The Effects of Clinical Task Interruptions on Subsequent Performance of a Medication Pre-Administration Task

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Abstract. There is a surge of research exploring the role of task interruptions in the manifestation of primary task errors both in controlled experimental settings, and safety critical workplaces such as healthcare. Despite such research providing valuable insights into the disruptive properties of task interruption, and, the importance of considering the likely disruptive consequences of clinical task interruptions in healthcare environments, there is an urgent need for an approach that best mimics complex working environments such as healthcare, whilst allowing better control over experimental variables with minimal constraints. We propose that this can be achieved with ecologically sensitive experimental tasks designed to have high levels of experimental control so that theoretical as well as practical parameters and factors can be tested. We developed a theoretically and ecologically informed procedural memory-based task - the CAMROSE Medication Pre-Administration Task. Results revealed significantly more sequence errors were made on low, moderate and high complex conditions compared to no interruption condition. There was no significant difference in non-sequence errors. Findings reveal the importance of developing ecologically valid tasks to explore non-observable characteristics of clinical task interruptions. Both theoretical and possible practical implications are discussed.

Keywords: Clinical task interruptions · Procedural memory · Medication administration

1 Introduction

Clinical task interruptions have been recognized as a contributing factor to the manifestation of clinical errors [1]. Such interruptions are not unusual given the socio-technical system in which healthcare workers usually operate within, which may often be 'interrupt driven' in that they deal with interruptions as part of their day-to-day work

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schedule [2]. Healthcare professionals are reliant upon the successful interaction of multiple work system factors (e.g., technology, organizational, patient factors, healthcare professionals) to ensure acceptable treatment and patient safety is maintained [3]. Such dynamic healthcare environments are highly demanding of the expertise of healthcare professionals, with such demands often coming with limited time constraints. Several healthcare studies have supported the notion of interruptions as a critical contributing factor to clinical errors [4] including having a negative impact on clinical task completion time [5] with some tasks not being completed at all [6]. Other consequences include increases in cognitive workload [7, 8] and elevated risks of medication errors [9]. The main aims of current study were to explore the effects of clinical task interruptions on procedural performance of a clinical task, and how performance might differ when clinical task interruptions vary in level of complexity.

Clinical errors can occur within and between all departments of a hospital environment and across a range of clinical tasks. Medication errors are very common and are often cited as having a collective detrimental effect on patients, the healthcare system, healthcare professionals, and economic impact [10]. Given the prevalence of medication errors and how negative they can be, it comes to no surprise that they are frequently cited as a cause for unintentional incidents and accidents [11], which can occur throughout all stages of the medication process e.g., ordering, prescribing, and administration [12]. It is widely recognized that given the dynamic healthcare environment, medication errors do not arise in isolation. While many contributing factors can occur throughout various stages and processes within a healthcare system/environment [13], the contributing role of clinical task interruptions to medication errors has been well documented [14]. Such interruptions are inevitable within healthcare settings, and at times may be necessary for quality of patient care [15]. Nevertheless, better understanding the cognitive factors underpinning the negative consequences of interruptions in such settings is of crucial importance in order to devise interventions to reduce such effects.

It is recognized that medication administration is a high-risk task, in which, for example, an appropriately qualified nurse is often the last clinical member to check the medication before it is administered [16]. There are a number of policies, procedures, and recommendations surrounding safe medication administration to help prevent medication errors occurring. One such recommendation involves a series of checks of patient and drug details before medication is administered (i.e., 'the rights of safe medication administration'). However, the amount and type of checks that are needed are often disputed [17]. Failures in any of these steps for any of the task types, due to inefficient resumption of a task after being interrupted say, could potentially have an adverse impact on the patient. The procedural nature of medication administration allows for the examination of where in the procedural process errors are likely to occur, despite such errors often only being identified at the end of the administration process [18].

In a descriptive study [19], explored the frequency and type of actual and near clinical errors as reported by 502 critical care nurses over a 28-day period. Medication errors were most frequently reported (N = 127), with the most reported type of medication error being medication administered at the wrong time (N = 48), an omitted medication dose (N = 28), or the wrong dose being given (N = 26). Furthermore, nurse narrative accounts often associated such errors to task interference (e.g., interruptions

and/or distractions). Another observational study revealed 855 medication errors of which 40.3% where due to the wrong time of administration, 34.6% resulted in the wrong medication dose, and 20.9% were due to the wrong administration technique being used, whereby clinical task interruptions were reported to be a critical error producing factor [20]. Clinical interruptions during the medication process may also vary in characteristics, such as frequency of occurrence [21], mode of communication [4] and the amount of cognitive resources needed to successfully complete the primary task [22].

Whilst many clinical studies have recognized various clinical task interruption characteristics that may impede clinical performance, these can be limited by the qualitative approaches often adopted. Some important characteristics, such as effects due to interruption complexity, are less observable using such methodologies and better explored with controlled experimental designs that mimic the setting. Given the diverse range of clinical tasks nurses are responsible for on a day-to-day basis, each of which varies in the utilization of professional expertise [18]; and how many of these may be impacted by an interrupting task [14], it seems pivotal to further understand the impact of the complex nature of such tasks. The current paper sets out to address this important issue.

Interruption task complexity is regarded as a key factor in determining the magnitude of negative effects on suspended task performance. [23] reported that when an interruption task demands reduced available resources to rehearse encoded elements of the primary task (for example, though an increase in complexity), the time to resume the primary task (known as the resumption lag) increased. [24] reported a time cost in retrieving tasks goals whilst resuming a Tower of London (ToL) planning task; markedly so when the interrupting task increased in complexity and became more demanding. However, there appears to be no consensus within the task interruption literature on how interruption complexity is defined, and no clear distinction between interruption complexity and task difficulty. It's important to distinguish the two as any task may be perceived as difficult, particularly to a novice, whereas the complexity of completing the task may be dictated by its unique elements (e.g., multiple end points and paths to such points, uncertainty, conflicting interdependence) regardless if it is difficult or not [25]. Such factors may be particularly important when considering interruption complexity in a healthcare context, whereby interruptions may be perceived as complex due to their safety critical nature and time constraints [18]. These elements of complexity may be explored in controlled experimental tasks, whereby the task interruption represents the hospital context (e.g., interruption requires a clinical decision to be made).

Whilst an ecologically valid controlled experimental task allows for the examination of non-observable clinical interruption characteristics (such as interruption complexity), it also provides an opportunity to develop tasks under well-versed experimental paradigms, and thus interpret results in relation to task interruption (and related) theories and models. One of the leading models often utilized to explain the effects of task interruption is the Memory for Goals model (MfG) [26, 27], which draws from literature on interference and decay. Recent work on the MfG model has explored

interruption characteristics using experimental tasks that represent well learnt procedures (e.g., procedural memory). [28] developed and used the UNRAVEL task to explore the effects of momentary/short task interruptions (e.g., secondary tasks taking an average of 4.4 and 2.8 s to complete). It is a procedural task where UNRAVEL is acronym that represents each step in a sequence and one of two possible responses for that step. For example, on the first step (U), participants respond U if stimuli (e.g., letters) are underlined or I (the other possible response) if the stimuli are in italics. [24] found that interruptions lasting 2.8 s can double the rate of certain procedural errors, and interruptions lasting 4.4 s tripled these errors compared to no interruption trials. These are very short interruption durations compared to other studies, with mixed effects being reported within other studies such as; error rates often raising as interruption duration increases but not always significantly different to non-interruption trials [29]. One key MfG assumption for performance on well learnt procedural tasks is that preparation for a procedural step occurs in semantic memory which then communicates with an execution process with the intention to complete the procedural step. If the communication between preparation and execution is disrupted by an interruption, errors in the procedure are more likely to arise [30]. Furthermore, in relation to interruption complexity, the MfG indicates primary task errors are likely to increase as complexity increases, due to more interruption task goals taking up a limited activation resource.

While both qualitative and quantitative approaches offer valuable insights into the role of task interruption and capture the complex nature of trying to understand interruptions in complex working environments such as healthcare, there appears to be a lack of a direct link between theoretically informed findings on the characteristics of clinical task interruptions that could underlie their disruptiveness. Bridging this gap with theoretically informed studies using tasks (primary and interrupting) with a high level of ecological validity is thus a very important step for both fields. Only then, should we consider possible methods to alleviate disruptive effects within workplaces, especially in situations (such as healthcare) where many interruptions cannot be avoided. The following experiment takes an initial step through the development of an experimental task informed by medical procedures and guidelines, and the theoretical principles of the MfG and UNRAVEL task, to explore clinical task interruptions that vary in complexity. Based on current literature, we make predictions on both sequence and non-sequence procedural errors. First, we predict sequence error rates to be higher in interruption conditions compared to a non-interruption condition, with such error rates increasing as interruption complexity increases. The effects of interruptions during procedural tasks has been attributed to disruption in the ability to control the sequence (e.g., keep active the required sequence for the task), as opposed to performance on each step within that sequence (e.g., choosing the correct response that a given step) [30]. This is evident in the consistent reporting of no interruption effect on non-sequence errors [28, 29]. We predict the same here, in that there should be no difference in non-sequence errors between interruption and non-interruption trials.

2 Method

Participants. An opportunity sampling method was used to recruit 42 psychology students aged 18–30 years of age (M = 19.82; SD = 2.09). 37 were female, three were male, and two did not specify gender. Participants were given course credits for their participation, linked to their UG BSc Psychology degree research methods training. All participants had normal-corrected vision and hearing and were English first language or highly proficient in English as a second language. During the data coding process, five participants appeared to misunderstand the experimental procedure resulting >90% inaccuracy on all dependent measures and thus their data was excluded from the main data analysis. Therefore, data was analyzed and is presented for N = 37.

Design. A repeated measures design was utilized with one independent variable: the amount of cognitive load the clinical interruption places upon the participant, defined as the complexity associated with completing the clinical interruption task. Complexity (and thus cognitive load) was determined by the number of steps needed to complete the secondary interrupting task, and this had four levels: No Interruption/Control, Low Complexity/1 Step, Moderate Complexity/3 Steps, High Complexity/5 Steps. We report findings for two dependent variables (DVs). DV-1 was primary task sequence errors following interruption determined by whether an incorrect step was performed (e.g., a step that does not logically follow on from the previous step). DV-2 was primary task non-sequence errors following interruption, i.e., when the correct step is performed but with the wrong response (each step has two possible responses).

Each experimental task step (see Materials) was considered as one trial, with seven trials equalling one sequence. An experimental block contained five sequences with each block represented a within-participant complexity level. Four blocks were completed, with a total of 140 trials. Each sequential trial was interrupted twice per block, equalling 14 interruptions per block, and these occurred at the end of one trial (after completing an UNRAVEL step) and before starting the next. Each experimental block was continuous until all trials were completed. Interruption complexity, and both primary and interruption task stimuli were counterbalanced using a Latin Square.

Materials. The primary task developed for the experiment was the CAMROSE Medication Pre-Administration Task and was programmed using PsychoPy2 experimental building software [31]. The development of the primary task was informed by the theoretical underpinnings of the UNRAVEL task [28], along with recommended procedures for safe medication administration [17]. CAMROSE is an acronym that represents seven sequential steps whereby C is the first step followed by A M R O S E, and once E is completed the sequence starts again. Each letter of the sequence also represents one of two possible responses for that step (Table 1).

Responses for each step are made based upon stimuli presented to participant (Fig. 1).

The title is in the top left of the interface (Fig. 1). Underneath the title is the routine medicines schedule which holds information regarding the patient, administration time, medication class, route to be administered, doctors' signature, response to medication, and dose of medication. On the right of the interface is an image of a medication bottle

Table 1. Sequential step instructions and possible responses for each CAMROSE step.

Acronym	Step instruction	Possible responses
C	Is it the **C**orrect or **I**ncorrect patient?	C or I
A	Is the time to administer medication **A**m or **P**m?	A or P
M	Is the medication to be administered **M**orphine or **D**iazepam?	M or D
R	Is the required medication dose **R**ight or **W**rong?	R or W
O	Is the route of medication to be administered **O**ral or **T**opical?	O or T
S	Has the doctor checked the medication and **S**igned or **N**ot Signed?	S or N
E	Is there an **E**ffective or **U**nsuccessful patient response to the medication?	E or U

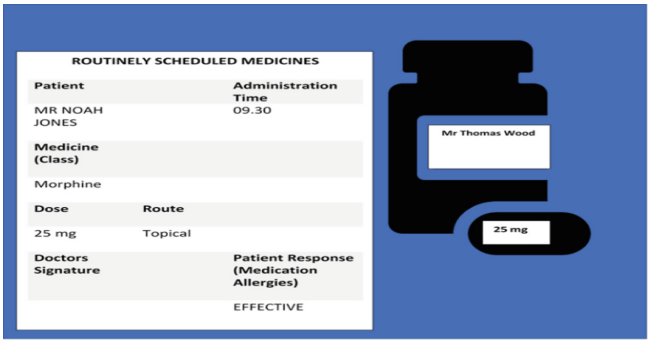

Fig. 1. Example of the primary task interface.

displaying the patient's name and medication, and an image of a drug capsule with the medication dose displayed. These elements are needed for the sequential steps that require checking if it is the correct patient and correct dose.

Throughout various stages/steps of the primary task, participants were interrupted and required to complete a clinical decision-making task, adapted from an National Health Service (NHS) Early Warning Score (NEWS). Interruptions occurred at the end of a task step (i.e., immediately after a step was completed) and were balanced so that each step was interrupted twice throughout the experiment. NEWS is a tool utilized across the UK NHS to assess basic physiological parameters of patients and allows for the identification of potential or established critical illness [32]. The interruption task required the use of a clinical score chart to measure five different physiological responses, and the appropriate action required was given based upon that score. Participants were determine a clinical score based upon an IF-THEN scenario initiated by a video recording of a nurse confederate delivering the questions. Sound was played through headphones. Participants were required to provide the clinical score and correct action required by typing the response and pressing 'enter' to confirm. For example, if the nurse asked, 'if a patient has a respiratory rate of 8 and a SpO2 of 92, what is the

first stage required': participants would ideally respond with 'CS score 5 (adding the scores together to which the responses fall under), hourly observations, and sepsis screen'. A paper reference version of the clinical score chart and actions required was present next to the participant for their use throughout the whole experimental session.

Procedure. Participants read through information and experimental instructions before providing informed consent. Instructions were also read aloud by the experimenter, expressing the importance of remembering the acronym and its associated responses. Participants were encouraged to ask questions. Then, Participants completed a short practice stage without any interruptions consisting of 14 trials. During practice trials, the CAMROSE acronym and associated responses were present to help participants learn the procedure. The researcher then explained the interruption task, and participants were instructed to complete an example by providing a clinical score and required response based upon the if-then scenario presented, and then to return back to the CAMROSE task at the point of suspension. Participants completed another round of 14 practice trials, this time with some interrupted by NEWS tasks varying in complexity. Participants then completed the main experimental trails. Participants were fully debriefed. The experimental took approximately 60–70 min.

3 Results

Table 2 displays the mean sequence and non-sequence error rate for interruption complexity conditions. There is a clear linear trend of mean sequence error rates, in that the more complex the task interruption, the more errors participants made, in general. There are fewer non-sequence errors in the high complexity condition compared to all other conditions, and were highest in the moderate complexity condition.

Table 2. Average sequence and non-sequence errors across all interruption conditions.

Sequence errors	Mean	Standard deviation
No interruptions	2.00	2.84
Low interruptions	4.35	4.41
Moderate interruptions	5.08	5.00
High interruptions	5.10	5.10
Non-sequence errors	Mean	Standard deviation
No interruptions	.86	1.54
Low interruptions	.83	1.23
Moderate interruptions	1.08	1.49
High interruptions	.72	1.04

Data was analyzed for sequence and non-sequence errors using repeated measures analyses of variance (ANOVA) with interruption complexity as the IV: No Interruption/Control, Low Complexity/1 Step, Moderate Complexity/3 Steps, High Complexity/5 Steps. For sequence errors, the assumption of sphericity was violated,

x2(5) = 13.85, $p < .05$, and therefore a Greenhouse-Geisser correction was applied. There was a significant difference in sequence errors, $F(2.34, 84.58) = 8.31$, $p < .001$, $MSE = 12.21$, $\eta p2 = .188$. Sequence errors were significantly higher in the low ($p < .01$), moderate ($p < .001$), and high ($p < .01$) complexity conditions compared to the no interruption condition. However, there was no significant difference in sequence errors between the low, moderate and high complexity conditions ($ps > .05$), possibly due to limited power despite the N of 37 (data analysed). Sphericity was assumed for non-sequence errors data, x2(5) = 8.00, $p > .05$. Another repeated measures ANOVA with complexity as the IV revealed no significant difference in non-sequence errors between each of the complexity conditions, $F(3, 108) = .759$, $p > .05$, $MSE = 1.05$.

4 Discussion

The current study was designed to explore the effects of clinical task interruptions varying in complexity using carefully designed ecologically valid CAMROSE procedural medication pre-administration (primary) and NEWS clinical decision-making (interrupting/secondary) tasks. Post-interruption performance was measured on two procedural outcomes: sequence and non-sequence errors. It was predicted that sequence errors would increase as interruption complexity increased, markedly so when interruption complexity was highest. It was also predicted that given the nature of how errors in procedural tasks arise post interruption, there would be no difference in non-sequence errors as individual step performance would not be affected by interruption complexity.

As predicted, sequence error rates increased as the complexity of the interruption increased and were all significantly higher than sequence error rates in the no interruption condition. However, whilst a visible trend (increase) in sequence errors was apparent as interruption complexity increased, this difference was not statistically significant. Somewhat surprisingly, non-sequence errors were highest in the moderate complexity condition, and, lowest in high complexity condition. However, non-sequence errors did not statistically differ between interruption complexity conditions.

Taken together, the findings suggest that the level of complexity only needs to be low for it to have a negative effect on performance of a procedural healthcare task designed to have high ecological validity. These findings partially support predictions the MfG model makes on interruption complexity, suggesting that other factors may be influencing performance. For example, according to the MfG model, more complex interruptions require greater allocation of task goals decreasing the opportunity to rehearse suspended task goals [23]. Additionally, interrupting tasks with more goals to satisfy are more likely to create a greater amount of interference to the representations of suspended goals than interrupting tasks with fewer goals. The current results may indicate that interruption complexity, in the current context, is more than the number of interrupting task goals. It may be that the interruption task is being perceived as complex due to its safety critical nature, regardless of the number of steps required to complete it [18]. Thus, the nature of interruption task could potentially reduce time to rehearse primary task goals and is an important factor to consider within a hospital environment.

Visual cues could also have been responsible for the findings on non-sequence errors. The use of associative cues within the task environment or internally stored by the individual may prime suspended task goals and enhance the likelihood of successful retrieval [33]. It is a possibility that global place keeping using visual cues could have been taking place, as the position of primary task stimuli in the interface was consistent throughout the experiment. This may explain the non-significant difference in sequence error rates between low, moderate and high interruption complexity conditions. Given that the level of interruption complexity did not significantly effect non-sequence errors on the primary task. In relation to non-sequence errors, the findings of the current study are in line with previous studies [28, 29]. This finding is in line with previous research and provides support for the MfG models proposition on the cognitive effects of task interruptions during procedural tasks [30]. That is, task interruptions negatively impact the cognitive control process needed for remembering the procedural process (as measured by sequence errors) but do not significantly affect individual step performance within the procedure (as measured by non-sequence errors), regardless of the level of complexity or contextual elements of the primary and interruption task.

The study has taken a novel approach in exploring clinical task interruptions through the development of primary and interruption experimental tasks that best represent common procedures within hospital environments. This development process was informed by both the healthcare and psychological literature on task interruptions and represents a step forward in better understand the effects of interruptions on healthcare professionals. We explored the effects interruption complexity on performance of a newly developed medical based procedural memory task - the CAMROSE Medication Pre-Administration task. Whilst interruption complexity has been researched extensively, to our knowledge, this is the first study to measure effects within a healthcare context. Here we present novel findings that indicate interruption complexity as a key factor to be considered in healthcare studies when exploring the characteristics of clinical task interruptions, particularly during the medication administration process. We posit that our findings represent a step forward in better understanding how cognition may be affected by such clinical task interruptions and enhances and/or extends the explanatory power of current interruption theories and models.

The findings should be interpreted tentatively due to this being the only study of its kind to date, and with consideration of the following limitations. Findings on sequence errors, whilst interesting, may be interpreted in different ways. To eliminate the role that other factors (e.g. visual cues) may have on the performance, more research is needed using a similar paradigm and controlling for their influence. In relation to non-sequence errors, post-hoc analyses revealed that there was not enough power to detect a significant difference if one exists, and a larger sample size is required. Given the nature of the procedural steps within the experimental task, it is also important to better understand each step individually (e.g., does the degree of cognitive load a step places on an individual vary?), and at which point a task interruption may become more disruptive. This data is currently being analyzed. Additionally, whilst the findings highlight the importance of using context specific healthcare tasks to better understand non-observable characteristics of task interruptions, participants were not healthcare professionals. With more research adopting a similar approach it can potentially inform

more robust, cost-effective technological designs, that offer ways to effectively handle such interruptions within dynamic safety critical work settings. Current technological interventions that are aimed at reducing clinical errors (e.g., Computerised Physician Order Entry) are often not designed to be resilient to negative effects of clinical interruptions [34, 35]. With a growing introduction of important yet 'disruptive' technology into healthcare settings, there is a need to better understand the cognitive underpinnings of clinical task interruptions on healthcare professionals, which can in turn inform better design principles and cognitive strategies for better handling of interruptions [36–39].

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