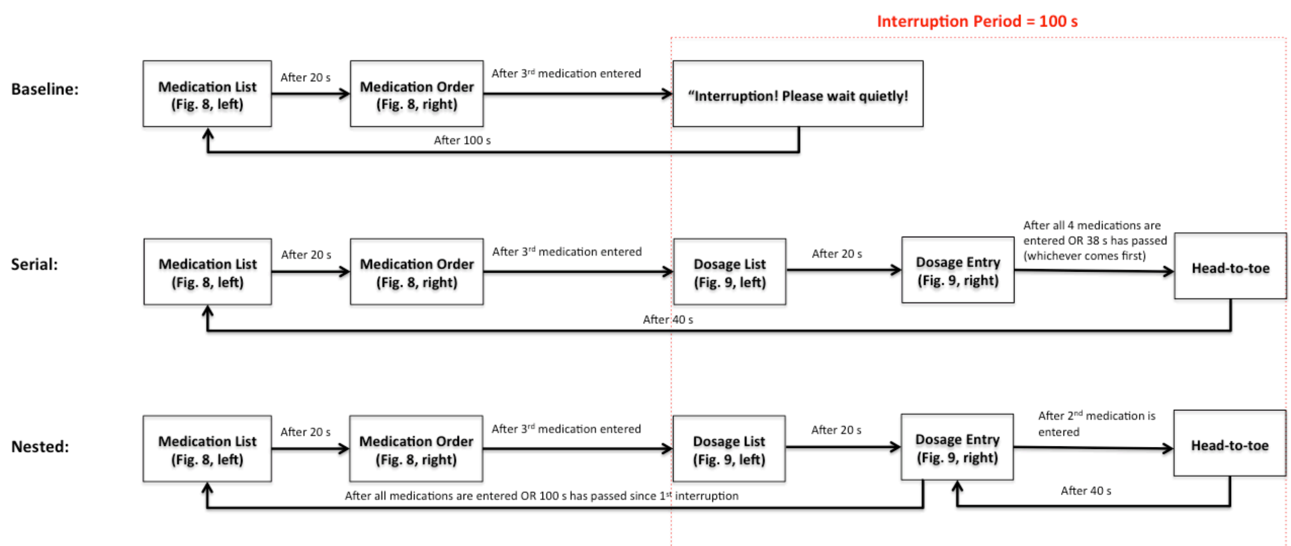


Figure 11. The experimental conditions, order of interfaces shown to participants, and transition criteria

In the serial condition, participants were allowed to perform the dose entry task for 60 seconds (20 seconds to view and memorize the list of dosages, 38 seconds to enter the dosages in the system, and 2 seconds for the task completion message). Participants then completed the head-to-toe task that took 40 seconds (38 seconds plus 2 seconds for the "Task Completed" message).

[5] www.Setma.com

If the participants were not done entering the dosages after 38 seconds passed, the dosages were filled automatically and the message "Task Completed" was displayed for 2 seconds. In case it took participants less than 38 seconds to enter all 4 medication dosages and units, the completion message would have been shown for 2 seconds and the head-to-toe task would have been presented but extended accordingly (i.e., 38 seconds plus the amount of time participants saved in the dosage entry task). This special case did not occur for any of the participants. In the nested condition, participants were interrupted after inputting the 2nd dose (the message "Interruption: Please Wait!" was displayed) and had to perform the head-to-toe task (40 seconds) before entering the remaining 2 dosage entries. The dosage entry task (including resumption) was time-controlled to be 60 seconds. Similar to the serial condition, if it took participants more than 38 to complete the dosage entry, the dosages were automatically completed and the message "Task Completed" was shown. There were no cases where participants took more than 38 seconds to complete the first 2 dosages.

5.4.4 Procedure

Upon arrival, participants were asked to sign an informed consent form. Participants were then asked to complete the modified Functional Assessment of Chronic Illness Therapy-Fatigue (FACIT-F) questionnaire (Cella, Lai, & Stone, 2011) to self-report their fatigue level at the time of the study. This tool was selected for ease of completion and high reported internal validity and reliability (Chandran et al., 2007). None of the participants had a score below 30 (associated with severe fatigue). Next, participants responded to a few demographic questions. Participants completed a training module that included a simplified (with fewer medications) medication order task and dosage entry task. Participants completed two practice trials: a serial condition where they completed both tasks and viewed the "task completed" screen following each tasks;

and a nested condition where their secondary task was interrupted by another task and they had to resume the primary task after completing the secondary task. The goal of the training was to ensure that participants were accustomed to the interfaces, messages, and data entry methods. The performance was observed and training was repeated if necessary. The training session took approximately 10 minutes.

Next, participants used the experimental interfaces to complete the three trials in a counter-balanced order. The experimental software recorded all the medication entries and the time it took the participants to perform each task. Finally, participants completed a short post-experiment interview to assess their perceived difficulty of different conditions. Overall the experiment took about 30 minutes.

5.5 Results

Two dependent variables were used: primary task resumption lag and resumption accuracy. Resumption lag was operationalized as the time (in seconds) it took nurses to press a key on the keyboard after the interruption period ended and the first (primary) interrupted task was shown to the participant again. The resumption accuracy was a nominal score assigned to the resumption performance in the context of remembering a list of medications (0: wrong medication entered or no medication entered, 1: partially entered but recognizable medication name, 2: correct medication name including minor typos). Two raters scored the performances separately. The raters disagreed on only one score and used discussion to come to a consensus.

5.5.1 Task Completion and Success Rate

For serial and nested interruption conditions, performance on interruption tasks was measured by calculating the completion and success rate of these tasks. During both the serial and nested conditions, all 30 participants conducted both the dosage entry and head-to-toe tasks. In terms of accuracy, participants had 79% and 75% success rates for the serial and nested conditions, respectively. The head-to-toe task had a 95% success rate.

5.5.2 Resumption Lag

The resumption lags were compared across the three experimental conditions. A model was fitted using PROC MIXED in SAS 9.2. The results showed that condition (baseline, serial, or nested) had a significant effect ($\chi^2(2) = 19.13$; $p < .0001$). As shown in Figure 12, both serial (M = 70.7s, SD = 59.6) and nested interruptions (M = 113.1s, SD = 68.8) resulted in significantly longer resumption lags compared to baseline (M = 36.7s, SD = 22.89) ($t(79) = 2.71$; $p = .005$ and $t(79) = 6.09$; $p = .0003$ respectively). In addition, nested interruptions resulted in significantly longer resumption lags compared to serial interruptions, $t(79) = 3.38$; $p = .009$.

5.5.3 Resumption Performance

To investigate the effects of serial and nested interruptions on resumption accuracy, we compared the accuracy scores across different experimental conditions. An ordinal logistic model was fitted using PROC GENMOD in SAS 9.2, with the specifications of cumulative logit link function and multinomial distribution. The results showed that condition (baseline, serial, or nested) had a significant effect ($\chi^2(2) = 18.23$; $p < .0001$). Participants in the nested condition had significantly less accurate resumptions compared to the control condition ($z = -3.57$; $p = .0004$). Analysis of Odds Ratios (OR) showed that nested interruptions had about four times higher odds of inaccurate resumptions compared to the base case condition (OR = 3.90, 95% CI = 1.85, 8.24). In addition, the resumption accuracy was significantly less during the nested condition compared to the serial condition ($z = -2.75$; $p = .006$). In particular, the odds of inaccurate resumption were almost two times higher when nurses experienced nested interruptions compared to serial interruptions (OR = 2.23, 95% CI = 1.26, 3.94). The resumption accuracy was not significantly different between the serial and the control conditions. Table 9 includes the descriptive statistics for accuracy scores for different experimental conditions.

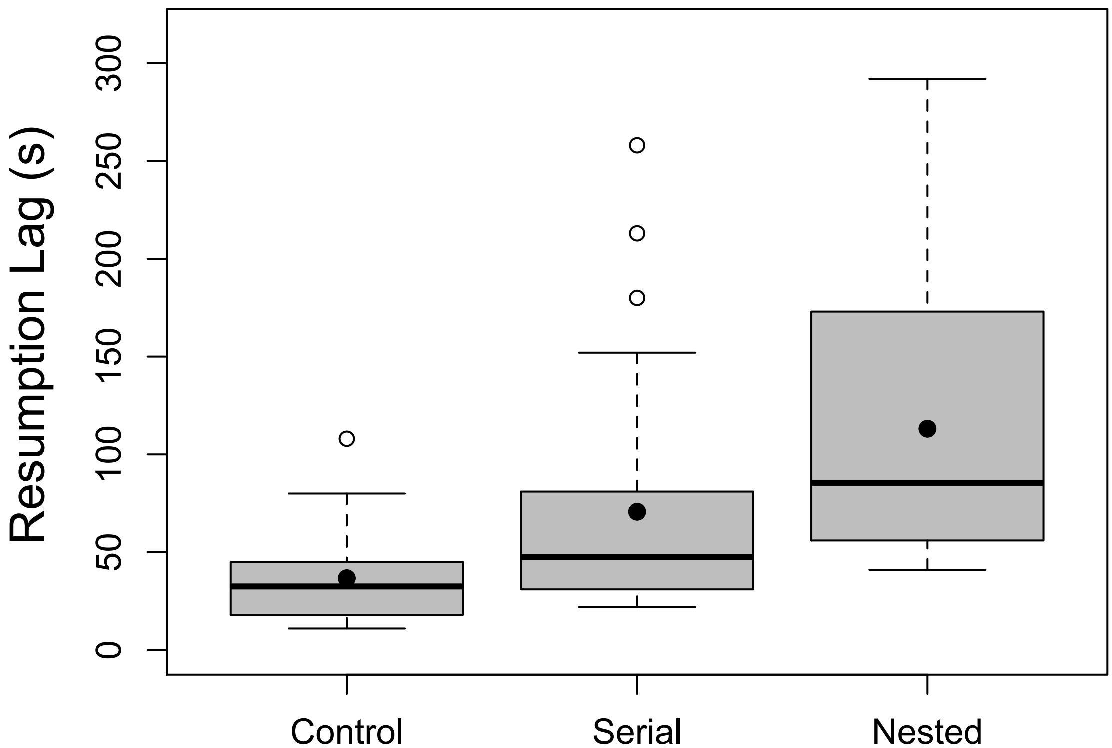


Figure 12. Comparison of resumption lags for control (baseline), serial, and nested conditions

In addition, although number of years of experience in ICU was intended to be used as a covariate for evaluating the effects of different experimental conditions on both resumption lag and resumption accuracy, only four participants had less than 5 years of experience (categorized as low-moderate experience) and therefore this variable was not used.

Table 9. Descriptive statistics for accuracy scores for different experimental conditions

	Accuracy Rating			
	(0) Wrong medication entered or no medication entered	(1) Partially entered but recognizable medication name	(2) Correct medication name including minor typos	**Total**
Control	4	9	17	**30**
Serial	8	8	14	**30**
Nested	11	13	6	**30**
Total	**23**	**30**	**37**	

5.5.4 Qualitative Results

Participants were asked to rank the experimental conditions in terms of difficulty. The majority of participants (18/30) ranked the nested interruption condition as the most difficult, while the remaining twelve ranked the serial as the most difficult. All participants ranked the baseline condition as the least difficult. The majority of participants (26/30) stated that nested interruptions are a common occurrence at the ICU. When participants were asked if they could remember cases where nested interruptions resulted in forgetting to resume a task, all 30 participants remembered such scenarios and provided a few examples. Several examples included nested interruptions that happened during medication administration, patient feeding, and medication order, and involved communications with other personnel (as an interruption to the secondary task) while away from these tasks resulting in forgetting to complete these primary tasks.

5.6 Discussion

A controlled study was conducted to compare the effects of nested interruptions, serial interruptions, and interruptions with no secondary task on resumption lag and resumption accuracy in an ICU context. The results support both hypotheses that nested interruptions affect resumption lag and accuracy significantly more than merely conducting and completing multiple serial tasks or performing no secondary task while away from the primary task. Nested interruptions may result in embedding additional goals in working memory that may mask the goal associated with the primary task and new prospective memories that may overload the working memory. This is in line with goal activation models of interruptions based on ACT-R architecture (Diez et al., 2002). According to these models, a new goal for resumption replaces or fades the most active goal in the working memory.

Results also show that serial interruptions increase the resumption lag compared to performing no secondary tasks. In the baseline condition, participants had a chance to rehearse the medication names that may have facilitated the resumption. On the other hand, in serial condition, participants were busy conducting other tasks and the opportunities for rehearsal were minimized. In addition, the statistically nonsignificant accuracy findings between the serial and baseline conditions suggest that although serial interruptions may result in longer resumption lags, they may not necessarily worsen resumption accuracy.

Previous research provides evidence for the decay of working memory over time when a task is interrupted (Grundgeiger et al., 2011). By controlling for interruption time, the current research builds on memory for goals theory by providing evidence that conducting two tasks during the interruption period, especially when one of these tasks also get interrupted, intensifies the working memory decay significantly. In line with “interference theory” of memory (Tomlinson et al., 2009), the goals encoded to resume the primary task may be replaced by other chunks of information related to new interrupted tasks and in the absence of opportunities to access these goals (e.g., rehearsing), this information may be off-loaded for more recent information (similar to a first-in-first-out queue). Furthermore, although there are no experimental data in the interruption literature to suggest that performing two secondary tasks would tax the working memory further compared to performing one secondary task, the working memory literature in general and "time-based resource sharing model" (Barrouillet et al., 2004) in particular posit that representations in the working memory decay faster with higher cognitive load. Performing more than one task is generally associated with switching costs, higher cognitive load, and use of more memory slots (Rogers and Monsell, 2005; Barrouillet et al., 2007).

The interviews with nurses suggest that both serial and nested interruptions are fairly common in the ICU and may result in longer (and perhaps erroneous) resumptions. These results warrant the need for systematic interruption mitigation methods, to not only minimize the amount of unnecessary interruptions especially during high-severity tasks, but also to assist interruptees to keep the resumption goals activated. In this chapter, I presented empirical evidence suggesting that the nurses may tolerate certain serial tasks without major decrements in task performance. Future work is needed to examine interruptions with varied frequency, lengths, complexity, and similarity to primary tasks to shed more light on this finding and to identify the point where the nurses are no longer able to compensate for the effects of serial interruptions. Furthermore, memory aid tools and technological mitigations could be developed to help nurses resume interrupted tasks. For generalizability, the occurrence of nested interruptions and their characteristics in other work environments where delays in decision-making may result in erroneous decisions or costly consequences (e.g., surgery, emergency response, command and control, and air traffic control) should be investigated.

Next chapter (Chapter 6) provides a summary of findings from the two observational studies

(Chapter 2, 3, and 4) and the controlled experiment discussed in this chapter along with contributions to the field, overall limitations of this research, and future work.

Chapter 6
Conclusion

6.1 Summary of Key Findings

- Some interruptions may have positive effects. Although some of the reviewed healthcare literature acknowledges this, the majority does not. Definitions of interruptions in the literature are somewhat biased toward negative interruptions and do not explicitly differentiate between positive and negative interruptions. This lack of distinction in definitions may have limited the previous observations to only consider negative interruptions.
- ICU nurses get interrupted frequently. We observed an average of 15 interruptions per hour (averaged across the two observational studies excluding the effects of TAT). Other nurses are the most common source of interruption (~47% averaged across the two observational studies excluding the effects of TAT).
- About 43% of interruptions (averaged across the two observational studies excluding the effects of TAT) happened during high-severity tasks. However, the content of the majority of interruptions were either patient-related (40% on average) or work-related (20% on average) that can lead to potentially positive effects.
- Interruptions with personal content happened significantly more during low-severity tasks compared to medium- and high-severity tasks that may indicate that interrupters evaluate the nurses' tasks before interrupting. Therefore, making task severity more transparent may help others modulate when and how they interrupt a nurse.

- Improving the awareness of the task-severity using an awareness display was found to be effective in mitigating unnecessary or non-urgent interruptions experienced by ICU nurses when they performed highly critical tasks. The personnel appear to use task-severity cues to regulate their interruption behavior by delaying their non-urgent interruptions to a more opportune time.
- Receiving additional interruptions on tasks performed in an interruption period (resulting in more than one task to resume) increases the resumption lag significantly more than completing other tasks sequentially or conducting no secondary tasks. These nested interruptions tax the working memory and negatively affect the resumption performance.

6.2 Contribution to the Field

This research provides empirical evidence to support the claim that majority of interruptions in CVICU have patient- or work-related content which may have positive effects on patient safety. That being said, interruptions in general likely have negative effects since they result in a break in task (e.g., Bailey & Konstan, 2006; Bergen, 1968; Cellier & Eytolle, 1992; Czerwinski et al., 2000). Understanding interruptions that occur in a complex system such as an ICU requires a holistic approach. As a first step to understanding different ICU interruptions with the ultimate goal of developing situation-specific mitigation approaches, this research proposed a taxonomy of interruption properties (3 Cs of interruptions). Investigating context, content, and characteristics of interruptions and their interaction could be used as a framework to provide insight into why and how interruptions occur.

Although interruptions in healthcare are documented well, the literature on ICU-specific interruptions is relatively small. This research contributed to the ICU literature by providing empirical evidence on the context in which interruptions happen and the prevalence of tasks performed in the CVICU environment.

This research also contributes to the literature on awareness displays. A participatory design approach was used to collect requirements for the design of a task severity awareness tool. The tool was tested in an actual ICU environment. This research provides empirical evidence to support the effectiveness of such awareness tools in reducing unnecessary interruptions in CVICUs. The idea of using displays to provide severity-awareness could be used in similar safety-critical domains in which interruptions from other personnel is problematic. Empowering the interrupters to make more informed assessments may induce a positive behavioral change and reduce unnecessary interruptions.

This dissertation also contributes to the working memory and interruption literature by introducing the nested interruption phenomenon. Although the focus of this research was interruptions to nurses in CVICU, the findings from this research can shed light on human's fundamental abilities to recall. In particular, this research concluded that the prospective memory and goals created as a result of additional interruptions (i.e., in a nested interruption) would overload the working memory and decay the memory of the previous interrupted tasks much faster.

Real-time data collection remains one of the challenges of observational studies. Due to high frequency of events, multiple task switches, and parallel tasks in complex work environments such as ICUs, time/motion data collection tools become especially helpful. Despite their utility, there are very few mobile time/motion tools with the capability to register parallel events. In the first observational study (Chapter 2), we used the Remote Analysis of Team Environment (RATE) that is a MS Windows-based software (Guerlain et al., 2002). Although the tool showed promise, there were several issues that reduced the utility of RATE for future observations. In particular, RATE's interface was unnecessarily cluttered. In addition, RATE could only be installed on a Windows-based computer or tablet. Finally, in order to modify the coding for a category in RATE the software needed to be restarted and on-the-spot changes to the interface were not possible. In order to facilitate data collection, a time-motion data collection tool was designed for Apple iPad that provided a simple interface with larger real estate for easier and faster touch interaction (see more details in Appendix A). The functionality is inspired by RATE but the simple and less cluttered display helped the research team to collect data more efficiently. In addition, due to the investigatory nature of some of our observations, whenever a new field is identified (e.g., a new ICU task), the field could be added in real-time using this new tool. This feature makes it easy for researchers to customize the tool for different purposes. The second observational study described in Chapters 3 and 4 was conducted using this tool. In addition, the tool is currently being used in several academic (e.g., University of Virginia and Indiana University) and industry research labs (e.g., TD Bank Design Research).

6.3 Limitations and Future work

This dissertation research has several limitations and potential future directions that are highlighted in this section.

One of the limitations of the two observational studies was that only the day shifts and weekdays were observed. Interruptions may, in fact, have different characteristics during night shifts and weekends where no admissions or rounds happen and communication is minimized. Future work can investigate the interruptions during the night shift and weekends where interruptions may become positive during low-workload periods. In a low workload situation interruptions with personal content may contribute to patient safety by reducing the amount of boredom and increasing the arousal level. In addition, other ICU environments (e.g., pediatric) may generate different patterns due to variations in workflow, culture, and policies. Moreover, although we captured exposure through task durations in the second observational study, some tasks may require more personnel to be present (e.g., procedures) and therefore might be more likely to be interrupted. In order to draw more generalizable conclusions, variations in interruption behavior among different ICU environments should be investigated.

An important limitation of this and other observational studies is the possibility of deviation from natural behavior due to the presence of an observer (also known as the Hawthorne effect). In addition, participants were aware of the study's objective of investigating interruptions and some have participated in both observational studies that might have influenced their behavior. However, if there were an influence, one would expect the frequency of interruptions to decrease, leading to an underestimation. Future work is needed to replicate these studies using less intrusive observational techniques such as video recording. In addition, in the two observational studies we did not collect participants' demographic information to alleviate privacy concerns and encourage natural behavior. Arguably, variables such as age, experience, and organizational ranking may result in differing interruption behaviors. For example, interruptions to and from nurse managers may differ significantly compared to interruptions experienced or initiated by junior nurses. Future studies should investigate these variables in their study design.

Furthermore, because of the complexity of data collection, time constraints, and observers' limited clinical knowledge, clinical errors were not documented, and the effect of different types of interruptions on task performance cannot be inferred from the data. Future research should replicate these studies while involving clinicians as observers to identify derivations from good practices and medical errors resulting from interruptions. Finally, the inter-rater reliability analysis should also include a comparison with an ICU healthcare professional.

Although TAT showed promise in reducing interruptions during high-severity tasks, it is possible that TAT also resulted in the delay or blocking of some important interruptions. An important limitation of the TAT study was the lack of data on interrupters' motivations (i.e., interruption content). Future studies should not only investigate the interruptions that occur, but also collect information about the interruptions that did not occur but should have to understand the net effects of such mitigation tools. In addition, this dissertation provided evidence for potential misuse of TAT. Future work should investigate ways to mitigate this issue.

One of the limitations of the TAT evaluation study (Chapter 4) was the lack of a true base case. Ideally the room with TAT should have been observed before the tool implementation. Similarly the nested interruption study lacked a true base case where no interruptions are present. Future work may compare nested and serial resumption performance with working memory performance when the tasks are not interrupted. In addition, to reduce the experimental design complexity, the nested interruption study did not include a condition with a single interruption task. The effects of serial and nested interruptions should be compared to no interruption and regular single task interruptions to expand our understanding of the effects of nested interruptions on performance.

The interviews with nurses suggest that both serial and nested interruptions are fairly common in the ICU and may result in longer (and perhaps erroneous) resumptions. These results warrant the need for systematic interruption mitigation methods, to not only minimize the amount of unnecessary interruptions especially during high-severity tasks, but also to assist interruptees to keep the resumption goals activated in their prospective memory. This research presented empirical evidence suggesting that the nurses can tolerate serial tasks under certain conditions. Further work is needed to examine interruptions with varied frequency, lengths, complexity, and similarity to primary tasks to shed more light on this finding. Furthermore, memory aid tools and technological mitigations could be developed to help nurses resume the interrupted tasks. The occurrence of nested interruptions and their characteristics in other work environments where delays in decision-making may result in erroneous decisions or costly consequences (e.g., surgery, emergency response, command and control, and air traffic control) should also be investigated.

Interruptions with personal content are likely to have only negative effects. However, negative effects would be minimal (and may even become positive) if these interruptions occur at opportune times, such as during low-risk tasks. On the other hand, patient- and work-related interruptions may contain important information necessary for the task at hand and the overall patient safety (Grundgeiger & Sanderson, 2009b; Henneman, Blank, Gawlinski, & Henneman, 2006; Rivera-Rodriguez & Karsh, 2010; Walji et al., 2004). Similarly, alarms usually convey important information about an off-nominal situation. Based on this broad reasoning, most observed interruptions in CVICU were potentially positive. This dissertation provides the first step in understanding and developing situation-specific mitigation approaches by considering the relevance of an interruption (to patient and/or task). Future work should investigate interruption management approaches that minimize the negative effects of necessary interruptions while removing unnecessary ones. Thus, future studies should consider categorizing interruption importance and urgency along with primary task severity. In addition, work is needed to investigate the effects of varying levels of interruption contexts, contents, and characteristics on performance.

References

Altmann, E. M., & Trafton, J. G. (2002). Memory for goals: an activation-based model. *Cognitive Science*, *26*(1), 39–83. http://doi.org/10.1016/S0364-0213(01)00058-1

Anderson, J. R., & Lebiere, C. J. (2014). *The Atomic Components of Thought*. Psychology Press.

Anthony, K., Wiencek, C., Bauer, C., Daly, B., & Anthony, M. K. (2010). No Interruptions Please: Impact of a No Interruption Zone on Medication Safety in Intensive Care Units. *Critical Care Nurse*, *30*(3), 21–29. http://doi.org/10.4037/ccn2010473

Baddeley, A. D. (1992). Working memory. *Science*, *255*(5044), 556–559. http://doi.org/10.1126/science.1736359

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior*, *14*(6), 575–589. http://doi.org/10.1016/S0022-5371(75)80045-4

Bailey, B. P., & Konstan, J. A. (2006). On the need for attention-aware systems: Measuring effects of interruption on task performance, error rate, and affective state. *Computers in Human Behavior*, *22*(4), 685–708. http://doi.org/10.1016/j.chb.2005.12.009

Ballermann, M. A., Shaw, N. T., Arbeau, K. J., Mayes, D. C., & Noel Gibney, R. T. (2010). Impact of a critical care clinical information system on interruption rates during intensive care nurse and physician documentation tasks. *Studies in Health Technology and Informatics*, *160*(1), 274–278.

Bancroft, T., & Servos, P. (2011). Distractor frequency influences performance in vibrotactile working memory. Experimental brain research, *208*(4), 529-532.

Bardram, J. E., Hansen, T. R., & Soegaard, M. (2006). AwareMedia: A Shared Interactive Display Supporting Social, Temporal, and Spatial Awareness in Surgery. In *Proceedings* *of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work* (pp. 109–118). New York, NY, USA: ACM. http://doi.org/10.1145/1180875.1180892

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. Journal of Experimental Psychology: General, *133*(1), 83.

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, *33*(3), 570.

Bergen, A. (1968). Task interruption. *Academisch proefIchrift, Universiteit van Arnsterdam. Arnsterdam: Nordi-Holland*.

Bordon, S. (2003). Medication errors in US hospitals. *Retrieved March*, *13*, 2005.

Cadiz, J. J., Venolia, G., Jancke, G., & Gupta, A. (2002). Designing and Deploying an Information Awareness Interface. In *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work* (pp. 314–323). New York, NY, USA: ACM. http://doi.org/10.1145/587078.587122

Carayon, P., & Gürses, A. P. (2005). A human factors engineering conceptual framework of nursing workload and patient safety in intensive care units. *Intensive and Critical Care Nursing*, *21*(5), 284–301. http://doi.org/10.1016/j.iccn.2004.12.003

Cella, D., Lai, J. S., & Stone, A. (2011). Self-reported fatigue: one dimension or more? Lessons from the Functional Assessment of Chronic Illness Therapy--Fatigue (FACIT-F) questionnaire. *Supportive Care in Cancer: Official Journal of the Multinational Association of Supportive Care in Cancer*, *19*(9), 1441–1450. http://doi.org/10.1007/s00520-010-0971-1

Cellier, J. M., & Eyrolle, H. (1992). Interference between switched tasks. *Ergonomics*, *35*(1), 25–36. http://doi.org/10.1080/00140139208967795

Chandran, V., Bhella, S., Schentag, C., & Gladman, D. D. (2007). Functional Assessment of Chronic Illness Therapy-Fatigue Scale is valid in patients with psoriatic arthritis. *Annals of the Rheumatic Diseases*, *66*(7), 936–939. http://doi.org/10.1136/ard.2006.065763

Coiera, E., & Tombs, V. (1998). Communication behaviours in a hospital setting: an observational study. *BMJ*, *316*(7132), 673–676. http://doi.org/10.1136/bmj.316.7132.673

Colligan, L., Guerlain, S., Steck, S. E., & Hoke, T. R. (2012). Designing for distractions: a human factors approach to decreasing interruptions at a centralised medication station. *BMJ Quality & Safety*, *21*(11), 939–947. http://doi.org/10.1136/bmjqs-2011-000289

Cowan, N. (1997). Attention anterd memory. Oxford University Press.

Cowan, N. (2008). What are the differences between long-term, short-term, and working memory?. Progress in brain research, 169, 323-338.

Commission, J., & Commission, J. (2002). Preventing ventilator-related deaths and injuries. *Sentinel Event Alert*, *25*.

Craig, J., Clanton, F., & Demeter, M. (2013). Reducing interruptions during medication administration: the White Vest study. *Journal of Research in Nursing, 19*(3), 248-261. 1744987113484737. http://doi.org/10.1177/1744987113484737

Czerwinski, M., Cutrell, E., & Horvitz, E. (2000). Instant messaging and interruption: Influence of task type on performance. In *OZCHI 2000 conference proceedings* (Vol. 356, pp. 361–367).

Dabbish, L., & Kraut, R. (2008). Research Note—Awareness Displays and Social Motivation for Coordinating Communication. *Information Systems Research*, *19*(2), 221–238. http://doi.org/10.1287/isre.1080.0175

Diez, M., Boehm-Davis, D. A., & Holt, R. W. (2002). Model-Based Predictions of Interrupted Checklists. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *46*(3), 250–254. http://doi.org/10.1177/154193120204600307

Dismukes, R. K., Young, G. E., Sumwalt, R. L., & Null, C. H. (1998). Cockpit Interruptions and Distractions: Effective Management Requires a Careful Balancing Act. *Air Line Pilot*. Retrieved from http://ntrs.nasa.gov/search.jsp?R=20020062698

Dodhia, R. M., & Dismukes, R. K. (2009). Interruptions create prospective memory tasks. *Applied Cognitive Psychology*, *23*(1), 73–89. http://doi.org/10.1002/acp.1441

Drews, F. A. (2007). The frequency and impact of task interruptions in the ICU. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *51*(11), 683–686. http://doi.org/10.1177/154193120705101117

Ebright, P. R., Patterson, E. S., Chalko, B. A., & Render, M. L. (2003). Understanding the complexity of registered nurse work in acute care settings. *The Journal of Nursing Administration*, *33*(12), 630–638.

Fogarty, J., Lai, J., & Christensen, J. (2004). Presence versus availability: the design and evaluation of a context-aware communication client. *International Journal of Human-Computer Studies*, *61*(3), 299–317. http://doi.org/10.1016/j.ijhcs.2003.12.016

Fuster, J. (2008). *The Prefrontal Cortex*. (pp. 107-109). Birkhäuser Boston.

Griffon-Fouco, M., & Ghertman, F. (1984). Recueil de donnees sur les facteurs humains a Electricite de France. *Operational Safety of Nuclear Power Plants*, 157–172.

Grundgeiger, T., Liu, D., Sanderson, P. M., Jenkins, S., & Leane, T. (2008). Effects of Interruptions on Prospective Memory Performance in Anesthesiology. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *52*(12), 808–812. http://doi.org/10.1177/154193120805201209

Grundgeiger, T., & Sanderson, P. M. (2009). Interruptions in healthcare: Theoretical views. *International Journal of Medical Informatics*, *78*(5), 293–307. http://doi.org/10.1016/j.ijmedinf.2008.10.001

Grundgeiger, T., Sanderson, P. M., MacDougall, H. G., & Venkatesh, B. (2010). Interruption management in the intensive care unit: Predicting resumption times and assessing distributed support. *Journal of Experimental Psychology: Applied*, *16*(4), 317–334. http://doi.org/10.1037/a0021912

Guerlain, S., Shin, T., Guo, H., Adams, R., & Calland, J. F. (2002). A Team Performance Data Collection and Analysis System. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *46*(16), 1443–1447. http://doi.org/10.1177/154193120204601608

Henneman, E. A., Blank, F. S. J., Gawlinski, A., & Henneman, P. L. (2006). Strategies used by nurses to recover medical errors in an academic emergency department setting. *Applied Nursing Research*, *19*(2), 70–77. http://doi.org/10.1016/j.apnr.2005.05.006

Hohenhaus, S. M., & Powell, S. M. (2008). Distractions and Interruptions: Development of a Healthcare Sterile Cockpit. *Newborn and Infant Nursing Reviews*, *8*(2), 108–110. http://doi.org/10.1053/j.nainr.2008.03.012

Hughes, R. G., & Blegen, M. A. (2008). *Chapter 37. Medication Administration Safety*.

Hymel, G., & Severyn, F. (1999). Typical shiftwork interruptions faced by supervising EM faculty in an EM residency setting. In *Society for Academic Emergency Medicine Midwest Regional Meeting, Ann Arbor, MI*.

JCAHO. (2001). A follow-up review of wrong site surgery. *Sentinel Event Alert*, *24*, 1–3.

JCAHO. (2002). Preventing ventilator-related deaths and injuries. *Sentinel Event Alert*, *25*.

Jett, Q. R., & George, J. M. (2003). Work Interrupted: A Closer Look at the Role of Interruptions in Organizational Life. *Academy of Management Review*, *28*(3), 494–507. http://doi.org/10.5465/AMR.2003.10196791

Keohane, C. A., Bane, A. D., Featherstone, E., Hayes, J., Woolf, S., Hurley, A., … Poon, E. G. (2008). Quantifying Nursing Workflow in Medication Administration: *JONA: The Journal of Nursing Administration*, *38*(1), 19–26. http://doi.org/10.1097/01.NNA.0000295628.87968.bc

Kohn, L. T., Corrigan, J. M., & Donaldson, M. S. (2000). *To Err Is Human: Building a Safer Health System*. National Academies Press.

Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, *33*(1), 159. http://doi.org/10.2307/2529310

Leary, J., Gallagher, T., Carson, J., Fagin, L., Bartlett, H., & Brown, D. (1995). Stress and coping strategies in community psychiatric nurses: a Q-methodological study. *Journal of Advanced Nursing*, *21*(2), 230–237. http://doi.org/10.1111/j.1365-2648.1995.tb02519.x

McFarlane, D. (2002). Comparison of four primary methods for coordinating the interruption of people in human-computer interaction. *Human Computer Interaction*, *17*(1), 63–139. http://doi.org/10.1207/s15327051hci1701_2

McGillis Hall, L., Pedersen, C., & Fairley, L. (2010). Losing the moment: understanding interruptions to nurses' work. *The Journal of Nursing Administration*, *40*(4), 169–176. http://doi.org/10.1097/NNA.0b013e3181d41162

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97. http://doi.org/10.1037/h0043158

Monk, C. A., Gregory, J., & Boehm-Davis, D. A. (2008). The effect of interruption duration and demand on resuming suspended goals. *Journal of Experimental Psychology: Applied*, *14*(4), 299–313. http://doi.org/10.1037/a0014402

Moss, J., Berner, E., Bothe, O., & Rymarchuk, I. (2008). Intravenous Medication Administration in Intensive Care: Opportunities for Technological Solutions. *AMIA Annual Symposium Proceedings*, *2008*, 495–499.

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. Journal of Memory and Language, *55*(4), 601-626.

Pape, T. M., Guerra, D. M., Muzquiz, M., Bryant, J. B., Ingram, M., Schranner, B., … Welker, J. (2005). Innovative approaches to reducing nurses' distractions during medication administration. *Journal of Continuing Education in Nursing*, *36*(3), 108–116; quiz 141–142.

Pinkney, S., Fan, M., Chan, K., Koczmara, C., Colvin, C., Sasangohar, F., … Trbovich, P. (2014). Multiple Intravenous Infusions Phase 2b: Laboratory Study.

Potter, P., Wolf, L., Boxerman, S., Grayson, D., Sledge, J., Dunagan, C., & Evanoff, B. (2005). Understanding the cognitive work of nursing in the acute care environment. *Journal of Nursing Administration*, *35*(7-8), 327–335.

Prakash, V., Koczmara, C., Savage, P., Trip, K., Stewart, J., McCurdi.e., T., … Trbovich, P. (2014). Mitigating errors caused by interruptions during medication verification and administration: interventions in a simulated ambulatory chemotherapy setting. *BMJ Quality & Safety*, bmjqs–2013–002484. http://doi.org/10.1136/bmjqs-2013-002484

Rivera-Rodriguez, A. J., & Karsh, B.-T. (2010). Interruptions and distractions in healthcare: review and reappraisal. *Quality and Safety in Health Care*, qshc.2009.033282. http://doi.org/10.1136/qshc.2009.033282

Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. Journal of experimental psychology: General, *124*(2), 207.

Rothschild, J. M., Landrigan, C. P., Cronin, J. W., Kaushal, R., Lockley, S. W., Burdick, E., … Bates, D. W. (2005). The Critical Care Safety Study: The incidence and nature of adverse events and serious medical errors in intensive care: *Critical Care Medicine*, *33*(8), 1694–1700. http://doi.org/10.1097/01.CCM.0000171609.91035.BD

Santell, J. P., Hicks, R. W., McMeekin, J., & Cousins, D. D. (2003). Medication Errors: Experience of the United States Pharmacopeia (USP) MEDMARX Reporting System. *The Journal of Clinical Pharmacology*, *43*(7), 760–767. http://doi.org/10.1177/0091270003254831

Sasangohar, F., Donmez, B., Easty, A. C., & Trbovich, P. L. (in press). Mitigating non-urgent interruptions during high-severity ICU tasks using a task-severity awareness tool: a quasi-controlled observational study. *Journal of Critical Care*. http://doi.org/10.1016/j.jcrc.2015.05.001

Sasangohar, F., Donmez, B., Easty, A. C., & Trbovich, P. L. (in press). The relation between interruption content and interrupted task severity in intensive care nursing: An observational study. *International Journal of Nursing Studies*, *0*(0). http://doi.org/10.1016/j.ijnurstu.2015.06.002

Sasangohar, F., Donmez, B., Easty, A., Storey, H., & Trbovich, P. (2014). Interruptions experienced by cardiovascular intensive care unit nurses: An observational study. *Journal of Critical Care*, *29*(5), 848–853. http://doi.org/10.1016/j.jcrc.2014.05.007

Sasangohar, F., Donmez, B., Trbovich, P., & Easty, A. C. (2012). Not All Interruptions are Created Equal: Positive Interruptions in Healthcare. *Proceedings of the Human Factors* *and Ergonomics Society Annual Meeting*, *56*(1), 824–828. http://doi.org/10.1177/1071181312561172

Shallice, T. (1988). *From Neuropsychology to Mental Structure*. Cambridge University Press.

Sim, J., & Wright, C. C. (2005). The Kappa Statistic in Reliability Studies: Use, Interpretation, and Sample Size Requirements. *Physical Therapy*, *85*(3), 257–268.

Speier, C., Valacich, J. S., & Vessey, I. (1999). The Influence of Task Interruption on Individual Decision Making: An Information Overload Perspective. *Decision Sciences*, *30*(2), 337–360. http://doi.org/10.1111/j.1540-5915.1999.tb01613.x

Tamayo, J. M. (1987). Frequency of Use as a Measure of Word Difficulty in Bilingual Vocabulary Test Construction and Translation. *Educational and Psychological Measurement*, *47*(4), 893–902. http://doi.org/10.1177/0013164487474004

Tomlinson, T. D., Huber, D. E., Rieth, C. A., & Davelaar, E. J. (2009). An interference account of cue-independent forgetting in the no-think paradigm. Proceedings of the National Academy of Sciences, *106*(37), 15588-15593.

Trbovich, P., Prakash, V., Stewart, J., Trip, K., & Savage, P. (2010). Interruptions during the delivery of high-risk medications. *The Journal of Nursing Administration*, *40*(5), 211–218. http://doi.org/10.1097/NNA.0b013e3181da4047

Van Dantzich, M., Robbins, D., Horvitz, E., & Czerwinski, M. (2002). Scope: Providing Awareness of Multiple Notifications at a Glance. In *Proceedings of the Working Conference on Advanced Visual Interfaces* (pp. 267–281). New York, NY, USA: ACM. http://doi.org/10.1145/1556262.1556306

Van Der Laan, J. D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies*, *5*(1), 1–10. http://doi.org/10.1016/S0968-090X(96)00025-3

Walji, M., Brixey, J., Johnson-Throop, K., & Zhang, J. (2004). A theoretical framework to understand and engineer persuasive interruptions. In *Proceedings of the Twenty-Sixth Annual Conference of the Cognitive Science Society* (pp. 1417–1422). Citeseer.

Westbrook J. I., Woods A., Rob M. I., Dunsmuir W. M., & Day R. O. (2010). Association of interruptions with an increased risk and severity of medication administration errors. *Archives of Internal Medicine*, *170*(8), 683–690. http://doi.org/10.1001/archinternmed.2010.65

Wong, D. H., Gallegos, Y., Weinger, M. B., Clack, S., Slagle, J., & Anderson, C. T. (2003). Changes in intensive care unit nurse task activity after installation of a third-generation intensive care unit information system: *Critical Care Medicine*, *31*(10), 2488–2494. http://doi.org/10.1097/01.CCM.0000089637.53301.EF

Appendix A – Time/Motion Instrument Manual

Event Observer Manual Version 04/28/15

Event Observer
Software User's Manual

Introduction
Event Observer is a software program written in Xcode for capturing time-motion studies. The functions of Event Observer are as follows:

1. Conduct Observations
   a. Track multiple events
   b. Add comments/annotations
   c. Add photos

2. Export Observations
   a. Share files and photos via email and export CSV files to load into Excel

This user manual will provide an overview of how to use the application. This application is customizable to capture different information and allow users to tailor the application for different studies. The headings included in the Event Observer were designed to evaluate and track interruptions experienced by nurses in a cardiovascular intensive care unit.

System Requirements
iOS 8.0 or later
Compatible with an iPhone or iPad device

Installation
1. Download the software from the Apple Store. When it has finished installing, the application will appear on your Home screen.

Log In
1. Select 'Register' to bring up a new user screen.
2. Enter your desired username and password.
3. Log in using the username and password you have just created (Figure 1).

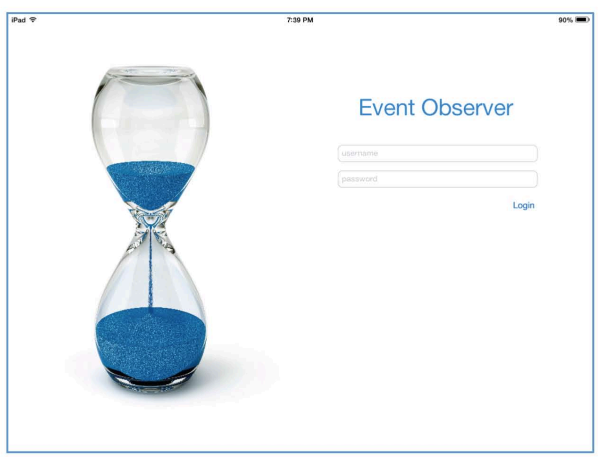


Figure 1: Login Screen

Main Menu

After the login, you will be brought to a main window (Figure 2) with several options:

- New Observation (for creating a new study)
- Export Observation (for printing out a log of all data collected for an observation)
- Logout (to logout of the current user and return to the login screen)

The user may switch back and forth between these options with ease. Because of the database structure used, each download only permits one user to be registered to the specific system on the device.

Figure 2: Main Menu Screen

New Observation

New observations enable you to track a new study. Studies are tracked by manually selecting variables from a customizable list.

To create a New Observation:

1. Select New Observation from the Main Menu.
2. Enter a name for the observation (Figure 3).
3. Change heading names if needed.
4. Change variables in each heading by adding or deleting the variables.
5. Click 'Start' to start the timer and begin the observation.

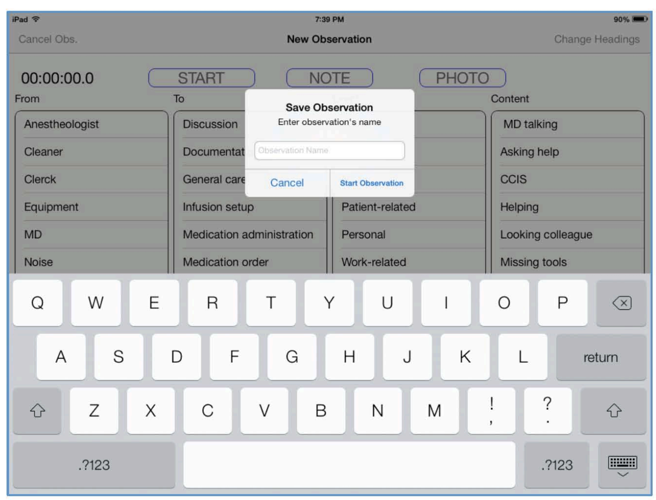


Figure 3: Enter Observation Name Screen

Track an Event

All events are time-stamped. The system allows you to track multiple parallel events. To record that a Medical Doctor started a discussion by asking for patient-related information:

1. Select 'MD' in the 'From' list, select 'Discussion' in the 'To' list, select 'Patient-related' in the 'Event' list and 'Asking help' in the 'Content' list respectively (Figure 4).

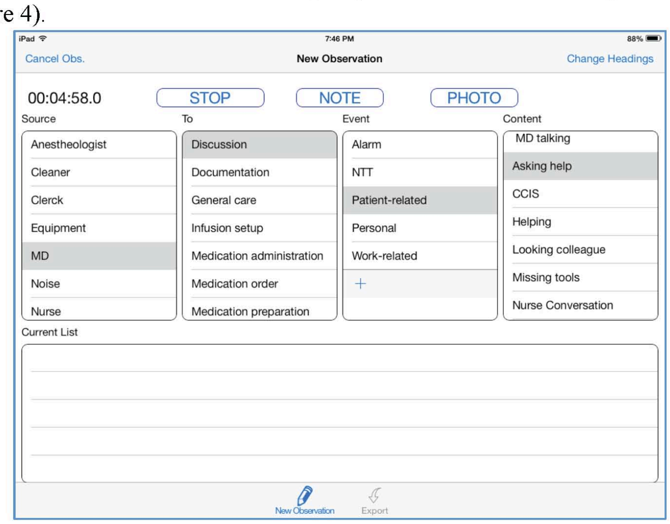


Figure 4: Selecting Variables in an Observation

2. Select any blank space on the screen or double tap 'Asking help', and a description of the event will be shown in the Current List section along with the start time of the event.
3. To end the event, select the description of the event under the Current List section. The event end time will be marked and the description of the event will be deleted from the Current List (Figure 5).

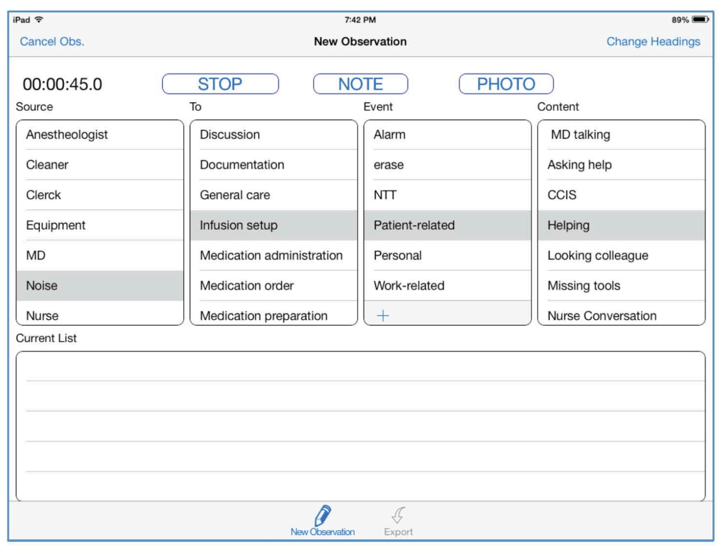


Figure 5: Tracking an Event

Edit Heading Names and Heading Information

All the headings and variables are editable.

1. To change the headings, select ‘Change Heading’ in the top right corner, which prompts a new screen. Type the new heading names under the respective text fields and select ‘Change’ (Figure 6).

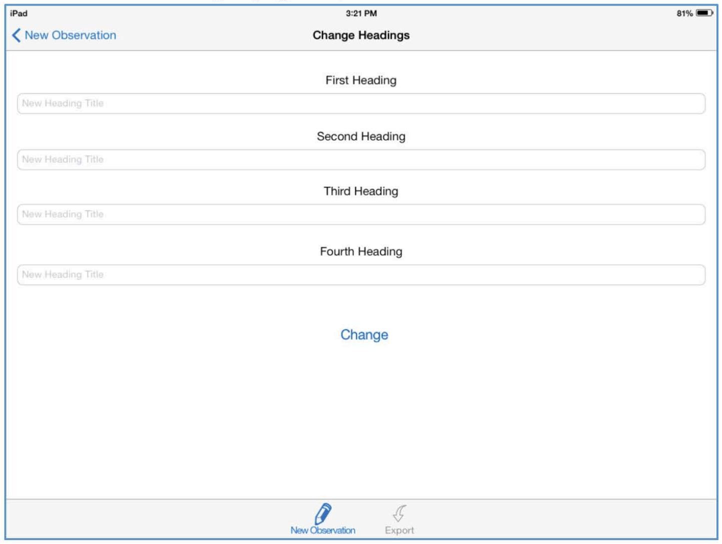


Figure 6: Change Headings Screen

2. To add a new variable, scroll to the bottom of the list and select ‘+’, which will prompt a new screen. Enter the new variable and select ‘Add’ (Figure 7).

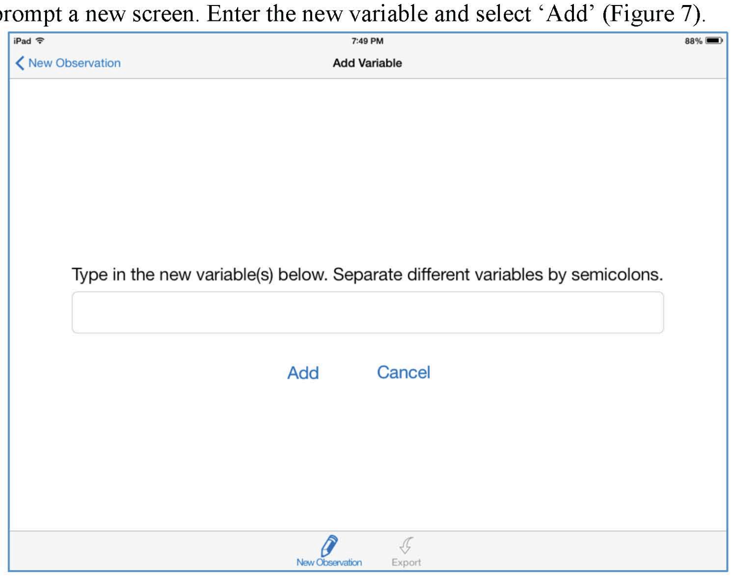


Figure 7: Add Variable Screen

3. To delete a variable, swipe the variable to the left and select 'Delete' (Figure 8).

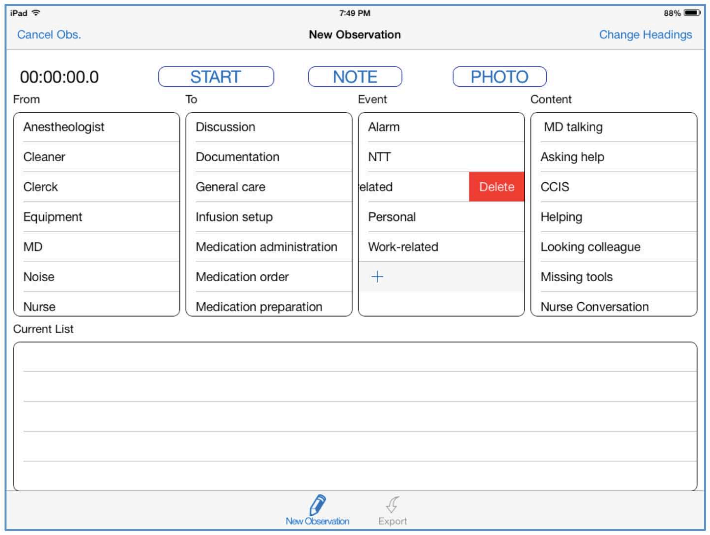


Figure 8: Deleting a Variable

Notes

The notes field can be used for the observer to add information that is not necessarily easily tracked using the set variables (Figure 9). Notes are time stamped and will appear under the Current List when a note is entered.

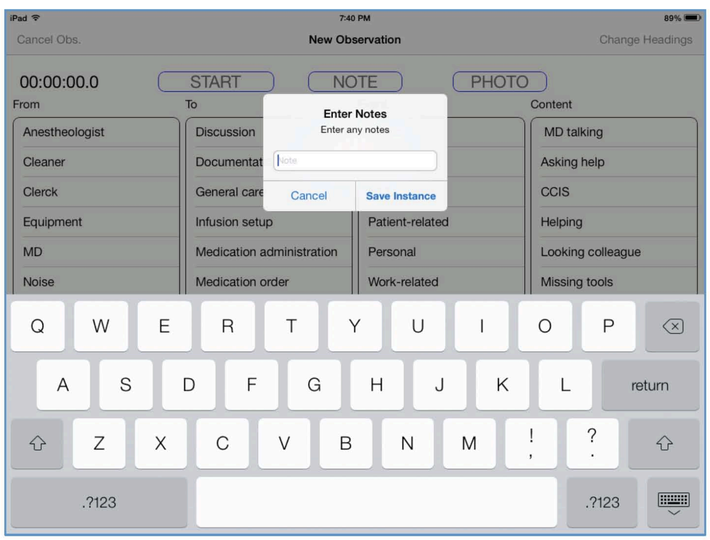


Figure 9: Enter Note Screen

Save and Exit a New Observation

To end an observation:

1. Select ‘Stop’ (Figure 12), or
2. Select ‘Cancel Obs.’ in the top left corner (Figure 13).

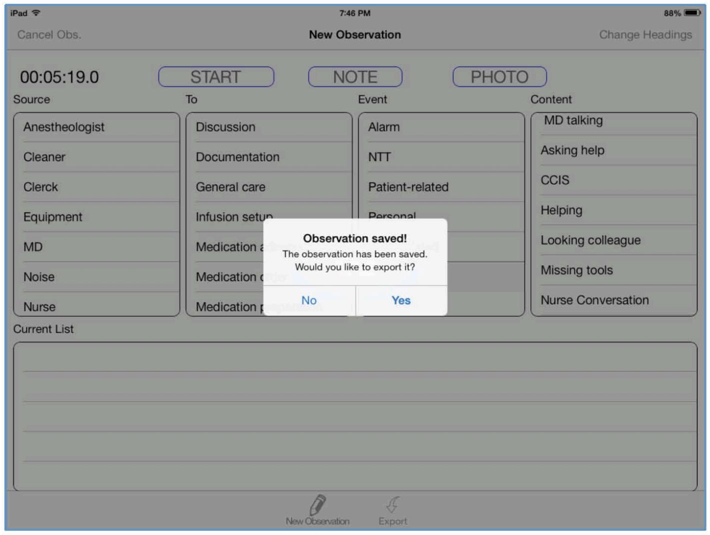


Figure 12: Save Observation Screen

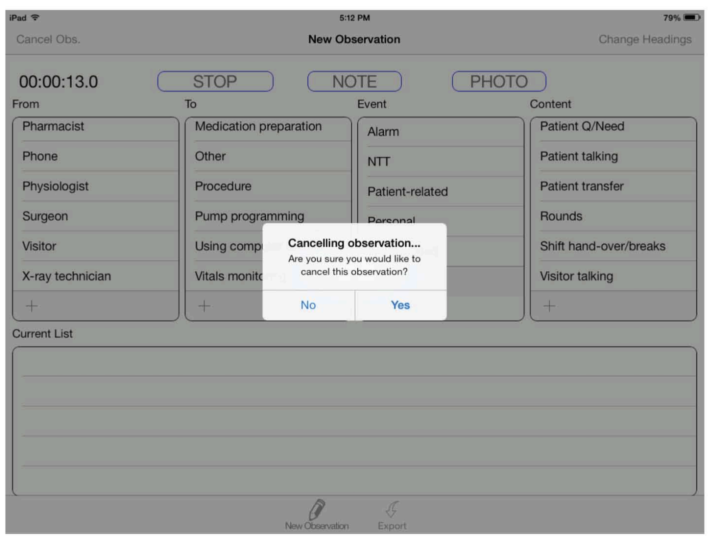


Figure 13: Cancel Observation Screen

Export Observation
The export observation section provides an interface for creating a file of all data collected for an observation by a user (Figure 14). This log can be shared via email.

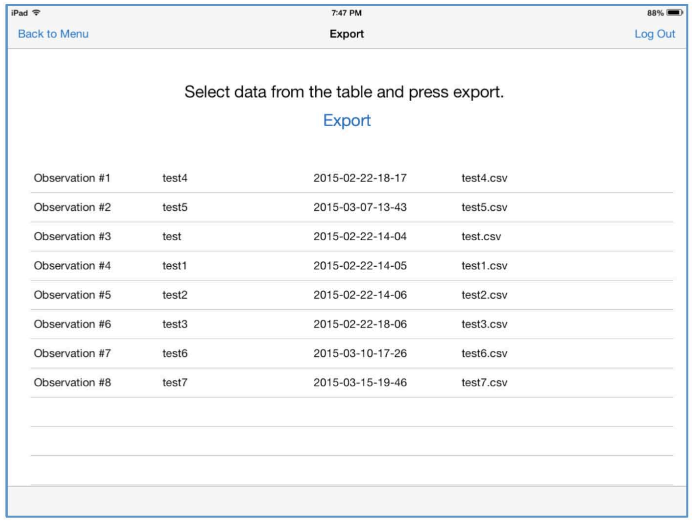


Figure 14: Export Observation Screen

To share a file:

1. Tap the observation name and select 'Export'. A screen will appear to compose a message.
2. Type the recipient's email address in the 'To' field.
3. If any photos were taken during the observation, tap the message field and select 'Insert photo or video' (Figure 15).
4. Select 'Send' at the top of the compose window to share the observation file and all relevant photos.

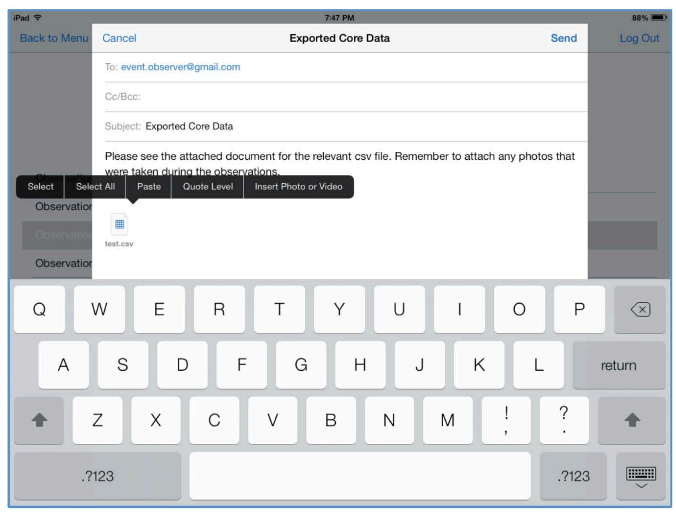


Figure 15: Inserting a Photo Taken During an Observation

Comments/Questions
Address to: Farzan Sasangohar, fsasango@gmail.com

Appendix B – Group Interview Protocol

Group Interview Questions

- Introductions and overview
- High-level summary of research

	Urgent/Necessary	**Non-urgent/Non-necessary**
Task-related	**RECOVER FROM** Example: Monitor alarms during procedure	**DELAY** Example: Physiotherapist interrupts during pump programming
Non-task-related	**TRANSFORM** Example: Pump alarms in the next room (another nurse is in charge of that room)	**BLOCK** Example: Personal conversation noise from the hallway during documentation

- Open-ended questions[6]:

1. Can you give an example from your experience in each of these categories?

---

[6] Adapted in part by from Cooperman, S.J. "Module 4 "Structuring and Interview" http://www.roguecom.com/interview/module4.html and http://www.yorku.ca/act/CBR/GoodQuestions.pdf

2. Can you give an example of strategies you used to deal with interruptions in each category?
3. What are some of the methods you used to delay task-related non-urgent interruptions?
4. Our results show that nurses interrupt with more personal contents during low-severity tasks. In addition patients interrupt significantly more during these low-severity tasks. Do you have any explanation for these results?
5. "Nurses are self-aware of and consider the task severity before interrupting." Do you agree with this statement?
6. One method to delay task-related non-urgent interruptions is to inform other ICU personnel about high-severity tasks (example). What do you like about this method?
7. What don't you like about this method?

- Closed questions:

1. Is it fair to say that majority of interruptions you receive may have positive effects (i.e., may contain important information related to patient or work)?

- Questions to get more information (Probing):

1. "What else can you say about that?"
2. "Can you give me an example?"
3. "Is there anything else you can add?"
4. "Can someone build on that?
5. "On a scale of 1-5 how important is this?"
6. "Why?" "Is there anything else you would like to add?"
7. "Can you tell me more about how you felt about X?"
8. "Why do you think you feel this way?"

- Questions to clarify a point:

  1. “I want to make sure I understand, can you explain more?”
  2. “Can you give me an example?”
  3. “What is the best way to summarize your point for the notes?”
  4. “What do you mean when you say X is [‘no good’]?”
  5. “What does X word mean to you?

- Questions to compare perspectives:

  1. “How do others feel about that point?”
  2. “Who has a different perspective on that?”
  3. “Can someone build on that?”

Appendix C –Group Interview Transcript

Speakers Codes:

1-Farzan Sasangohar

2- Patricia Trbovich

3-Tony Easty

4- Nurse #1

5- Nurse #2

Transcript of Interview

1-Let's talk about the first quadrant (task-related, urgent interruptions). An example of these types of interruptions is a nurse leaving the room to get equipment during procedure. Can you comment on this or add any example based on your experience?

- ***Leaving the task to get required equipment***

5- During our tasks, we (the nurses) always need someone to get us the equipment we need. However, we usually have to do it ourselves. There are a lot of times when we need equipment but we are in the middle of a procedure or the patient is unstable. So, there is a trade-off between staying with the patient and going to get the equipment we need.

They stock CDEF (drawers) equipment minimally due to recent policies.

4- Under the condition of having an unstable patient, we usually have to rush to get what we need. But then we usually input the wrong password or similar sorts of things happen. Example: we are milking the chest tube and miss equipment so have to run the hallway.

Other examples of self-interruption: We are getting something done and MDs ask for something like titrating the drugs. Also we used to have medication on the bedside, now we have to go to the medication room

1- Let's look at the second quadrant. These are non-task-related urgent interruptions. Can add any examples based on your experience?

- ***<u>Phone calls</u>***

5- We always get phone calls and that's one source of interruption.

1-Do you think it is necessary to pick up the phone when you are busy?

5- Well yeah because sometimes the person who is calling is the MD that we had paged before and sometimes it's the patient's family who has been waiting in the waiting room. Also, we get phone calls from other staff that have been contacted by patient's family and have been asked if they can visit the patient.

Sometimes I can't pick-up the phone (e.g., during a cardiac arrest) so I ask other nurses or clerks to pick it up.

- ***<u>Overloading</u>***

1-Can you think of any other example that could fit into the second category (Non-task related and urgent)?

5- There are times when you are in the room and doing your task and then someone comes to you and asks: Can you do the X-ray now? Can you send this blood test now? You don't know which one to do first. Or sometimes the MD or the physiotherapist come to you and say I want this, this, this, and this to be done and I'm like Ok, but I only have two hands. You have to keep reminding them that you are only one person and it's not possible to do everything at the same time. The doctor thinks that we can perform the tasks with the same speed he is thinking of them. We have to keep telling them that we can't do them that fast.

4 – I can only do one-at-a-time and MDs lots of verbal order. Things like X-ray can wait, and can be put in the computer, but most of the other verbal orders (stack) are not documented and not process-efficient. The orders are sometimes urgent, sometimes not. We are used to prioritize.

Computer

4 – The computer is another interruption because after whatever we do, we have to put everything in the computer.(*Sometimes we're so busy that we need to ask someone to come and do a procedure (let's say an x-ray) so that we can put it in the computer.) what?????*

4 – There are times when the MD orders something and when they come back, they forget that they had ordered it. From experience, I've learned to note the time and details of their order when they order something, in case they forget and say "I never ordered that".

1 – A lot of these orders don't require immediate attention, do they?

4 – Sometimes they do, so you have to memorize them all, and then prioritize the list.

New Nurses

4 – Sometimes new nurses say that they know they need to do something, but that they haven't gotten the order from the MD yet. I tell them to go and get the order; if you know what needs to be done then why aren't you doing it? Doctors assume that nurses already know some stuff, so they don't tell them every trivial task. But new nurses don't know a lot of these different things, so the more experienced nurses have to train them, which acts as an interruption.

Staff Crashing your Room

1 – How do you deal with other staff when they crash your room when you're performing a task?

4 – Sometimes (for example) physiotherapists come, and we ask them to come back later. However, they are usually very insistent on performing their task at that very moment, and that they don't have any other time that day to perform the task. They perform their task regardless of what you were doing. Sometimes, however, they're reasonable people, and they agree to delay their work.

5-Physiotherapists don't take no fro an answer. They're like "Bulldozers."

1 – How about MDs? Do they interrupt unnecessarily?

4 – Sometimes they do, for example when I’m behind a curtain, MDs will sometimes just pop their heads in to ask something and leave.

5-Drs are more aware of task-severity and their interruptions may have a higher priority. MDs have a shorter window

1 – Is it more ok for the doctors to interrupt you?

5 – Sometimes they only have an hour to do something, so they have to do it. We try to help them because we know that their time is limited.

4 – We are only taking care of one patient, but doctors and other staff have to deal with all patients, so their busy. It makes sense if they ask us to do something right away.

Non-Urgent Non-Task Related

1 – Non-urgent and non-task related interruptions should be blocked. Do you have any solid examples of these?

4 – “*Drug reps*??” come and ask you to look as something for 5 minutes, but then that 5 minutes becomes 20 minutes. This becomes very annoying when the patient is unstable, and you don’t want to be rude.

1 – During low-severity tasks, we have more patient related and personal interruptions. Why?

5 – Because you’re more relaxed, and you start a conversation. Besides, they know when to interrupt, they don’t interrupt you when you’re doing a procedure and they see you’re busy.

4 – Because most of us have been here a while, so we’re all friends. We know each other’s personalities, so we know who and when to interrupt.

1 – Do you think you’re self-aware?

5 – Yes we are, we can even tell from their body language.

4 – There was this time when my patient was unstable, but the physio was at her rest time, so I needed them but I felt so awkward to go and ask for their help. But I couldn’t wait any longer, so

I had to go and ask the *cardio* to come, but that was also awkward, because sometimes they snap at you if your patient's status isn't that bad. So it really depends on the patient's status, if the patient is in urgent need of help, you go and interrupt someone to get their help.

5 - We assess the situation. We know what they do. There are cues like head down.

<u>How to avert an interruption</u>

Let's say you're programming the pumps, and someone interrupts you. How would you deal with that?

4 – We usually ask them to wait if we're pump programming, to make sure we don't make an error.

5 – The other strategy would be to involve them, for example, have them to come and take a look at your work and see what they think. E.g., can you check my pump?

1 – We're thinking of showing the conditions in the room to those outside using some sort of device so that people know what's going on in the room so that they won't interrupt. Do you think that's a good idea?

5 – We actually do have a paper that we put outside the room saying that "A procedure is going on right now, don't interrupt". We also have another paper with a flower on it, suggesting that the patient in the room is passing or has passed away, so that people speak more quietly in passing out of respect.

<u>Random</u>

5 – It's really annoying when we're in the middle of a procedure, let's say we're bathing a patient, and we need someone's help, and we have to call them. But in order to do that, you have to take off your gloves and put on a new pair.

Back to "How to avert an interruption"

3 – For a pilot, landing and take-off are so intensive that the pilot sends a message to the cabin crew not to be interrupted during that time. Do you have anything similar to that?

4 – 5 – No, we just sometimes put our hands up to tell people to wait. It is considered rude, but if it becomes a norm, I suppose no one would be offended anymore.

4 – That's how I do it sometimes, for example to tell my kids not to talk to me when I'm on the phone. So I think it's OK, I do it.

Stress

4 – Not all the nurses have the same level of stress while doing their daily tasks. We cope with high levels of stress every day. Because what I do is very stressful, I'm used to it now, and I don't get as stressed out as other people anymore. Sometimes my kids stress out about stuff and I tell them that this is nothing, etc. They ask me why I don't get stressed out about anything, and I just tell them "do you have any idea what I do at work?" Because we have to deal with a much higher levels of stress at work, trivial daily problems seem insignificant.

5 – Our coping skills are evolved in the ICU. You develop these skills through experience. It's a huge learning curve. Nursing in the ICU has a different focus and is a different skill than other kinds of nurses. Nurses in other sections only do what they're told. They don't know why they have to inject … they just know that they have to do it. We, however, see the whole picture, and are involved in a lot of decision making every day.

Intervention

1 – We're thinking of using a lighting signal system to show people in the hallway the severity of the task being performed in the room. You would press a button (for example red, yellow, green) and it would alert those in the hallway as to the severity of the task being performed in the room. What do you think of that?

4 – If the buttons are close to us, then that would be fine. But if they're far, like at the entrance of the room, then that would be an interruption itself, because we would have to take off our gloves, etc.

Someone – maybe it would be better if the buttons were on the floor?

2 – Do you think that they (people and other nurses) would conform to the lighting system?

5 – There already are some policies, but they are not respected. There's your answer. You can't change human nature. But it might be helpful; if it becomes a rule then it might help. It's better to use that lighting system to inform the key people (like the clerk) so that people first have to go to them and ask for permission first, and given the signal, may or may not be given permission to visit a room. It would especially be nice if we had security at night, because anyone can come to the ICU. When someone comes as a visitor, you don't know what they're going to do.

4 – Going back to the lighting thing, in our ICU, it's good to have buttons both on the floor and on the wall by the door, so that if for example you're bathing a patient (yellow) and their pressure drops, you can quickly and easily show the change in severity to red. A set of buttons on the floor that are close and accessible for quick changes during a procedure and another set on the wall by the door would be good.

Table 10 provides the high-level requirements derived from the group interview, individual interviews, and designer's ideation sessions.

Table 10. Summary of design requirements for TAT

Design Element	Summary of Requirements
Buttons	- Proximity: Buttons should be located close to areas where nurses perform high-severity tasks (e.g., pump-related tasks, medication-related tasks, procedures). - Redundancy: Buttons should be spread around the room for ease of access. - Size: Buttons should be large to facilitate interaction. - Status Cue: Buttons should provide visual cues (e.g., blink) to remind nurses that the tool is activated. - Minimize Visual Distractions: Visual cues should be provided in a manner that minimizes the distractions to the primary task.
Display	- Size: Display should be noticeable by personnel approaching from the hallway or neighboring rooms. - Location: Display should fit the area between the top of ICU room's door frame and the ceiling. - Colour: Should indicate the severity of the task (e.g., red for high-severity). - Message: o Should be polite o Should be self-explanatory o Should be fully visible o Should not be distracting (e.g., does not flash/blink).
Microcontroller	- Location: Should be located in an area with minimized access. - Device should not be covered to prevent heating up.

Appendix D – Nested Interruption Training Module

Training Module

Experimental Tasks

- In this study, you will use an experimental display to conduct some ICU-related tasks.
- You will conduct three tasks:
  - Medication Order Entry
  - Medication Dosage/Unit Entry
  - Head-to-toe
- Your tasks may be interrupted, in which case you need to return to the task and complete it after the interruption ends.
- There are three trials each taking approximately 3 minutes to complete

Task 1: Medication Order Entry

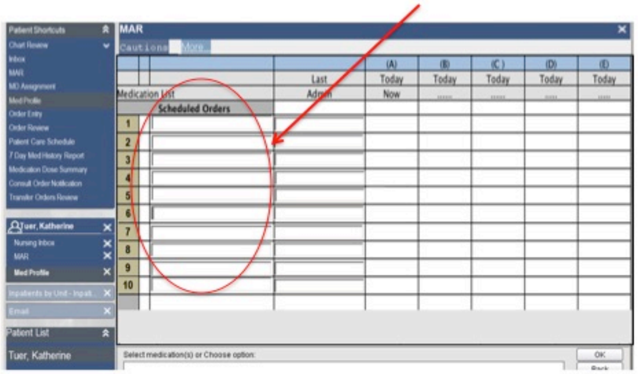
- You will see a list of medications
- You will get a set amount of time (in this example 15 seconds) to memorize the medications.

You have 15 seconds to memorize these medications

1. Esmolol
2. Alprostadil
3. Normal Saline

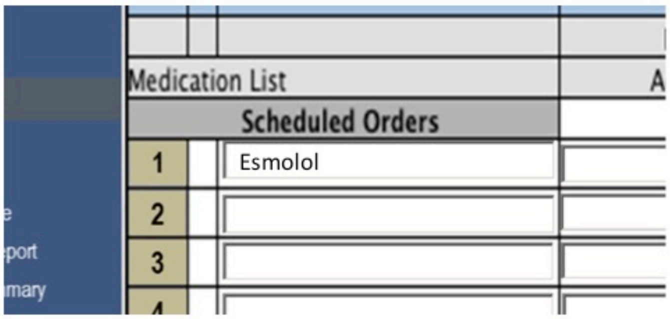
Task 1: Medication Order Entry

- Next, you will see a MOE/MAR interface where you should enter the medications in ANY ORDER



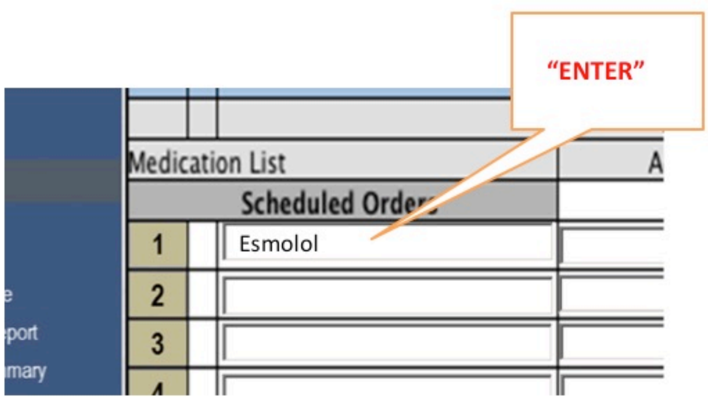
Task 1: Medication Order Entry

- You can enter the first medication without clicking on the form or using the TAB button.



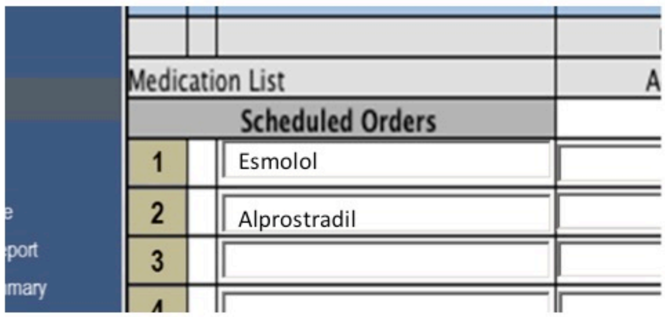
Task 1: Medication Order Entry

Press ENTER to enter next medication



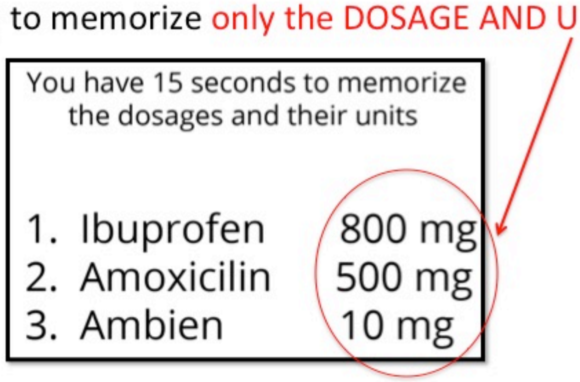
Task 1: Medication Order Entry

Note that you CAN NOT change your answers after you press ENTER.



Task 2: Dosage/Unit Entry

- You will see a list of medications with their associated dosage and unit
- You will get a set amount of time (in this example 15 seconds) to memorize only the DOSAGE AND UNIT.



Task 2: Dosage/Unit Entry

- Next, you will see the list of medications and will be asked to enter the dosage AND units separately for each medication

		Scheduled Orders	Dosage	Unit
1		Ibuprofen		
2		Amoxicillin		
3		Ambien		
4				
5				
6				
7				
8				
9				

Task 2: Dosage/Unit Entry

- You can enter the first medication without clicking on the form or using the TAB button.

		Scheduled Orders	Dosage	Unit
1		Ibuprofen	800	
2		Amoxicillin		
3		Ambien		
4				
5				
6				
7				
8				
9				

Task 2: Dosage/Unit Entry

Medication List			Dose	
		Scheduled Orders	Dosage	Unit
1		Ibuprofen	800	
2		Amoxicillin		
3		Ambien		
4				
5				
6				
7				
8				
9				
10				

Remember to press "ENTER"!

Task 2: Dosage/Unit Entry

- Please note that you should enter the dosage and unit separately.
- Also note that you CAN NOT change your answers after you press ENTER.

		Scheduled Orders	Dosage	Unit
1		Ibuprofen	800	mg
2		Amoxicillin		
3		Ambien		
4				
5				
6				
7				
8				
9				

Task 2: Dosage/Unit Entry

An example of completed dosage/unit entry task

		Scheduled Orders		
1		Ibuprofen	800	mg
2		Amoxicillin	500	mg
3		Ambien	10	mg
4				
5				
6				
7				
8				
9				

Interruptions

- You may receive an interruption in the middle of your tasks.
- When an interruption happens you see an interruption message display (examples on the next slide).
- When you see this display (i.e., get interrupted you may be asked to wait for up to two minutes quietly OR you may be asked to conduct another task.
- It is important to note that you will have to resume your interrupted task after the interruption (wait period or tasks) ends.

Interruption Message

- There are two types of interruptions messages:

Interruption!
Please wait quietly!

Type 1: You will be asked to wait quietly for up to 2 minutes

Interruption!

Type 2: You will be asked to conduct another task. The message lasts only for few seconds.

Task Completed Message

Task Completed!

When you see the "Task Completed!" message, it means that the task is completed and you do NOT need to come back to this task. If you don't see this message however, it means that you will be asked to complete this task later.

-Please note that you are not being judged on **spelling** of the **medication**! As long as the medication is identifiable you will get a pass.

-5 best performers in all three trials will enter a draw to win the **iPad!**

Appendix E – Nested Interruption Test Protocol

Pre-test Questionnaire:

1. What is your age?

2. How many years of experience do you have in CVICU or other ICU?

3. How would you rate your computer experience and proficiency?

Poor		Average		Excellent
1	2	3	4	5

Training Session:

Hello, you are participating in a research study. In this study, you will use an experimental display to conduct some ICU-related tasks.

[The experimenter opens the experimental software]

You will conduct three tasks. I am going to show you all three tasks.

[The experimenter starts the training trial 1]

[The list of medications is displayed]

The first task is a medication order entry. Here you see a list of 4 medications and you are asked to memorize these medications. You have 15 seconds to memorize these medications. In the actual test you might see a different number of medications and may be given more time to memorize them.

[The MOE/MAR system is displayed]

Now you should type the medications you memorized into MOE/MAR system in any order. Note that to enter the next medication you need to press the ENTER button on the keyboard. The TAB key or MOUSE BUTTONS are disabled.

Also note that you can't change your answer once you press ENTER. If you need to change your answer after pressing ENTER you should let me know and I'll write down the change.

[Interruption Message is displayed]

Your task may be interrupted. Whenever an interruption happened you would see this display. Whenever you get interrupted you will be asked to complete the task (in this case the medication entry) later unless you see a message that reads "Task Completed" in which case, you do NOT need to complete the task later.

[List of dosage/units are displayed]

This is task 2. Here you will see a list of 3 medications, and their associated dosage/units. You are asked to memorize only the dosage and units. Here you have 15 seconds but in the actual test you may have more or less time and more or less medications in this list.

[Dosage/Unit Entry form is displayed]

Now you should enter the dosages and units you memorized for the medications listed. Note that you need to enter dosages and units separately. Also note that you can't change your answers.

[Task is timed-out and the form is automatically completed]

[The message "Task Completed!" is displayed]

Note that these tasks are timed. In some cases (such as this one) after a certain time is passed, you may see the form to be completed automatically. In this case when you see the "Task Completed!" message, it means that you do NOT need to come back to this task and complete. If you don't see this message however, it means that you will be asked to complete this task later.

Now let's look at another training session.

[The experimenter starts training Trial 2]

[The list of medications are displayed]

Similar to the last scenario you should memorize and enter these medications. Do you have any questions here?

[The MOE/MAR system is displayed]

Now I'm entering the medications in ANY ORDER. Note that I use the ENTER button to enter the next medication.

[Interruption message is displayed]

Now you are interrupted and haven't received a "Task Completed!" message meaning that you will return later to complete this task.

[List of dosages/Units are shown]

Similar to the last scenario, you should now memorize only the Dosages and Units for these medications. Any questions so far?

[Dosage/units Entry form is shown]

Now I'm entering the dosages and units. Again, I'm inputting the dosages and units separately using the ENTER button. Also note that I can't change my answer.

[Interruption message is displayed]

Now you are interrupted. Note that you did NOT see a "Task Completed!" Message this time so it means that you will be back to complete this task.

[Dosage Entry screen is displayed]

Now you should complete the dosage entry task.

["Task Completed!" message is displayed]

[MOE/MAR is displayed]

Now you can complete the first task. So let's order the last medication. In any of these scenarios if you can't remember the medication/dosage/or unit you can leave it empty. You can just click ENTER.

Please note that you are not being judged on spelling of the medication! As long as the medication is identifiable you will get a pass.

It is mentioned in the consent form that one of the best performers will receive an Apple iPad. Your performance in all the tasks will be combined into a single performance score and the top 5 best performers will enter a draw to win the iPad. Please do your best to perform the tasks you will be asked to perform to increase your chance of winning.

Now it's your turn to practice these tasks. Let's start with Trial 1.

[The participant completes Training Trial 1]

Do you have any questions?

Let's start trial 2.

[The participant completes Training Trial 2]

Any questions?

Experimental Trials:

OK let's start the actual experimental trials. Imagine you are nursing [Patient's Name]. I am Dr. Spencer, one of the CVICU fellows. Please start ordering the medications listed on the display. I may interrupt you to ask some questions about this patient. Please go ahead and click on Trial [1, 2, or 3].

Overall the task of remembering the medication names after the interruption was:

Very Hard		Average		Very Easy
1	2	3	4	5

OK. Let's move on to the second scenario. Again, Please start ordering the medications listed on the display. I may interrupt you to ask some questions about this patient. Please go ahead and click on Trial [1, 2, or 3].

Overall the task of remembering the medication names after the interruption was:

Very Hard		Average		Very Easy
1	2	3	4	5

Let's move on to the last scenario. Again, Please start ordering the medications listed on the display. I may interrupt you to ask some questions about this patient. Please go ahead and click on Trial [1, 2, or 3].

Overall the task of remembering the medication names after the interruption was:

Very Hard		Average		Very Easy
1	2	3	4	5

List of questions for the Head-to-toe task:

1. What is patient's blood pressure?
2. How is patient's appetite?
3. When was this patient admitted?
4. What is the last measured temperature?
5. What is patient's current diet?
6. What are the main diagnoses? (Probing if status is skipped)
7. Did the patient have any recent activities?
8. What is the estimated discharge date?
9. Did the patient eat their meal?
10. What is patient's weight?
11. What was patient's maximum temperature in the last 24 hours (TMax)?

Post-study Questionnaire

1. How would you rank the three trials in terms of difficulty?

2. Why do you think Task [Task ranked 1st] was hard?
3. Have you experienced scenarios where an interruption resulted in switching tasks and another interruption happened during the secondary task?
4. What are some common interruptions you receive in CVICU?
5. Can you remember cases where you forgot to continue an interrupted task?
6. Can you think of cases where interruption affected your performance?
7. Can you think of examples in each of these categories? [The experimenter describes the matrix]
8. Do you have any suggestions on how to mitigate interruptions in ICU?

Appendix F – Nested Interruption Simulation Screenshots

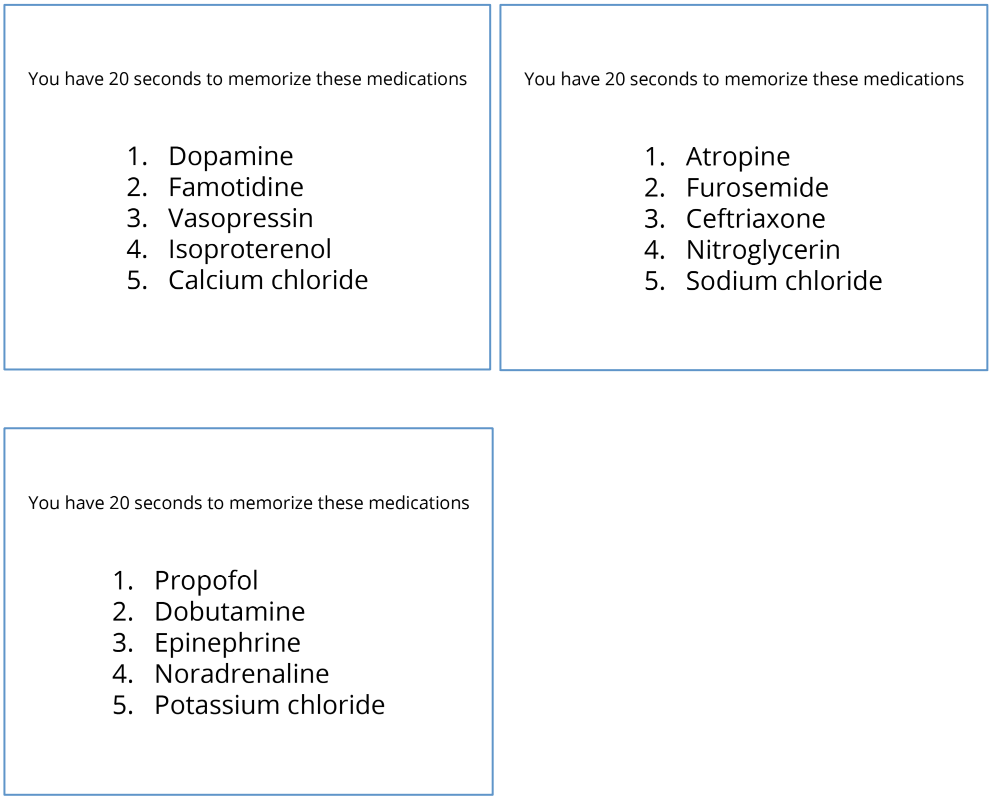


Figure 13. Three variations of the medication list for the primary task

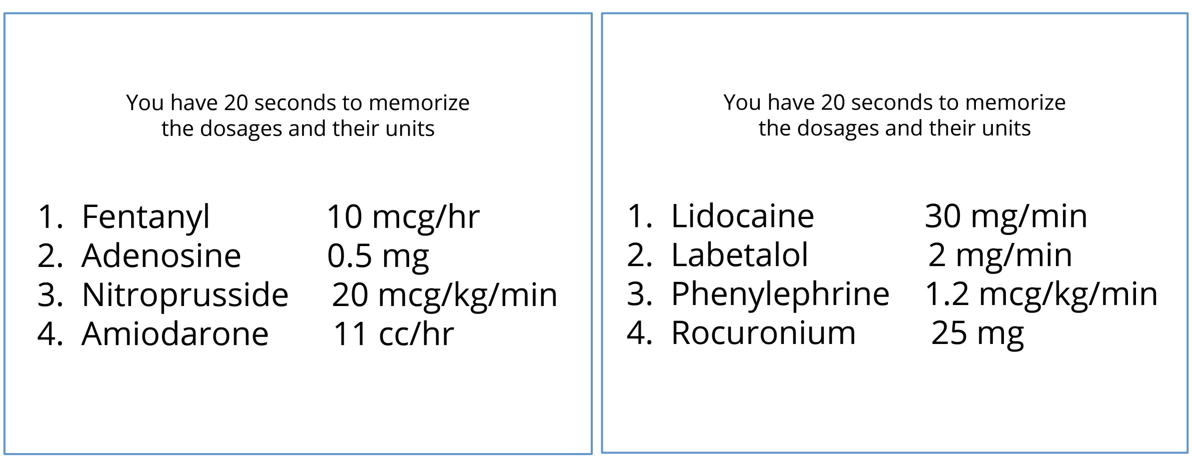


Figure 14. Two variations of the dosage lists for the secondary task

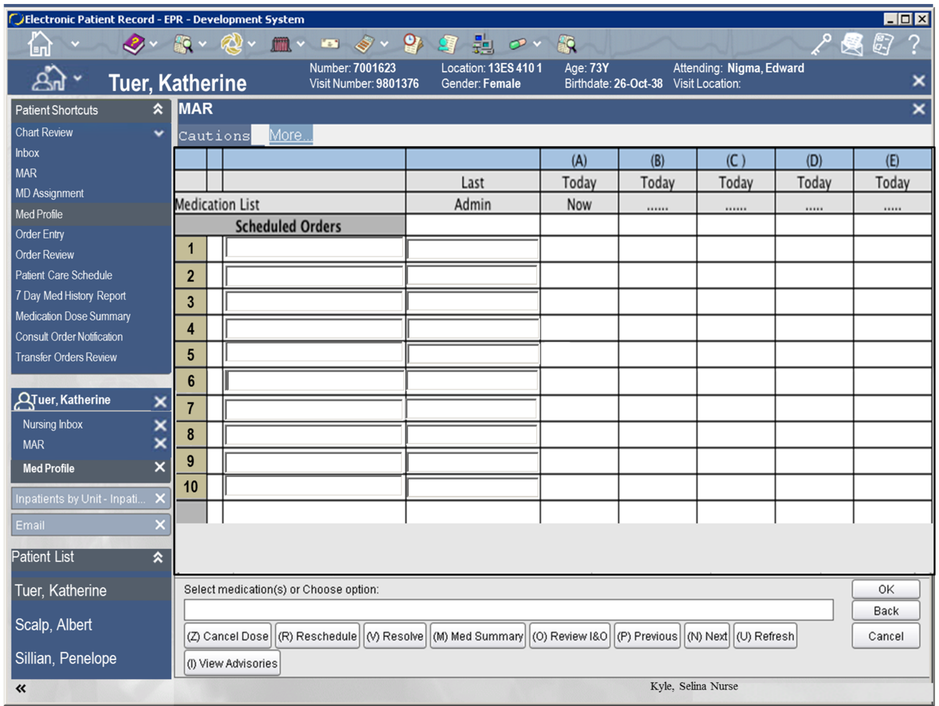


Figure 15. The medication entry form for the primary task

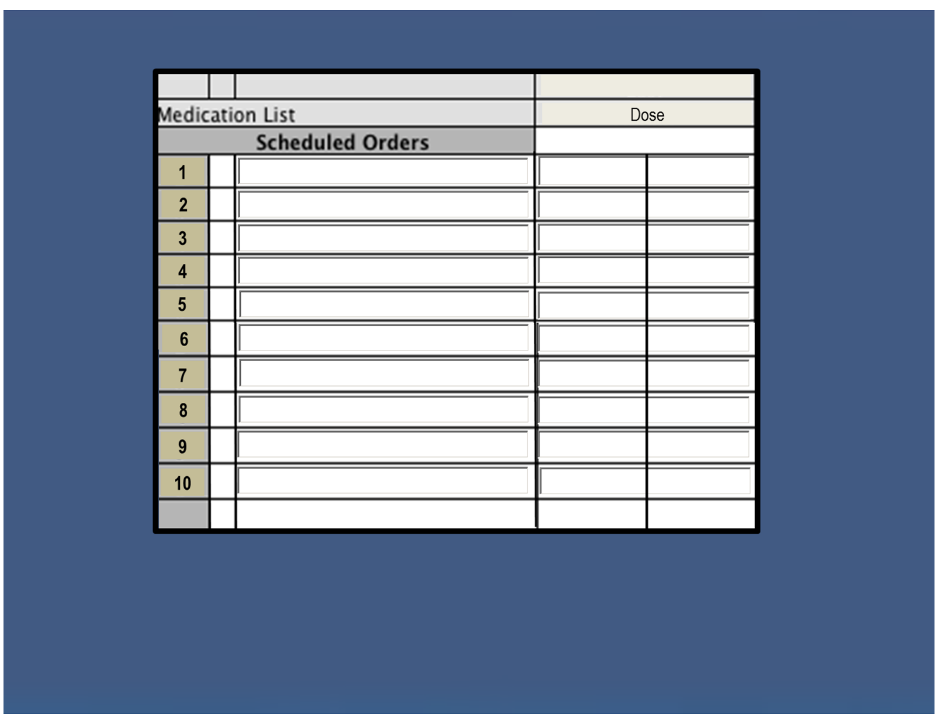


Figure 16. The dosage entry screen for the dosage entry task

Figure 17. The message displayed after each interruption for 2 seconds

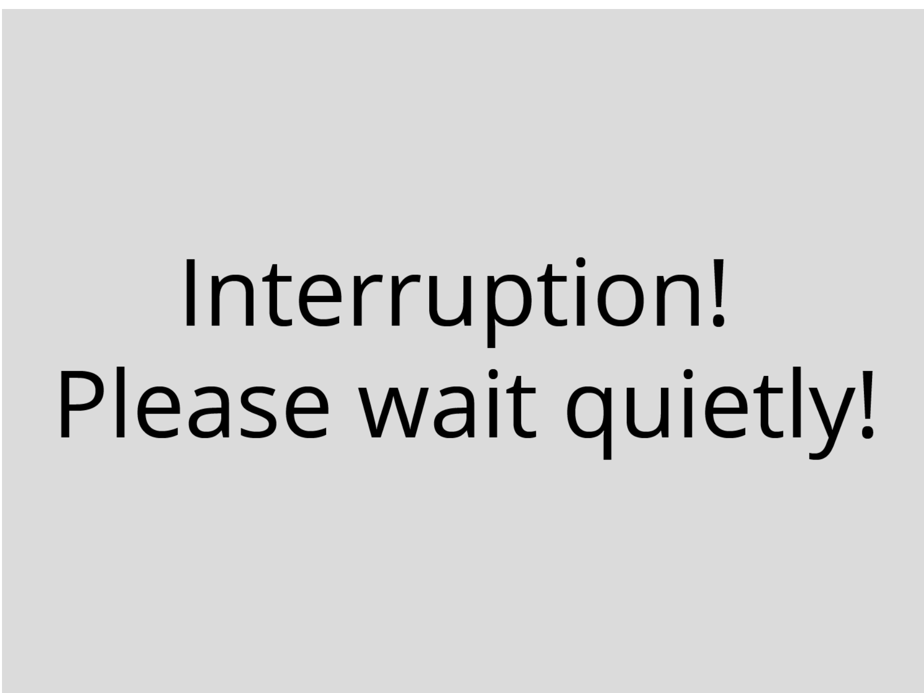


Figure 18. The message shown after the interruption in the baseline (no task) scenario

Figure 19. The message displayed after the completion of the dosage entry task in serial interruption scenario. This message was also displayed after the completion of the head-to-toe task

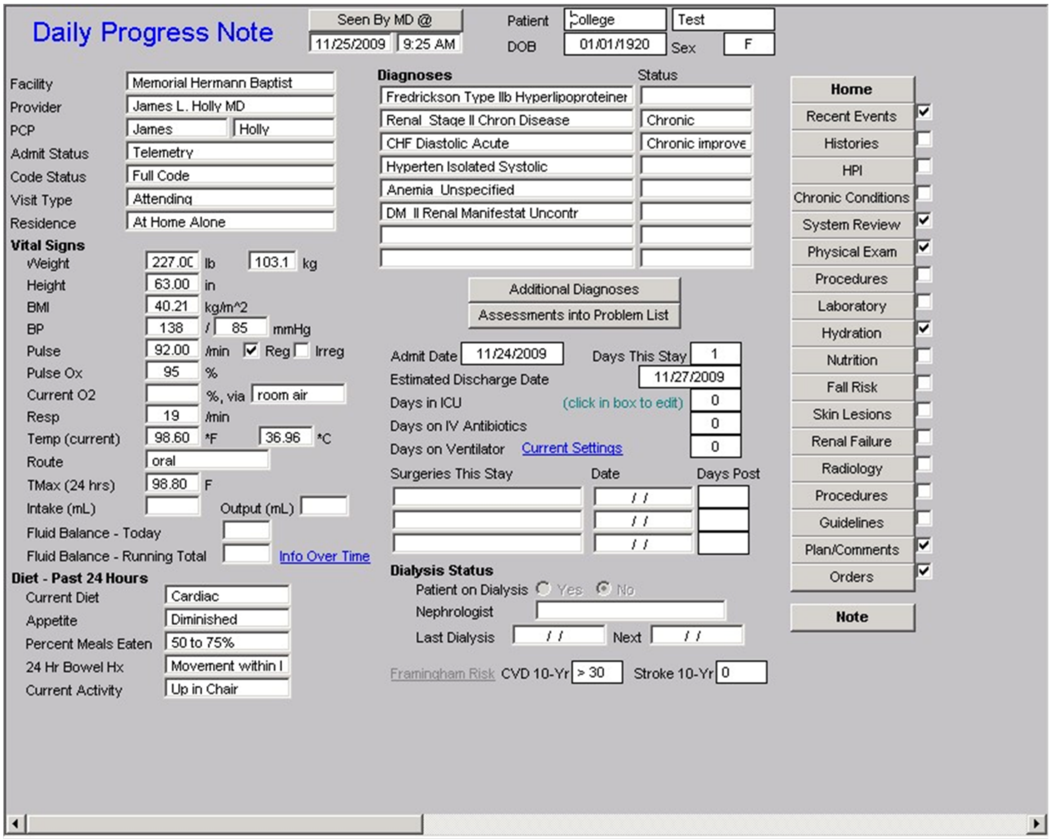


Figure 20. The head-to-toe task