

Effects of Nested Interruptions on Task Resumption: A Laboratory Study With Intensive Care Nurses

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Objective: Interruptions to secondary tasks resulting in multiple tasks to resume may tax working memory. The objective of this research is to study such interruptions experienced by intensive care unit (ICU) nurses.

Background: ICU nurses are frequently interrupted, resulting in a switch from primary to secondary tasks. In two recent studies, we observed that some of these secondary tasks also get interrupted, resulting in multiple tasks that have to be resumed, a phenomenon we refer to as nested interruptions. Although completing multiple secondary tasks in a serial fashion during an interruption period can create context-switching costs, we hypothesize that nested interruptions tax the working memory even more than just performing multiple secondary tasks sequentially because the nurse would have to encode in working memory the resumption goals for both the primary and the interrupted secondary tasks.

Method: We conducted a laboratory study with 30 ICU nurses, who performed an electronic order-entry task under three interruption conditions: (a) baseline—no secondary task during the interruption period; (2) serial—performance of two tasks one after the other during the interruption period; and (3) nested—performance of two tasks during the interruption period, one of which was also interrupted.

Results: Nested interruptions resulted in significantly longer primary-task resumption lag and less accurate task resumption compared with both the serial interruption and baseline conditions.

Conclusion: The nested nature of interruptions adds to the resumption lag and diminishes resumption accuracy by likely populating the working memory with goals associated with interrupted secondary tasks.

Keywords: critical care, task switching, nursing, patient safety, working memory

INTRODUCTION

Intensive care units (ICUs) stand out as one of the most complex and demanding health care 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 due to interruptions. Interruptions to ICU nurses are indeed frequent, for example, 10 times per hour in Drews (2007); 15.3 times per hour in Grundgeiger, Sanderson, MacDougall, and Vankatesh (2010); and 4.5 times per hour during documentation tasks in Ballerman, Shaw, Arbeau, Mayes, and Noel Gibney (2010). ICUs 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, 1988; Miller, 1956; Shallice, 1988), it is likely that interruptions combined with multiple concurrent tasks facilitate errors (Westbrook, Woods, Rob, Dunsmuir, & Day, 2010). For example, interruptions may result in the health care personnel forgetting to resume a task (also known as nonresumption; Grundgeiger, Liu, Sanderson, Jenkins, & Leane, 2008), longer task resumptions (Grundgeiger et al., 2010; Monk, Trafton, & Boehm-Davis, 2008), or erroneous task resumptions upon returning to the primary task due to failure in memory retrieval (Westbrook et al., 2010).

In two recent observational studies conducted in a Canadian cardiovascular ICU (CVICU) (Sasangohar, Donmez, Easty, Storey, & Trbovich, 2014; Sasangohar, Donmez, Easty, & Trbovich, 2015), we witnessed that the nurses experienced *nested interruptions*, whereby their secondary tasks were also interrupted, thereby resulting in more than one task to resume. For example, an ICU nurse was interrupted by a physician during medication preparation (first or

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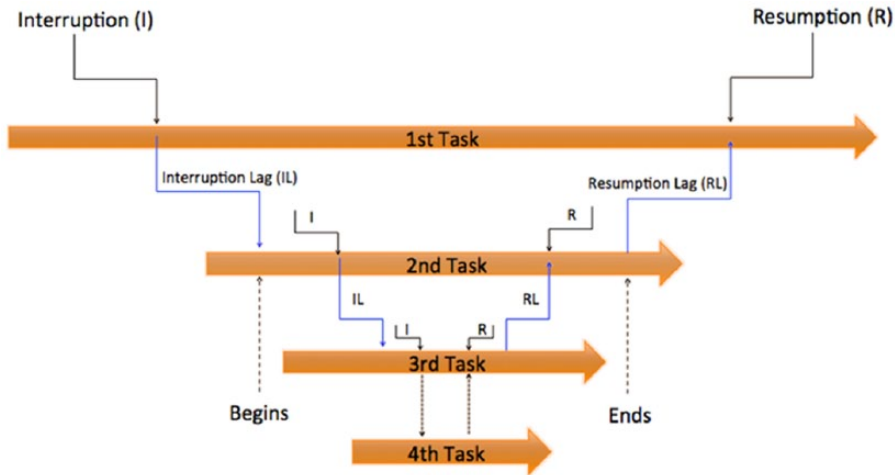


Figure 1. Anatomy of nested interruptions; visualization inspired by Boehm-Davis and Remington (2009).

primary task) asking her to order medication using the computerized system (second or secondary task). While performing the medication order, this nurse was interrupted by a pump alarm that needed immediate attention (third or tertiary task). In one of these studies, we recorded 87 instances of nested interruptions similar to this example within 48 hr of data collection. Although less likely, nested interruptions can go beyond the tertiary task and may result in deeper levels of interruptions and several interrupted tasks that may need to be resumed (Figure 1).

Although authors of previous research investigated 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 are largely absent from the literature. In this paper, we introduce the phenomenon of nested interruptions by drawing upon a cognitive theory of interruption called memory for goals (Altmann & Trafton, 2002) to hypothesize the effects of nested interruptions on working memory and task resumption. We then present a laboratory study conducted with 30 CVICU nurses in which we investigated the effects of nested interruptions on task resumption lag and accuracy.

Although the words *interruption* and *distraction* have often been used interchangeably in the health care literature (Grundgeiger & Sanderson, 2009), the difference has become well established

in recent work. Interruptions are considered as external events that break task continuity and lead to sequential multitasking, whereas distractions are considered as events that use attentional resources but lead to concurrent multitasking (Sasangohar, Donmez, Trbovich, & Easty, 2012). Whereas distractions to an ongoing task have been documented well in domains such as driving, concurrent multitasking due to distractions in health care generally involve tasks that are not easily observable (e.g., overhearing conversations while preparing medication). Due to this limitation, our observational studies in the ICU focused on interruptions in which a break in task was observable. Thus, the nested-interruption phenomenon we introduce in this paper is based on sequential multitasking.

Working Memory, Nested and Serial Interruptions

Resumption-related effects of interruptions are often associated with limitations in working-memory retrieval (Altmann & Trafton, 2002). *Working memory* refers to the temporary storage and processing of information during cognitive activities (Baddeley, 1992) and is generally assumed to have limited capacity (also known as limited working-memory span; Cowan, 2005; Miller, 1956). The “interference theory” of working memory posits that the new information stored in working memory competes with

old information and makes the old information more difficult to retrieve (Bancroft & Servos, 2010; Oberauer & Göthe, 2006). Although there are various models of working memory, Altmann and Trafton's (2002) memory-for-goals model has been widely used in interruption literature to explore the working-memory retrieval mechanisms involved in postinterruption task resumption (see the review by Grundgeiger & Sanderson, 2009). According to this model, the interruptee encodes mental representations of remaining steps in a task in working memory as goals for completion. For the nested interruption example provided earlier, the resumption goals for the primary task would include where in the medication order process the nurse had to stop as well as the remaining steps he or she would have to conduct.

Borrowing from the ACT-R theory of cognition (Anderson & Lebiere, 2012), Altman and Trafton (2002) argue that initial goals fade gradually or are masked by new goals in working memory unless activated (i.e., retrieved). According to this model, interruptions result in suspended goals, and 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 when one is interrupted, newer goals may interfere with the old goals, affecting task resumption (Diez, Boehm-Davis, & Holt, 2002). 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).

It is possible that during an interruption period, nurses can complete multiple secondary tasks in a serial fashion, and the context switching may create additional load on working memory (Liefoghe, Barrouillet, Vandierendonck, & Camos, 2008). However, we hypothesize that nested interruptions tax working memory even more than just performing multiple secondary tasks sequentially (i.e., serial interruption) because the nurse would have to encode in working memory the resumption goals for both the primary task and the interrupted secondary tasks. Nested interruptions may in turn result in

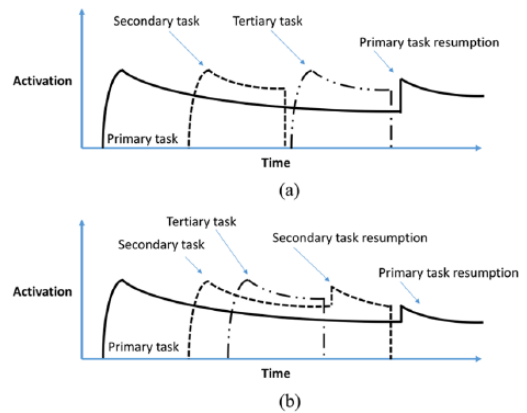


Figure 2. Goal activation timeline for serial (a) and nested (b) interruptions, adapted from Altmann and Trafton (2002).

a more difficult task resumption compared with serial interruptions.

The goal activation timeline for serial and nested interruptions is illustrated in Figure 2 (adapted from Altmann & Trafton, 2002). The curves in Figure 2 show expected activation for each task as a logarithmic function because ACT-R defines goal activation as a logarithmic function of information retrieval rate (Anderson & Lebiere, 2012). According to Altmann and Trafton (2002), each task creates a goal that is rapidly strengthened, depicted by the initial rise in the curve. At its peak, the activated goal drives the behavior. ACT-R posits that this activation cannot be sustained once engaged in the task operations, and the goal activation starts to decline. When the primary task is interrupted by a secondary task, the cognitive system turns to secondary task processing, and the goal for the primary task gradually loses activation. In a nested-interruptions scenario (Figure 2b), a tertiary task interrupts the secondary task, leading to a new goal being created, masking both the primary and secondary task goals in terms of activation. On the other hand, in a serial-interruptions scenario (Figure 2a), the secondary task is completed without being interrupted by a tertiary task. Theoretically, the goal for the secondary task will lose activation before the start of the next task (i.e., offloaded from the working memory); hence the primary task resumption takes place under higher levels of activation than

nested interruptions due to reduced interference with previous goals.

To investigate whether nested interruptions result in a more difficult primary task resumption (as measured by resumption accuracy and lag) compared with serial interruptions, a laboratory experiment was conducted with 30 CVICU nurses comparing nested with serial interruptions. A baseline condition was also included to account for the effects of time away from the primary task.

METHOD

Participants

Thirty nurses (27 females, three males) from the same CVICU observed in Sasangohar et al. (2014, 2015) were recruited to participate in the experiment. Participants' age ranged from 26 to 57 years ($M = 38$, $SD = 8.6$), and their ICU experience ranged from 1.5 to 31 years ($M = 13$, $SD = 9.3$), with only four participants having less than 5 years of experience. As expected, age and experience were highly correlated ($r = .78$, $p < .0001$). Two age-experience groups emerged: younger-less experienced ($n = 19$) and older-more experienced ($n = 11$). The younger group was between 26 and 39 years old ($M_{\text{age}} = 32$, $SD_{\text{age}} = 3.4$), and their experience ranged from 1.5 to 16 years ($M_{\text{exp}} = 6.8$, $SD_{\text{exp}} = 3.8$). The older group was between 45 and 57 years old ($M_{\text{age}} = 51$, $SD_{\text{age}} = 3.7$), and their experience ranged from 15 to 31 years ($M_{\text{exp}} = 24$, $SD_{\text{exp}} = 3.8$).

Participants received C\$50 for their participation, and one participant received an Apple iPad 3 in a random draw from the top five performers. This iPad award was used to recruit participants and enhance their motivation to perform the experimental tasks. The study received approval from the ethics boards of the hospital (No. 14-7758-AE) and the University of Toronto (No. 29711). Informed consent was obtained from each participant.

Experimental Design

A repeated-measures design was used whereby each participant completed three experimental conditions in a counterbalanced order: (a) baseline, in which participants were interrupted during a primary task but did not

conduct any task during the interruption period and were asked to wait quietly; (b) serial interruption, whereby participants were interrupted during a primary task and had to complete two consecutive tasks during the interruption period before resuming the primary task; and (c) nested interruptions, whereby participants were interrupted during a primary task and had to conduct a second task, which was later interrupted by a third task; they had to resume the second task after completing the third task before being able to resume the primary task.

Experimental Tasks and Data Collection Instrument

All experimental tasks were completed in full-screen mode on a 15-inch Lenovo laptop and were created with Microsoft Visual Basic. An overview of how different experimental tasks were conducted in different experimental conditions is provided in Figure 3. Pilot testing was performed to ensure that the tasks were of sufficient difficulty.

Primary Task

The primary task used for all three conditions was an ICU medication order-entry task. Nurses interacted with a mock computerized prescriber order-entry system used in Pinkney et al. (2014) that emulated their hospital's medication order-entry system. Nurses viewed a list of five ICU medications and were given 20 s (derived from pilot testing and deemed to be sufficient time to memorize the medications) to memorize this list (Figure 4, left). They were then presented with the medication order system, where they had to enter the medications in the order presented to them earlier (Figure 4, right). They could provide blank responses and skip to the next entry; however, they could not go back to fix their previous responses.

Three versions of the medication list were created corresponding to the three factor levels and were presented to the participants always in the same order (regardless of the order that the participants completed the experimental conditions). Previous research indicates that frequency of use (Tamayo, 1987), as well as word length and number of syllables (Baddeley,

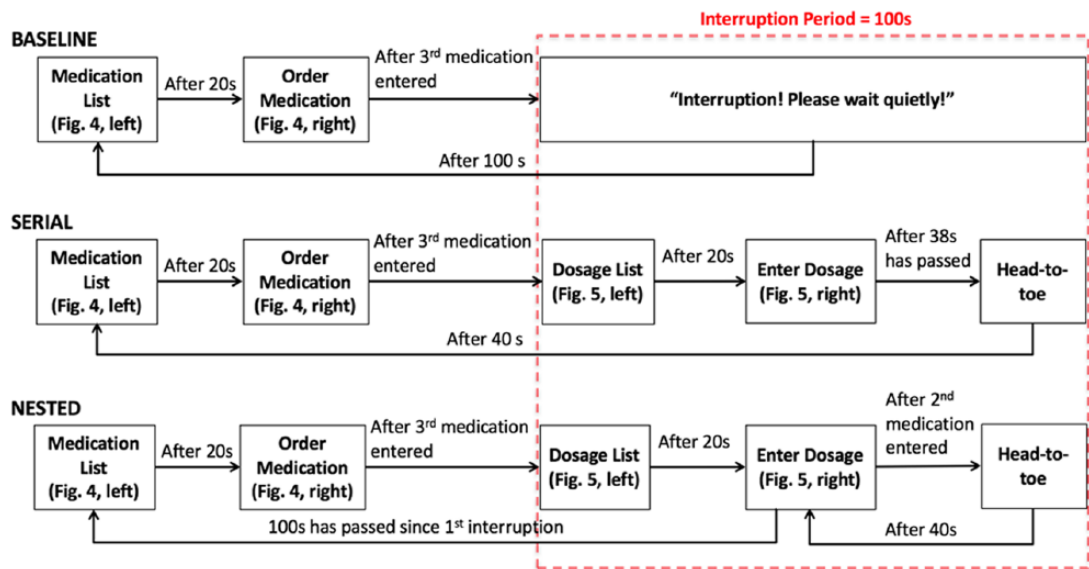


Figure 3. Experimental conditions, order in which the interfaces were shown to participants, and transition criteria.

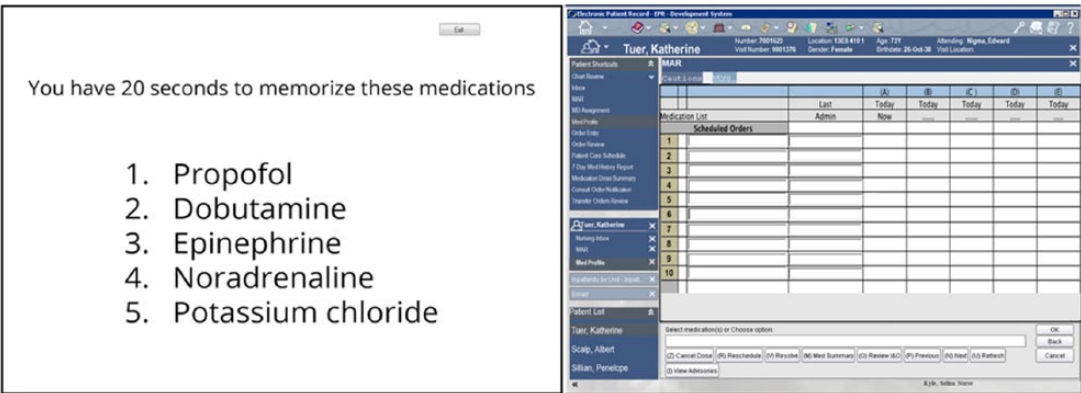


Figure 4. Medication order task. List of medications to memorize (left); medication order-entry interface (right).

Thomson, & Buchanan, 1975), contributes to the difficulty of memorizing words. The three medication lists were generated carefully to have the same number of words, number of syllables per word, and number of letters per word. For example, the first medications in the three lists were dopamine, atropine, and propofol; each consists of one word, three syllables, and eight letters. The nurse educator and the nurse manager at the participating CVICU were consulted to ensure that only the medications used in the unit were included and to confirm similar

frequency of medication use across the three lists.

Interruption Period

For all three experimental conditions, the primary task was interrupted for 100 s. This interruption length was chosen based on our previous observations at this CVICU (Sasango-har et al., 2014) showing an average interruption length of about 50 s (× 2 for two interruptions). For all experimental conditions, the interruption

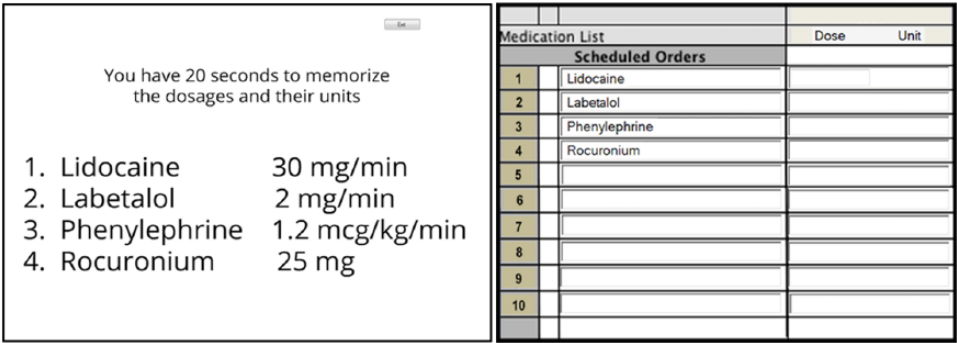


Figure 5. Dose entry task. List of medications and their doses (left); dose entry interface (right).

to the primary task happened after the nurse entered the third medication in the system. A new screen was presented with the text “Interruption: Please wait!” for 2 s to indicate that the interruption period had started. In the baseline condition, the participants were then presented with the text “Interruption! Please wait quietly!” and were asked at that point to not speak to the experimenter and remain seated quietly. In the serial and nested conditions, the participants performed two tasks: a medication-dose entry task and a head-to-toe task.

Medication dose entry. Similar to the primary task, the medication-dose entry task was a memory task whereby participants were shown a list of four medications along with their recommended dose (Figure 5, left) and were given 20 s to memorize the dosage information. Next, the participants were shown the list of medications in the same order that was presented to them and were asked to enter the doses and the associated units in the order entry system (Figure 5, right). They could provide blank responses and skip to the next entry; however, they could not go back to fix their previous responses. Two versions of the medication/dosage list were created and were presented in a counterbalanced fashion. Dose and unit lengths were chosen to be similar between the two versions.

In the serial condition, the dose entry task took an uninterrupted block of 60 s. Participants were given 20 s to view and memorize the list of doses and 38 s to enter the doses in the system in the order presented to them earlier. If the participants were unable to complete this task in the

allocated time, the entries were filled automatically at the end before the message “Task Completed” appeared and was displayed for 2 s. If the participants completed the task before the allocated time, then the message “Task Completed” was presented for longer. Participants were then given 38 s for the head-to-toe task described next (plus 2 s for the message “Task Completed” after the head-to-toe task was completed). After these 40 s, the participants resumed the primary task, that is, the medication order task.

Head-to-toe task. The head-to-toe task involved answering a series of questions about an ICU patient by locating the information on a patient information sheet presented on the screen. The information sheet was adopted from Southeast Texas Medical Associates daily progress templates (www.setma.com) and included information such as patient’s vital signs, diet, and diagnoses. Each participant was asked the same series of questions, for example, “What is the patient’s blood pressure?” and “What is the patient’s discharge date?” and had to visually search the screen for the requested information and verbally respond. As mentioned earlier, the head-to-toe task was controlled to take 40 s total.

In the nested condition, the dose entry task was again time controlled to be 60 s overall (excluding the interruption time) and was interrupted after the participants input the second dose, including blank responses (all participants achieved this input within the first 18.8 s). The message “Interruption: Please Wait!” was displayed for 2 s to indicate the interruption. The participants then performed the head-to-toe task,

which took 40 s. At the end of the 40 s, the participants were taken back to where they left off with the dose entry task to enter the remaining two doses. They were cut off if they could not finish the dose entry task within their allotted time; the entries were filled automatically at the end before the message "Task Completed" appeared and was displayed for 2 s. If the participants completed the task before the allotted time, then the message "Task Completed" was presented for longer. They then resumed the primary task, that is, the medication order task.

Procedure

Upon arrival at the laboratory, the participants were asked to sign an informed consent form. They were then asked to complete the modified Functional Assessment of Chronic Illness Therapy–Fatigue 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 internal validity and reliability (Chandran, Bhella, Schentag, & Gladman, 2007). None of the participants had a score below 30 (associated with severe fatigue).

The participants responded to a few demographic questions and completed a training module, which started with a PowerPoint presentation explaining the different tasks that they would be performing. Here, the participants were also reminded about the Apple iPad 3 draw and that the device would be rewarded based on performance. Participants then completed one practice trial each for the serial and nested conditions. Simplified (with fewer medications) versions of the medication order and the dose entry tasks were used. The head-to-toe task was replaced by a verbal conversation with the experimenter. The goal of the training was to ensure that participants were accustomed to the screens and messages presented as well as data entry methods. Performance was observed and training was repeated if the participant expressed confusion with any of the instructions. The training session took approximately 10 min.

Next, the participants completed the experimental conditions. Their responses to each task and interactions with the software were recorded. Finally, the participants completed a short post-experiment interview to assess their perceived

level of difficulty for different conditions. Overall, the experiment, including the training session, took about 30 min.

RESULTS

Primary Task Performance

Two dependent variables were used to assess the effect of interruptions on primary task performance (i.e., entering the remaining two medication names): resumption accuracy and resumption lag. An ordinal score was assigned to resumption accuracy based on the number of recognizable medication entries with tolerance for typos: 0 = medications entered were not recognizable or entries were left blank, 1 = only one medication entered was recognizable, and 2 = both medication names entered were recognizable with minor typos allowed. Two raters independently scored accuracy. The raters disagreed on only one score and came to a consensus after discussions. Resumption lag was operationalized as the time (in seconds) it took nurses to press a key on the keyboard after the interruption period had ended and the medication order screen was presented again.

Resumption accuracy. Table 1 presents the descriptive statistics for resumption accuracy. An ordered logit model was fitted using PROC GENMOD in SAS, with the specifications of cumulative logit link function and multinomial distribution. Repeated measures were accounted for by using generalized estimating equations. The model included the independent variable experimental condition and the covariate age–experience as defined in the Participants section. Their interaction was not significant and was dropped from the model. Experimental condition had a significant effect, $\chi^2(2) = 17.05$, $p = .0002$. The nested-interruption condition resulted in 4.37 and 2.39 times the odds of having less accurate resumptions than the baseline (odds ratio [OR] = 4.37, 95% confidence interval [CI] = [1.91, 10.00]) and the serial-interruption condition (OR = 2.39, 95% CI = [1.30, 4.37]), respectively. The resumption accuracy was not significantly different between the serial-interruption and the baseline condition. Age–experience had a marginally significant effect, $\chi^2(1) = 3.46$, $p = .06$, with the older–more

TABLE 1: Descriptive Statistics for Primary Task (Medication Order) Resumption Accuracy; Cell Counts Represent Number of Participants

Experimental Condition	Accuracy Rating			Total
	(0) Wrong Medication Entered or No Medication Entered	(1) Only One Medication Was Recognizable, Including Minor Typos	(2) Both Medication Names Recognizable, Including Minor Typos	
Baseline	4	9	17	30
Serial	8	8	14	30
Nested	11	13	6	30
Total	23	30	37	

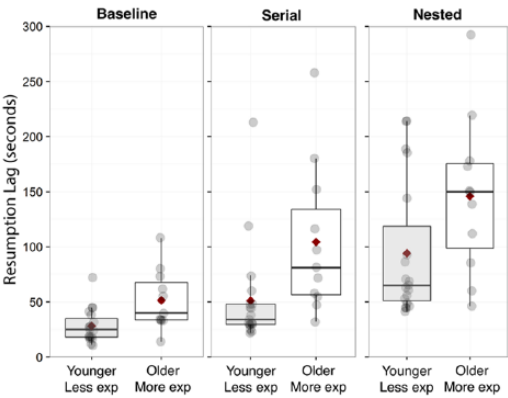


Figure 6. Box plots for resumption lag (seconds). The box plots present minimum, first quartile, median, third quartile, and maximum, as well as data points indicated with gray circles and means indicated with solid diamonds.

experienced group having 2.91 times the odds of having less accurate resumptions than the younger–less experienced group (OR = 2.91, 95% CI = [0.94, 8.95]).

Resumption lag. Resumption lag (Figure 6) was analyzed through a mixed linear model using PROC MIXED in SAS. Participant was introduced as a random factor. The fixed factors were the independent variable experimental condition and the covariate age–experience. Their interaction was not significant and was dropped from the model. Resumption lag was log transformed to correct for heteroscedasticity. Experimental condition had a significant effect, $F(2, 58) = 69.96$, $p < .0001$, $\eta^2_{\text{sempartial}} = .35$. Both the serial- ($M = 70.7$ s, $SD = 59.6$) and the nested-interruption

conditions ($M = 113.1$ s, $SD = 68.8$) resulted in significantly longer resumption lags compared with the baseline ($M = 36.7$ s, $SD = 22.89$), $t(58) = 5.99$, $p < .0001$, and $t(58) = 11.83$, $p < .0001$, respectively. In addition, the nested-interruption condition resulted in significantly longer resumption lag compared with the serial-interruption condition, $t(58) = 5.84$, $p < .0001$. The covariate, age–experience, had a significant effect, $F(1, 28) = 11.28$, $p = .002$, $\eta^2_{\text{sempartial}} = .14$, with older–more experienced nurses ($M = 100.5$ s, $SD = 69.4$) having significantly longer resumptions compared with younger–less experienced nurses ($M = 57.8$ s, $SD = 52.0$).

Secondary Task Performance

For the dose entry task, the unit recall proved to be particularly hard and thus was not considered in our analysis. The accuracy of the dose entry task was therefore based on the dosage recall. Given that the dose entry task was resumed in the nested condition for the last two entries, response accuracy for the last two entries were compared across the nested- and serial-interruption conditions. An ordinal score was assigned to response accuracy for the last two dosage entries: 0 = medication dosages were incorrect or entries were left blank, 1 = only one medication dosage was correct, and 2 = both medication dosages were correct. This variable can also be considered as the resumption accuracy for the nested secondary task. An ordered logit model was fitted using PROC GENMOD in SAS, with the specifications of cumulative logit link function and multinomial distribution. Repeated

measures were accounted for by using generalized estimating equations. The model compared nested with serial interruptions while controlling for age–experience level. The interaction of experimental condition and age–experience was not significant and was dropped from the model. Experimental condition had a significant effect, $\chi^2(1) = 15.40, p < .0001$, with nested-interruption condition resulting in 10.07 times the odds of having less accurate responses than the serial condition ($OR = 10.07, 95\% CI = [3.18, 31.90]$). This finding is not surprising as the nested condition presented an interruption to this secondary task, whereas the serial condition did not. In addition, age–experience had a significant effect, $\chi^2(1) = 7.30, p = .007$, with older–more experienced nurses having less accurate responses than the younger–less experienced nurses ($OR = 6.64, 95\% CI = [1.68, 26.25]$).

The response accuracy for the first two dose entries was also analyzed. The model compared nested with serial interruptions while controlling for age–experience level. Neither the main effects nor their interaction was significant. This result was expected because the participants did not have knowledge of when they would experience the nested condition.

Tertiary Task Performance

Overall, although the number of questions asked during the head-to-toe task generally varied between 7 and 9 (one participant answered three questions), all participants except two (one during the nested and one during the serial condition) answered all questions accurately. Therefore, the head-to-toe task was in general an easy but engaging task with no difference in performance between the nested and serial conditions.

Subjective Responses

After completing the experimental conditions, the participants were asked to rank them in terms of difficulty. Eighteen of the participants ranked the nested-interruption condition as the most difficult one, and the remaining 12 ranked the serial as the most difficult. The majority of participants (26) stated that nested interruptions are a common occurrence in their

ICU. When asked if they could remember cases when 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, when the interruption to secondary tasks generally involved communications with other personnel. For example, while mixing medication, a nurse was interrupted by a doctor ordering medication. On her way to the medication-dispensing machine, the nurse was interrupted by another nurse and engaged in a short conversation.

DISCUSSION

The memory-for-goals model suggests that new goals held in working memory (e.g., secondary tasks) may interfere with the resumption of old goals held in working memory (e.g., primary tasks) (Altmann & Trafton, 2002). The results of the present research support this theory and provide detailed information about the conditions that influence the extent to which new goals will tax working memory and interfere with old goals.

A laboratory study was conducted to compare the effects of nested and serial interruptions on resumption accuracy and lag in an ICU context. The results showed that nested interruptions degrade resumption accuracy compared with both serial interruptions and performing no secondary tasks during the interruption period (the baseline condition in our study), with no difference observed between the latter two conditions. The results also showed that both nested and serial interruptions increase resumption lag compared with performing no secondary tasks during the interruption period but that nested interruptions increase resumption lag significantly more than serial interruptions. Thus, having to resume a secondary task during the interruption period generates longer resumption lags than merely conducting and completing multiple serial tasks during the interruption period. In line with the literature (e.g., Salthouse & Babcock, 1991), our results also showed that age negatively affects working-memory performance. Even though older nurses (45–57 years

old) were more experienced than younger nurses (26–39 years old), their resumptions were significantly more delayed and marginally less accurate.

In the baseline condition, participants had a chance to rehearse the medication names, which could have kept the goals activated in their working memory. On the other hand, in the serial- and nested-interruption conditions, the opportunities for rehearsal were minimized. The rehearsal opportunities can in part explain the shortest resumption lag observed in the baseline condition as well as the superior resumption accuracy observed in the baseline compared with the nested-interruption condition. There were no differences between the serial-interruption and baseline conditions when it came to resumption accuracy, suggesting that performing multiple tasks during an interruption period without further interruptions may not necessarily replace or interfere with the primary task goals in the working memory but may delay the retrieval of this information, as evidenced by the longer resumption lag observed in the serial-interruption condition compared with the baseline.

In the serial condition, although two different tasks were performed during the interruption period, these tasks were completed without being interrupted and no additional resumption-related information taxed the working memory. As shown in Figure 2a, once the secondary task is perceived to be complete, the goal associated with that task will lose activation. In the nested condition, the interruption caused by the tertiary task required the encoding of additional resumption goals in working memory, which had to be kept active along with the resumption goals of the primary task (Figure 2b). As indicated by the worst task resumption accuracy and lag as well as the inferior secondary task performance observed in the nested condition, this extra working-memory load appears to have interfered with both the primary- and secondary-task resumption goals (as shown in Figure 2b). This explanation is in line with the memory-for-goals model (Altmann & Trafton, 2002), which states that the goals encoded to resume the primary task may be replaced by other chunks of information (e.g., resumption goals) related to new interrupted tasks, and in the absence of opportunities to

access these goals (e.g., rehearsal), primary-task goal activation may decline.

One of the limitations of this study was the lack of a single-task-interruption condition that required the performance of a single task during the 100-s interruption period. Research on task switching (e.g., Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Liefoghe et al., 2008) suggests that alternating between multiple tasks impairs the working-memory performance. However, with the current experiment, we do not have the data to show that the serial-interruption condition resulted in a task-switching cost. In addition, although the secondary-task resumption accuracy was reported in this paper, secondary-task resumption lag data were not collected. Still, the secondary-task and tertiary-task performance results as measured through accuracy indicate that the tertiary task resulted in a resumption cost for the nested condition without a performance decline in the tertiary-task performance itself (no difference was observed between nested and serial conditions). Thus, the tertiary task was interruptive and the participants may not have necessarily prioritized the interrupted secondary task over the tertiary task.

Although we present empirical evidence suggesting that the nurses may tolerate certain serial tasks without accuracy costs, different task characteristics can impair accuracy. Further work is needed to examine interruptions with varied frequency, length, complexity, and similarity to the primary task to identify the boundaries of both the serial and the nested task characteristics that lead to a break in performance. Although this study focused on task resumption for static memory tasks as a first step in investigating nested interruptions, their effects on dynamic and time-critical ICU tasks should also be investigated. For example, patient condition may worsen due to interrupted care, or alarms may not be addressed in time. In addition, new events may evolve during a nurse's absence and be missed when the nurse reorients back to the primary task (a phenomenon referred to as change blindness). Furthermore, although memory plays an important role in information processing, work is needed to understand the effects of interruptions on other stages of cognition and

decision making, such as detection, selection, and execution, for a variety of ICU tasks.

The present findings provide an important perspective on the influence of interruptions on task performance. However, although this research is the first to study nested interruptions in the ICU setting, the simulated tasks and controlled laboratory conditions do not truly represent the complexity of the natural ICU work environment. Further, although our participant interviews suggest that the nested interruptions are fairly common in the ICU and may lead to resumption failures, these interviews are subjective accounts. Thus, future studies should more systematically investigate nested interruptions through ICU observations. The phenomenon of nested interruptions should also be investigated within 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). Given the detrimental effects of nested and serial interruptions revealed in our study, our results warrant the need for identifying mitigation methods to minimize the occurrence of such interruptions and to assist interruptees with external and internal memory aids when such interruptions occur (e.g., visual cues, such as Post-it notes and mental rehearsal after the interruption). Work is in progress to evaluate the efficacy of providing a sensor-driven visual timeline of tasks to act as a cue for resumption in case of an interruption.

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KEY POINTS

- A laboratory experiment was conducted with 30 intensive care unit nurses.
- Nested interruptions increase resumption lag and diminish resumption accuracy compared with merely completing multiple secondary tasks during an interruption period.
- Results provide support to the hypothesis that nested interruptions populate working memory with goals associated with interrupted secondary tasks.

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