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Interruptions experienced by cardiovascular intensive care unit nurses: An observational study

Farzan Sasangohar, SM [a,b], Birsen Donmez, PhD [a,*], Anthony Easty, PhD [b,c], Helen Storey, BScN [d], Patricia Trbovich, PhD [b,c]

[a] Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, ON, Canada
[b] HumanEra, Techna, University Health Network, Toronto, ON, Canada
[c] Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, ON, Canada
[d] University Health Network, Toronto, ON, Canada

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ABSTRACT

Purpose: 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.
Methods: An observational study was conducted in a cardiovascular ICU at a Canadian teaching hospital. Four observers (1 PhD and 3 undergraduate students) trained in human factors research observed 40 nurses, approximately 1 hour each, over a 3-week period. Data were recorded by the observers in real time, using touchscreen tablet PCs and special software designed for this purpose.
Results: Although approximately half of the interruptions (~51%) happened during high-severity tasks, more than half of these interruptions, which happened during high-severity tasks, conveyed either work- or patient-related information. Furthermore, the rate of interruptions with personal content was significantly higher during low-severity tasks compared with medium- and high-severity tasks.
Conclusions: Mitigation strategies other than blocking should also be explored. In addition, interrupters might have evaluated primary task severity before interrupting. Therefore, making task severity more transparent may help others modulate when and how they interrupt a nurse.

1. Introduction

Intensive care units (ICUs) are complex and demanding modern work environments. Intensive care unit nurses perform various procedures, document patient care, interact with medical devices, respond to the needs of patients and families, and often multitask [1]. Furthermore, ICU nurses are frequently interrupted (eg, [2-4]). Intensive care units are generally known to be error prone [5] and given the limitations of human working memory and attentional resources (eg, [6-9]), it is likely that interruptions combined with performing multiple concurrent tasks facilitate errors [10]. In line with this expectation, interruptions observed in health care 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 the so-called sterile cockpit approach and no interruption zones (eg, [11-13]). However, interruptions at times are necessary as they can convey critical information [14-17]; therefore, mitigation strategies should be designed accordingly.

As a first step to understanding different ICU interruptions with the ultimate goal of developing situation-specific mitigation approaches, we propose that the following 3 Cs of interruptions should be considered:

(1) Characteristics (eg, 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 (ie, time taken to resume the primary task once the interruption is over), which can hinder performance for time-critical tasks [18,19]. Furthermore, more frequent interruptions decrease decision accuracy and increase decision time [20]. 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 [21]; 15.3/hour excluding multitasking in Grundgeiger et al [19]; 4.5/hour during documentation in Ballermann et al [22]) and an increased task resumption time for longer interruptions [19].

(2) Context (eg, 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

* Corresponding author at: 5 King's College Rd, Toronto, Ontario, Canada, M5S 3G8. Tel.: +1 416 978 7399; fax: +1 416 978 7753.
E-mail address: donmez@mie.utoronto.ca (B. Donmez).

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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 study, we focus on primary task (or task at hand) severity and interruption sources. To our knowledge, an analysis of interruptions according to primary task severity has not been conducted in ICU settings. In general, previous ICU-specific studies report other nurse interruptions to be one of the top sources (24% in pediatric ICU by McGillis Hall et al [4]; 37.3% in adult ICU by Drews [21]) and patient care and documentation as the most commonly interrupted primary tasks (34% and 21%, respectively, reported by McGillis Hall et al [4] for pediatric ICU).

(3) Content (eg, 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 (eg, another patient having a cardiac arrest). In pediatric care (critical, surgical, and medical care combined), McGillis Hall et al [4] 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 (eg, 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.

Understanding interruptions in a complex system such as an ICU requires a holistic approach. We believe that studying context, content, and characteristics of interruptions and their interaction could be used as a framework to provide insight into why and how interruptions occur. In this article, an initial step is taken through an observational study to explore the relations between the 3 Cs of interruptions, by identifying interruption content and associated primary task severity.

2. Methods

Nurses of the cardiovascular ICU (CVICU) of a Canadian teaching hospital were asked to participate in an observational study. 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. The study was approved by the research ethics board of this hospital. Four observers (1 PhD 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 [21]; 30 hours in Grundgeiger et al [19]; 60 hours in Ballermann et al [22]). Each working hour from 8:00 to 18:00 was observed at least 3 times. Undergraduate students were trained by the PhD student regarding data collection (5 hours each) and performed 2 pilot studies (2 hours each) along with the PhD student. In addition, a codebook was developed to ensure standard adoption of terminology and to homogenize event coding (Table 1).

Interrater 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 (ie, interruption source, interrupted task, and interruption content) separately between the PhD student 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 the PhD student (ie, $0.55 < \kappa < 0.6$ for 2 categories). This undergraduate observer participated in 3 hours of additional training. Considering the large number of categories used to establish interrater reliability, the results show an adequate level of agreement between observers [23].

2.1. Apparatus

An observational tool called 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 [24], 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 [25] 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 (ie, 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, it was time stamped and 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 in this article due to data collection limitations.

2.2. Cardiovascular ICU staff

The CVICU observed in the present study 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.

2.3. 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, 1 observer shadowed 1 RN 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, we wanted to limit the observation period 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 (eg, MD entered the room to discuss laboratory results).

The definition of interruption adopted for this article 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 [26] but does not consider the secondary task to be unplanned or unexpected

Table 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 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: PCAs are in charge of helping the medical team in tasks such as moving the patient, bed setup, walking the patients. PCC: PCC works directly with CVICU manager and entire health care 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 Telephone: Any telephone that is answered Physiologist: Hospital personnel in charge of postsurgical 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	Connecting equipment: Connecting medical equipment to patient (eg, defibrillator, dialysis, ventilator) Discussion: Conversations with other health care providers about the status of the patient Documentation: Bedside clinical 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 Line change: Process of changing the IV tubing Medication administration: Process of administering medication orally, through infusion, or injection (eg, 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 (eg, priming IV lines or syringe, preparing the medication cup, connecting IV lines to patients) Patient assessment: Assessing patient status by manual measurement of vital signs, etc Procedure: Medical procedures performed on the patient (eg, 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 (eg, research, email) Vitals monitoring: Acquiring patient vital signs visually from the displays of the various monitoring devices to which the patient is connected	Patient related: Interruptions that convey information about patient the observed nurse was treating (eg, MD orders a new medication, telephone call from the laboratory to discuss blood test) Work related: Interruptions that are related to CVICU tasks but not about the patient in care (eg, PCC discusses a new transfer, other nurses request help for their patients) Personal: Personal communications that are not about the patient or CVICU tasks (eg, greetings, personal conversations about vacations) Alarm: Medical equipment or emergency alarms

as these 2 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 [26] because we were not able to assess primary task performance. Although the observers attempted to record data on potential distractions as well (eg, noise from the hallway), due to reliability issues associated with the identification of distractions, this article focuses only on interruptions as defined above.

3. Results

3.1. 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.

3.2. 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 3 reports the frequency percentage (mean and SD) of different interruption sources and contents within the 3 task severities. To obtain this table, we first calculated the frequency percentages within each task severity for each participant; we then calculated the means and SDs of these values. 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.

A 3 (task severity: high, medium, or low) × 4 (source: nurse, MD, equipment, or patient) mixed linear model was built with participant included as a random factor. 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 ($F_{6,357} = 0.38$; $P = .89$).

3.3. 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 one third (20.18%) of interruptions by other nurses were about personal matters.

Table 2
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%

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 is provided here to inform future observational studies.

A 3 (task severity: high, medium, or low) × 4 (content: patient related, work related, personal, or alarm) mixed linear model 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 ($P > .05$).

4. Interpretation

4.1. Summary

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

Table 3
Overall statistics of context, characteristics, and content of interruptions

Context		Characteristics	Content
Severity of task at hand	Top 4 interruption sources[a]: mean % within severity group (SD)	Interruption frequency (% of all interruptions)	Interruption content ranking[a]: mean % within severity group (SD)
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] When there were no interruptions recorded for a participant for a specific task severity level, the data were treated as a missing value.

Table 4
List of interruption content categories based on observation notes

Interruption content
Patient related
Question/conversation about the patient status—health care 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
Telephone call
Searching/asking for information
Shift hand-over
Updating Critical Care Information System
X-ray/asking about x-ray
Personal
Nonstaff person talking to the nurse
Nurse talking to visitor
Other nurses talking to the nurse
Patient talking to the nurse

with personal content was significantly higher for low-severity tasks compared with medium- and high-severity tasks.

4.2. Explanation of findings

We observed 19.7 interruptions per hour, slightly larger than other observational studies in ICU settings, which reported 4.5 to 15.3 per hour, a range that itself represents large variability [19,21,22]. 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 [4]; 37.3% in adult ICU in Drews [21]), we observed other nurses to be the most common source of interruption (~43%).

Similar to Trbovich et al [27] 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 nonurgent, 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. Work is underway to evaluate technological interventions to improve task severity awareness by enabling nurses to inform other personnel of the severity of task at hand.

4.3. Limitations

One of the limitations of this study was that only the day shifts were observed. Interruptions may, in fact, have different characteristics during night shifts where no admissions or rounds happen and communication is minimized. In addition, other ICU environments (eg, pediatric) may generate different patterns due to variations in workflow, culture, and policies. Moreover, the high prevalence of interruptions during certain primary tasks might be due to the fact that these tasks constitute a majority of nurses' work.

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 2 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. Lack of data collection on primary tasks when interruptions were not present is a general limitation of this study.

Participants were aware of the study's objective of investigating interruptions. This awareness might have influenced their behavior. However, if there were an influence, one would expect the frequency of interruptions to decrease, leading to an underestimation. 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. Finally, the interrater reliability analysis should include a comparison with an ICU health care professional.

4.4. Future work

An important future direction is to differentiate between negative and positive interruptions. Intuitively, 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 [15-17,28]. Similarly, alarms usually convey important information about an off-nominal situation. Based on this broad reasoning, most observed interruptions in CVICU were potentially positive. 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 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.

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References

[1] Carayon P, Gürses AP. A human factors engineering conceptual framework of nursing workload and patient safety in intensive care units. Intensive Crit Care Nurs 2005;21(5):284–301.
[2] Ebright PR, Patterson ES, Chalko BA, Render ML. Understanding the complexity of registered nurse work in acute care settings. J Nurs Adm 2003;33(12):630–8.
[3] Potter P, Wolf L, Boxerman S, Grayson D, Sledge J, Dunagan C, et al. Understanding the cognitive work of nursing in the acute care environment. J Nurs Adm 2005;35(7–8):327–35.
[4] McGillis Hall L, Pedersen C, Fairley L. Losing the moment: understanding interruptions to nurses' work. J Nurs Adm 2010;40(4):169–76.
[5] Rothschild JM, Landrigan CP, Cronin JW, Kaushal R, Lockley SW, Burdick E, et al. The critical care safety study: the incidence and nature of adverse events and serious medical errors in intensive care. Crit Care Med 2005;33(8):1694–700.
[6] Miller GA. The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychol Rev 1956;63(2):81–97.
[7] Fuster J. The prefrontal cortex. London, UK: Academic Press; 2008.
[8] Shallice T. From neuropsychology to mental structure. Cambridge, UK: Cambridge University Press; 1988.
[9] Just MA, Carpenter PA. A capacity theory of comprehension: individual differences in working memory. Psychol Rev 1992;99(1):122–49.
[10] Westbrook JI, Woods A, Rob MI, Dunsmuir WT, Day RO. Association of interruptions with an increased risk and severity of medication administration errors. Arch Intern Med 2010;170(8):683–90.
[11] Hughes RG, Blegen MA. Medication administration safety. In: Hughes RG, editor. Patient safety and quality: an evidence-based handbook for nurses. Rockville (MD): Agency for Healthcare and Quality; 2008.
[12] Hohenhaus SM, Powell SM. Distractions and interruptions: development of a healthcare sterile cockpit. Newborn Infant Nurs Rev 2008;8(2):108–10.
[13] Anthony K, Wiencek C, Bauer C, Daly B, Anthony MK. No interruptions please: impact of a no interruption zone on medication safety in intensive care units. Crit Care Nurse 2010;30(3):21–9.
[14] Coiera E, Tombs V. Communication behaviours in a hospital setting: an observational study. BMJ 1998;316(7132):673–6.
[15] Grundgeiger T, Sanderson P. Interruptions in healthcare: theoretical views. Int J Med Inform 2009;78(5):293–307.
[16] Rivera-Rodriguez AJ, Karsh BT. Interruptions and distractions in healthcare: review and reappraisal. Qual Saf Health Care 2010;19(4):304–12.
[17] Walji M, Brixey J, Johnson-Throop K, Zhang J. A theoretical framework to understand and engineer persuasive interruptions. Proc Cog Sci Soc Annu Meet 26; 2004.
[18] Monk CA, Gregory J, Boehm-Davis DA. The effect of interruption duration and demand on resuming suspended goals. J Exp Psychol Appl 2008;14(4):299–313.
[19] Grundgeiger T, Sanderson P, MacDougall HG, Venkatesh B. Interruption management in the intensive care unit: predicting resumption times and assessing distributed support. J Exp Psychol Appl 2010;16(4):317–34.
[20] Speier C, Valacich JS, Vessey I. The influence of task interruption on individual decision making: an information overload perspective. Decis Sci 1999;30(2):337–60.
[21] Drews FA. The frequency and impact of task interruptions in the ICU. Proc Hum Factors Ergon Soc Annu Meet, 51; 2007. p. 683–6.
[22] Ballermann MA, Shaw NT, Arbeau KJ, Mayes DC, Noel Gibney RT. Impact of a critical care clinical information system on interruption rates during intensive care nurse and physician documentation tasks. Stud Health Technol Inform 2010;160(Pt 1):274–8.
[23] Sim J, Wright CC. The kappa statistic in reliability studies: use, interpretation, and sample size requirements. Phys Ther 2005;85(3):257–68.
[24] Guerlain S, Shin T, Guo H, Adams R, Calland JF. The RATE tool: multimedia observation and analysis of teams. Proc Hum Factors Ergon Soc Annu Meet, 46; 2002. p. 755.
[25] Sasangohar F, Donmez B, Trbovich P, Easty AC. Not all interruptions are created equal: positive interruptions in healthcare. Proc Hum Factors Ergon Soc Annu Meet, 56; 2012. p. 824–8.
[26] Grundgeiger T, Liu D, Sanderson P, Jenkins S, Leane T. Effects of interruptions on prospective memory performance in anesthesiology. Proc Hum Factors Ergon Soc Annu Meet, 52; 2008. p. 808–12.
[27] Trbovich P, Prakash V, Stewart J, Trip K, Savage P. Interruptions during the delivery of high-risk medications. J Nurs Adm 2010;40(5):211–8.
[28] Henneman EA, Blank FS, Gawlinski A, Henneman PL. Strategies used by nurses to recover medical errors in an academic emergency department setting. Appl Nurs Res 2006;19(2):70–7.