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The Effects of Interruption Relevance and Complexity on Primary Task Resumption and Mental Demand

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THE EFFECTS OF INTERRUPTION RELEVANCE AND COMPLEXITY

ON PRIMARY TASK RESUMPTION AND MENTAL DEMAND

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ABSTRACT

THE EFFECTS OF INTERRUPTION RELEVANCE AND COMPLEXITY
ON PRIMARY TASK RESUMPTION AND MENTAL DEMAND

Brandon Allan Fluegel
Old Dominion University, 2020
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In the present study, undergraduate students viewed patient charts and entered numerical values from these charts into a medical record database. They were unexpectedly interrupted by secondary tasks that differed in relevance and complexity. The secondary tasks varied by whether they facilitated or inhibited (i.e., relevant or irrelevant) rehearsal of the suspended task and whether they placed a demand on working memory (i.e., high complexity or low complexity). The primary measures of interest were the duration of time needed to resume the primary task and perceived mental demand. The Memory for Goals model (Altmann & Trafton, 2002) predicts that task relevant interruptions would lead to faster task resumptions, when compared to task-irrelevant interruptions. The Time-Based Resource Sharing model (Barrouillet, 2007) predicts that high complexity interruptions would lead to slower task resumptions and higher perceived mental demand, when compared to moderate and low complexity interruptions. Alternatively, the Memory for Problem States model (Borst, 2015) predicts that high complexity and moderate complexity interruptions would not lead to significant differences in task resumption speed. Results revealed two important findings. First, participants resumed the primary task faster and reported lower perceived mental demand following relevant interruptions, when compared to irrelevant interruptions. Second, as the magnitude of interruption complexity increased, participants resumed the primary task slower and reported higher perceived mental demand. Thus, the findings offered support for the Memory for Goals

and Time-Based Resource Sharing models, but not the Memory for Problem States model. In general, the current research illustrates the importance of minimizing the demand on attentional resources when interrupting individuals during the performance of visuospatial tasks, particularly when the interruption is irrelevant to the suspended primary task.

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CHAPTER I

INTRODUCTION

Regardless of the environment, interruptions can pose a threat to the performance of tasks (Pankok et al., 2017; Cellier & Eyrolle, 1992; Hess & Detweiler, 1994; Gillie & Broadbent, 1989; Kirmeyer, 1988). Though a minor interruption (e.g., receiving a text message) may lead to frustration and annoyance (Mark et al., 2008), the effects of disruptive events in high-stakes environments (e.g., surgery, aviation, military combat, etc.) may encounter greater consequences.

As suggested by Couffe and Michael (2017), a genuine task interruption encompasses four criteria: a primary task is paused temporarily, there is an intention to return and finish the task, the interruption task is introduced by an event (i.e., interruption alert), and can be internal or external to the operator. In general, an *interruption* can be conceptualized as an internal or external stimulus (i.e., a secondary task) that leads to a temporary pause in a primary task, prior to its completion, with the intent of completing the respective task (Boehm-Davis et al., 2009; Jett & George, 2003; Mark, Gonzalez, & Harris, 2005).

Although similar to an interruption, a *distraction* is a stimulus that does not necessarily cause an individual to suspend performance of the primary task and researchers have shown that distractions affect human operators in qualitatively different ways (Bourne, 1986; Flynn et al., 1999). For example, both external (e.g., humming of a computer) and internal (e.g., digestive sounds) distractions may tax attentional resources, but they do not force a temporary abdication of the primary task. Furthermore, managing a task interruption requires the use of maintenance processes to support activation of the suspended task goal in working memory, along with mechanisms to facilitate primary task resumption (Altmann & Trafton, 2002).

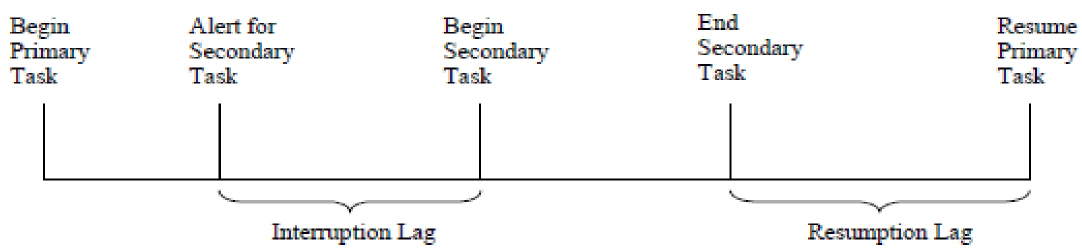

*Figure 1***.** Time-course of an interruption (adapted from Trafton et al., 2003)

The time course of an interruption is illustrated in Figure 1. As an example, consider what may happen when a computer programmer is interrupted while working on a coding task. The programmer is working to debug a batch of code (the *primary task*), when her manager walks into the office and asks a question regarding a different task (the *second task alert*). The time interval between the onset of the alert and the act of answering the manager's question (the *second task*) is defined as the *interruption lag.* Following completion of the second task, the programmer can then re-engage focus on her primary coding task. This interval between the suspension of the second task and the resumption of the primary task is defined as the *resumption lag (*Altman & Trafton, 2004).

Task Benefits from Interruption

Interestingly, prior research has documented that not all interruptions negatively impair performance. For example, Westbrook (2010) found that interrupted medical tasks were completed quicker than non-interrupted tasks. Specifically, the authors observed forty physicians over the course of six months and found that when controlling for length-biased sampling, task completion times were shorter for interrupted tasks than for tasks with no interruptions. Specifically, for tasks that included one interruption, completion time was almost half that of uninterrupted tasks. The authors proposed that clinicians compensated for the time spent managing an interruption by quickening task completion.

Similar findings have been documented in research on interruptions in office environments. For example, Mark (2008) examined the effects of interruptions in an office environment and found that interrupted email tasks were completed faster than non-interrupted tasks. However, this result may be explained by the fact that participants in the interrupted groups wrote shorter emails than participants in the non-interruption groups, on average. Finally, Speier (1999) documented similar findings in his research on interruptions during simulated computer tasks. Specifically, results found that interruption of both simple and complex computer tasks were completed faster and with similar accuracy, when compared to non-interrupted tasks. Therefore, the task performance benefits from interruptions could simply be due to a faster work rate (i.e., truncation effect), reduction of the effort allocated to task elements, or even neglecting to complete certain task components (Westbrook, 2010; Mark, 2008; Speier, 1999).

Interruptions in Different Domains

Research on the prevalence and performance effects of interruptions has been conducted in various domains. In general, the methods used to measure these effects has predominately applied workplace observation and controlled, lab- and simulator-based experimentation.

Office Settings

Previous research has shown that the context in which an interruption occurs can determine whether the event will be beneficial or detrimental to various work-related outcomes (Mark et al., 2005). For example, in a simulated office environment, Mark and colleagues (2008) interrupted participants while they played the role of a human resources manager. The participants were instructed to view a simulated message inbox and to reply to all of the emails “quickly, correctly and politely.” While performing the primary task, half of the participants were interrupted intermittently, while the other half were not interrupted and served as a control. Surprisingly, the results showed that primary task performance outcomes for the interrupted group were not statistically different than those of the noninterrupted group. The authors suggested that when individuals are continuously interrupted, they work faster to make up for the time they anticipate will be interrupted in the future. However, the individuals who were interrupted were found to report statistically greater levels of stress, frustration and effort compared to those in the non-interruption control group.

Aviation

Prior research has documented the deleterious effects of interruptions during aviation-based tasks. For example, Turner and Huntley (1991) analyzed 195 aviation incident reports to evaluate the relationship between flight checklist usage, task interruption, and performance effects. The authors identified that most of the incidents were the result of task interruption during communication with air traffic control, whereas the second most prevalent incidents were due to execution of a checklist that interrupted the primary operational task (e.g., maintaining position in a runway queue). Additionally, Latorella (1996b, 1998) investigated the effects of air traffic management (ATM) interruptions on flight-deck performance in a simulated aviation task. She found that participants were 53% more likely to commit a flight error when an ATM interruption occurred.

Healthcare

Interruptions in hospital settings have been shown to increase the frequency of task-related errors. In a study that observed medical workers as they prepared and administered medications, Westbrook et al. (2010) found that for every interruption, the risk of subsequent medication error increased by an average of 12.7%. Moreover, the researchers found that once a medical worker was interrupted more than six times during their shift, this probability of medication error tripled for every additional interruption. Additionally, in a review of twenty-three medication administration studies, Biron and colleagues (2009) found that medical workers were interrupted once every 6.7 minutes, on average. In general, it was reported that vocal communication by nursing staff was the most prevalent form of disruption, accounting for 36.5% of the total observed interruptions.

The prevalence of interruptions in the operating theatre has also been documented. In a recent study, Yoong and colleagues (2015) reported an average of 26 interruptions during a gynecological operating procedure, with 81% of the interruptions affecting the entire operating staff. Additionally, Weigl and colleagues (2015) documented the frequencies of interruptions throughout 56 surgical procedures. Observing both general and orthopedic surgery, the authors found that an interruption occurred about once every six minutes, on average.

In medical environments, investigating the causal effects of interruptions on task performance is exceedingly difficult. Specifically, the introduction of experimental interruptions during patient treatment is not only an ethical risk, but a substantial health risk. However, a few prior studies have examined the effects of realistic operating room distractions and interruptions (ORDIs) in simulated environments. For example, Feuerbacher and colleagues (2012) examined the frequency of task-related errors and prospective memory recall during a simulated laparoscopic cholecystectomy. Results found that major surgical errors were committed in 44% of procedures in which ORDIs occurred, compared to only 6% of procedures in which no ORDIs occurred. Replicating previous observational research (Biron et al., 2009; Westbrook et al., 2010), it was found that interrupting questions from simulated staff led to the highest amount of task-related errors. The authors proposed that the ORDIs impaired performance by shifting attention away from the simulated surgical task to management of the unexpected secondary task. As shown, interruptions during execution of a task can lead to error following resumption of the task, irrespective of the domain. A large body of prior research has examined the ways in which interruptions can consume our limited attentional resources while completing tasks.

Attention & Workload

Prior research has examined the influence of visual (Gulum et al., 2012; Hameed et al., 2009; Latorella, 1998), auditory (Peryer et al., 2005; Sugimoto et al., 1997; van der Lubbe et al., 2005), tactile (Hopp et al., 2006; Hopp et al., 2005) and even olfactory (Arroyo et al., 2002) interruptions on attention. Some researchers have proposed that attention be viewed as a limited capacity fuel, or *resource*. For example, Moray (1967) proposed that the brain be thought of as a type of digital computer which has a “limited capacity processor”. This idea was quite influential because it suggested an attentional model that was composed of a general “pool” of resources that contrasted the previous all-or-nothing single channel, or “bottleneck” view of attention (Broadbent, 1958). The basic assumption of this theoretical pool was that as task demand increased, the amount of available resources within this pool will continue to decrease, leaving additional tasks with fewer resources available for use. Kahneman (1973) further refined Moray’s view by emphasizing how the demand of the primary task would affect the availability of resources that could be used to manage a peripheral task. Specifically, performance of an additional task was hypothesized to decrease proportionally to the increased demand of the first task.

A related construct, *mental workload* (MW), has been defined as the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support, and experience (Hancock & Meshkati, 1988). Additionally, MW has been defined as the association between an individual’s mental processing capacity and the demands required for a task (Hart & Staveland, 1988). In general, studying MW can help to identify how moments of overload or underload affect performance outcomes during complex tasks. For example, in situations of overload, the amount of available attentional resources needed to execute a task may not be enough to meet the demands imposed by a task (e.g., a pilot managing an interruption while attempting to land on an aircraft carrier during a severe storm). High levels of MW have been found to lead to increases in perceived stress, task-related errors, attentional tunneling, and a variety of other deleterious outcomes.

Interruption Characteristics

Interrupted Task

The research literature has shown that the particular sensory modality of both the interrupting task and the ongoing primary task can lead to performance decrements in different ways. For example, research from Latorella (1998) evaluated pilot performance in a simulated flight deck while interruptions of different sensory modality were presented. Results showed that participants had three times as many performance errors when auditory interruptions were presented during auditory tasks, compared to visual tasks. These findings follow the logic that when a primary task is utilizing a specific sensory modality, less attentional resources are available for use when attempting to manage a secondary task of similar modality. In a meta-analysis that investigated interruption alert times (i.e., the time needed to become aware of an interruption) during ongoing visual tasks, Lu et al. (2013) found that interruption alert processing times differed across sensory modalities. Results showed that, on average, participants performing a visual task took longer to respond to visual interruptions, when compared to auditory interruptions.

Interruption Lag

Altmann and Trafton (2002) proposed that individuals may strategically rehearse, in memory, the point in the primary task where they were at, prior to managing the interruption (i.e., the *interruption lag*). To examine this proposal, Hodgets and Jones (2003) had participants complete the five-disc Tower of London problem (Ward et al., 1997), while receiving intermittent verbal-reasoning interruptions. The task required participants to move discs from an initial configuration to a specified "target" arrangement, one disc at a time. The researchers investigated whether task resumption time could be reduced if the interruption was preceded by a brief interruption lag. Their results demonstrated that the insertion of a pause, prior to engagement of the secondary interruption task, significantly reduced the time needed to return to the disc arrangement task. The authors suggested that during the period of interruption lag, the current configuration of the discs was being repeatedly sampled in memory, thereby reducing the amount of time needed to resume the task following management of the interruption. These findings were some of the earliest to offer evidence on the importance of the period of interruption lag in preparing to resume a suspended task.

However, other research has failed to identify any benefits of rehearsal during the period of interruption lag. For example, Miller (2002) investigated how individuals manage interruptions during a team decision-making task. Participants worked to assess the threat level of aircraft that appeared on a simulated radar scope. Additionally, they received intermittent message alerts on their screen that provided further details regarding the various levels of the threat for the aircraft. To read the message (i.e., the secondary task), the participants were required to select the onscreen message by clicking on an icon. The intervals between the secondary task alert and selection of the message (i.e., the interruption lag) and the resumption of the suspended primary task were measured. To examine the role of rehearsal during the interruption lag interval, participants were assigned to either a rehearsal or no rehearsal condition. Participants who could rehearse during the interruption lag took significantly longer to return to the primary task (i.e., resumption lag) than those who did not actively rehearse. The authors suggested that these counterintuitive findings may have resulted from participants who failed to use the rehearsal strategy. However, regardless of whether an operator chooses to strategically use this period of interruption lag, they ultimately must shift their attention to manage the interruption.

Interruption Complexity

Previous research has defined interruption complexity as the number of mental operations (Cades et al., 2008) involved in an interrupting task. For example, an interruption that requires two mental operations ([100+20/6] =?) would be described as more complex than an interruption with one mental operation ([100/5] =?). However, other researches have provided a more specific definition for complexity that focuses on the attentional demand characteristics of the interruption task. For example, Monk & colleagues (2008) defined *interruption complexity* as the processing demands on working memory that can facilitate or impair rehearsal of suspended task goals (Monk et al., 2008). In general, as the complexity of an interruption increases, less attentional resources will be available for maintenance of suspended task goals. Alternatively, as the complexity of an interruption decreases, more attentional resources will be available to rehearse or maintain the suspended task goals. Thus, it may be predicted that greater interference (and slower primary task resumption) would occur following highly complex interruption, when compared to less complex interruptions. However, prior research has documented mixed findings.

In one camp, research has shown increased resumption lags following interruptions of greater complexity. For example, Hodgetts and Jones (2005, 2006) found evidence for an effect of complexity on task resumption times following interruption of a visuospatial puzzle task (i.e., Tower of Hanoi). After presenting the puzzle's goal state, participants were tasked with moving rings one at a time until the arrangement of rings matched the goal state. Participants were unexpectedly interrupted by either a mood questionnaire (i.e., the simple interruption) or a verbal reasoning task (i.e., the complex interruption). The authors predicted that resumption times would be slowest following the most complex interruptions, due to increased interference from the additional mental operations. Results supported their prediction, such that task resumptions were quicker following a simple interruption, when compared to complex interruptions. The authors proposed that increased retroactive interference from additional mental operators in the complex interruptions led to longer resumption lags. Specifically, following the complex interruption, a longer time interval was needed for the primary task goal activation to be strengthened to a high enough level to overcome the interference threshold set by the additional mental operations. However, as noted by the authors, this result may be confounded by having not controlled for the length of the interruption in both the simple and complex conditions. Previous research by Cades and colleagues (2008) has also documented the effects of interruption complexity on primary task performance. Participants completed a computer-based task that required them to program a simulated video cassette recorder. During execution of the primary task, participants were unexpectedly interrupted by one of two tasks that differed in complexity. Specifically, participants were either interrupted by a task that required them to identify which of a pair of two numbers was larger (i.e., the simple interruption) or a task that required them to add together the two presented numbers and identify if this sum was either odd or even (i.e., the complex interruption). Results found that resumption lags were significantly longer following the complex interruption, when compared to the simple interruption. The authors proposed that this finding was due to the additional number of mental operators required by the complex interruptions, which led to fewer opportunities for concurrent rehearsal of the primary task goal, thereby increasing resumption lag. Next, research by Zilistra and colleagues (1999) also found that resumption lag following reengagement of the primary task differed between interruptions of different complexity. In their study, participants were interrupted during execution of a text editing task that included making handwritten corrections, deleting and replacing text, and ordering a list of references. While performing the primary task, participants were interrupted by a telephone call that requested the performance of an additional task. The tasks were either looking up a phone number (i.e., the simple interruption) or an additional editing task (i.e., the complex interruption). Results found that resumption lags were significantly longer following the complex interruptions. The authors proposed that the more elaborate cognitive processing required by the complex interruptions led to a longer interval of time needed to disengage from the interruption and resume the primary text editing task. Finally, Monk & colleagues (2008) found an effect of complexity on primary task resumption. Specifically, when completing a visuospatial VCR programming task, participants were unexpectedly interrupted by interruptions that differed in complexity. These interruptions were either a blank screen (i.e., low complexity), a tracking task (i.e., moderate complexity), or a 1-back task (i.e., high complexity). The authors selected these different interruption tasks due to their predicted effect on working memory demand. Specifically, it was expected that as the complexity of the interruption increased, there would be greater demand on working memory and subsequently fewer resources available to rehearse the suspended primary task goals. Results supported their prediction by showing that resumption lags were significantly longer following the high-complexity n-back task. Moreover, resumption lags were longer following the moderate complexity tracking task, when compared to the low complexity blank screen interruption.

In another camp, previous research has not found support of interruption task complexity effects on primary task resumption. For example, Pankok and colleagues (2017) found no evidence of prolonged resumption lags following interruptions of varying complexity in a procedural Lego assembly task. Specifically, participants were unexpectedly interrupted by secondary tasks that varied in both task similarity and interruption complexity. For the task similarity manipulation, the interruptions were either an additional Lego assembly task (i.e., the similar interruption) or pencil-and-paper math problems (i.e., the dissimilar interruption). For the task-similar group, participants had to perform the additional assembly task using either just one type of Lego brick (i.e., simple) or a variety of bricks (i.e., complex). Moreover, for the task-dissimilar group, the interruptions were basic addition problems (i.e., simple) or multiplication problems requiring carry-over of a digit to the hundredths place (i.e., complex). Although results found that participants took significantly longer to complete the primary task following complex interruptions, compared to simple interruptions, the authors did not find a significant difference in the amount of time needed to resume the task (i.e., resumption lag). However, results did find a significant effect of task similarity on prolonged resumption lag. Specifically, resumption lags were significantly longer following an interruption that was similar to the primary task, compared to the dissimilar arithmetic interruption task. However, these findings may be potentially confounded by the availability of the primary task instructions on the computer monitor following management of the interruption.

Although it has been shown that findings for the effect of interruption complexity on resumption lag are mixed, these differences may be due to the inconsistent definitions, and manipulations, of *complexity*. For example, whereas Cades (2007), Hodgets & Jones (2006), and Gillie & Broadbent (1989) manipulated complexity by altering the amount of mental operations, Monk & colleagues (2008) manipulated the cognitive demands on working memory. Thus, these mixed results may be partially attributed to inconsistent operationalization of complexity.

Interruption Relevance

A concept related to task similarity (Pankok et al., 2017) is *interruption relevance* and it has been defined as the extent to which an interruptive task facilitates performance in the primary task (Gould et al., 2013). For example, if an interruptive task requires an operator to reflect on aspects of the suspended primary task, this interruption can be described as relevant. Alternatively, an interruption can be described as irrelevant if it is unrelated to the performance of the suspended task. Salvucci (2010) proposed that relevant interruptions can help in reconstructing the suspended primary task context, prior to and upon resuming the primary task. Thus, it may be expected that resumption lags will be shorter following task-relevant interruptions, when compared to task-irrelevant interruptions. However, like the previously discussed research on interruption complexity, mixed findings have been documented for the effects of interruption relevance on resumption lag.

On the one hand, prior research has not found evidence of increased resumption lag following irrelevant interruptions. For example, Iqbal & Bailey (2008) employed a notification management system to investigate the relationship between interruption onset point and task relevance on primary task performance. Specifically, during the execution of a computer-based programming task, participants received on-screen notifications that differed in relevance (i.e., whether the interruption was similar in content to the primary task or a general interest news articles) and onset point (i.e., whether the interruption occurred immediately or during a breakpoint in between task sub-steps). Results showed that the onset of notifications during task breakpoints led to significantly less frustration and faster reaction times when compared to notifications that occurred immediately during the task. Additionally, participants reported significantly greater levels of frustration following notifications of dissimilar content to the primary task. However, participants resumed the suspended tasks significantly faster following dissimilar notifications, when compared to similar content notifications. Finally, Latorella (1999) investigated the effects of semantic similarity on performance of a simulated flight deck aviation task. Specifically, she predicted that interruptions that are semantically similar to the suspended primary task should result in worse performance upon resumption, compared to semantically dissimilar interruptions. However, results found that there were no significant differences in interruption acknowledgment time, the amount of procedural errors, or resumption lag.

On the other hand, research has found task irrelevant interruptions to be deleterious to primary task resumption. For example, Czerwinski & colleagues (2000) found a negative effect of task-irrelevant messages during the execution of a web search task. Specifically, participants completed a computer-based task which required them to perform a web search for prespecified target content. During task execution, participants were interrupted by either a task-relevant message to aid primary task performance or a task-irrelevant message about the webpage they are currently on. Results found that the amount of time spent reading the message and the amount of time needed to resume the suspended primary task (i.e., resumption lag) were significantly longer for task-irrelevant messages. The authors proposed that this task-irrelevance effect was due to a longer amount of time needed to reestablish the suspended task context, when compared to task-relevant instant messages. Additionally, throughout completion of a medical data-entry task, Gould and colleagues (2013) unexpectedly interrupted participants by secondary tasks that were either related (e.g. "what subtask did you just complete?"; i.e., relevant) or not related (e.g., "which subtask label is this?"; i.e., irrelevant) to the suspended primary task. They found significantly longer resumption lags following task-irrelevant interruptions, when compared to relevant interruptions. Both of these findings contrast those from Iqbal & Bailey (2008) who documented significantly longer resumption lag times for content-dissimilar interruptions, when compared to content-similar interruptions.

These inconsistent findings may be partially due to differences in the way that interruption relevance has been operationalized. For example, the previous researchers did not make a clear distinction between interruption relevance and content similarity. Specifically, whereas Czerwinski and colleagues (2000) and Gould and colleagues (2013) interrupted participants with secondary tasks that either did or did not aid performance on the primary task (i.e., relevant or irrelevant interruptions), Iqbal and Bailey (2008) and Latorella (1999) interrupted participants with tasks that were or were not similar in content to the suspended task. Although the differences between relevance and content similarity may not appear meaningful, the two impose different demands on memory. Specifically, while task relevant interruptions may facilitate rehearsal of the suspended task context or goals, interruptions of similar content may lead to the generation of retroactive interference (Altmann & Trafton, 2002). Moreover, when interruptions are dissimilar in content, they offer no information that may aid the maintenance of suspended task goals and context. Therefore, whereas task relevant (R) interruptions may reduce the amount of time needed to resume the suspended task, irrelevant interruptions of similar content (ICS) and irrelevant interruptions of dissimilar content to the primary task (ICD), may increase the amount of time.

Primary Task Suspension & Resumption

As previously discussed, many factors influence the ability to efficiently and accurately resume a suspended task. Prior research has led to the development of goal encoding and retrieval frameworks that seek to explain this resumption process. For example, the Adaptive Character of Thought (ACT-R; Anderson et al., 1996,1997) cognitive architecture offers insight into how cognitive processing is affected during and following the management of a secondary task interruption. In general, ACT-R describes cognitive processing as a collection of modules that interact via a centralized production system. In addition to visual, auditory, and motor modules, ACT-R proposes cognitive modules for declarative memory and procedural memory that drive the centralized production system.

Memory for Goals

Extending the ACT-R cognitive architecture, Altmann and Trafton (2002) proposed a theoretical framework, *Memory for Goals* (MFG), to predict the efficiency of primary task suspension and resumption following the onboarding and management of a secondary task (i.e., an interruption). The MFG model has been used to explain findings from goal encoding and memory retrieval research. Their model has been validated in several task-interruption studies (Li et al., 2006; Monk et al., 2004; Trafton, Altmann, Brock, & Mintz, 2003) and will serve as a theoretical framework in the present study. The model assumes that a goal's retrieval history and its resultant activation strength affect the ability to recall an encoded goal following interruption. Specifically, the model proposes three core constraints that influence goal-directed behavior: secondary goal interference, goal strengthening, and priming from associative contextual cues.

First, the level of interference can informally be thought of as mental "noise" or "clutter" from either previous or newly encoded task goals that are still active in memory. Formally, interference level has been proposed as the mean level of activation of the most active distractor (i.e., nontarget) goal being held in memory. Altmann and Trafton (2002) proposed that this characteristic of relative activation levels can lead to predictions of whether the correct (i.e., target) goal is sampled. Specifically, if the correct goal has a higher activation level than the most active distractor goal (i.e., interference level), it is more likely to be retrieved when an individual samples memory. Alternatively, if the correct goal has a lower activation level than the most active distractor goal, it is less likely to be retrieved.

Next, the goal strengthening constraint refers to the level of activation to which suspended task goals must build, so they can overcome retroactive interference from newly formed goals (e.g., task interruption). Specifically, retroactive interference is evident when recollection of an original set of information is affected by having learned a new set of information, whereas proactive interference concerns the learning of one set of information (e.g., an old task goal) that interferes with the later learning of another set of information (e.g., a new goal; Ebert & Anderson, 2009). An additional characteristic of the strengthening constraint is that following task switching, the level of activation for the primary task goal will begin to decay in declarative memory.

As shown in Figure 2, the steep initial incline in activation from repeated sampling of the primary task goal is followed by a gradual decline in activation due to an inability to maintain high rates of sampling (i.e., rehearsal) when switching to execution of a secondary task. Importantly, if enough time passes to allow for a significant decay of the primary task goal in declarative memory, the associated level of activation may begin to asymptote.

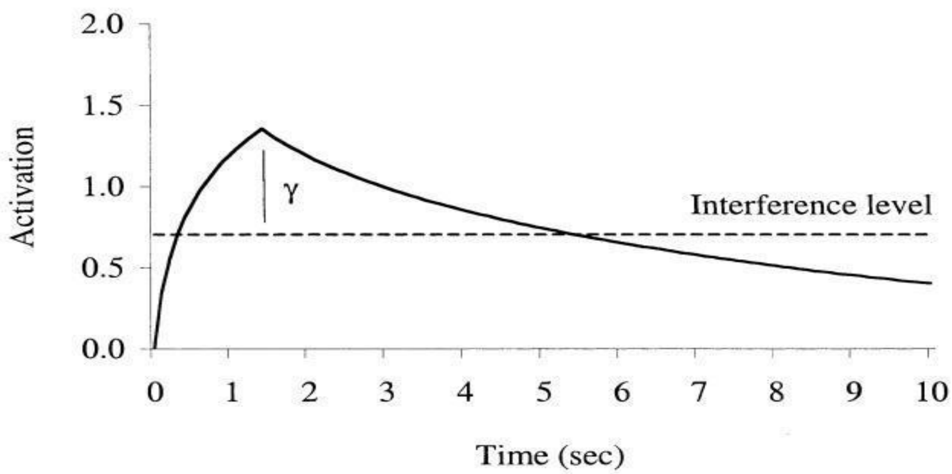

Fig. 2. The time course of activation of a primary goal and interference level of secondary goals. (adapted from Altmann & Trafton, 2002)

Thus, secondary tasks (e.g., interruptions) that last longer than the time required for this asymptotic effect to occur may be relatively similar in their impact on primary task goal retrieval. This characteristic of the MFG model can help explain the results from studies that failed to identify any differences in primary task resumption rate following interruptions of various temporal length. For example, Gillie and Broadbent (1989) had participants complete a prospective memory task that required the memorization of items from a list. They were then interrupted for either 30 or 165 seconds to perform a computer-based task requiring the identification and selection of previously memorized items. The authors did not find any differences in task performance between the two interruption durations and concluded that the temporal length of interruption was not a “critical factor” in whether it would be disruptive. Taking this finding into consideration, the MFG model suggests that no differences were found because the level of activation for the primary task goal had already reached asymptotic levels prior to the completion of either of the two interruption durations.

Finally, the priming constraint of the MFG model states that suspended goals that have not been rehearsed during secondary tasks can only be retrieved following priming from associative contextual cues (Altmann & Trafton, 2002). For a cue to facilitate goal retrieval, Field (1987) argued that the cue not only has to be available when attempting to retrieve the suspended goal, but it must have been associatively linked to the goal prior it its suspension. In general, for a cue and a goal to be linked, the cue had to have been in focal awareness when the task goal is being sampled in memory (Anderson, 1990). Prior research has shown that associative cues can help to facilitate reorientation to suspended primary tasks. For example, Borst and colleagues (2013) found that participant resumption lags were significantly shorter when they were provided with a contextual cue of their position in suspended math tasks. In general, MFG predicts that secondary tasks (i.e., interruptions) which offer associative contextual cues to a suspended task goal can help facilitate task resumption, when compared to secondary tasks which do not provide cues. The relationship between cue identification and primary task goal retrieval is illustrated in Figure 3.

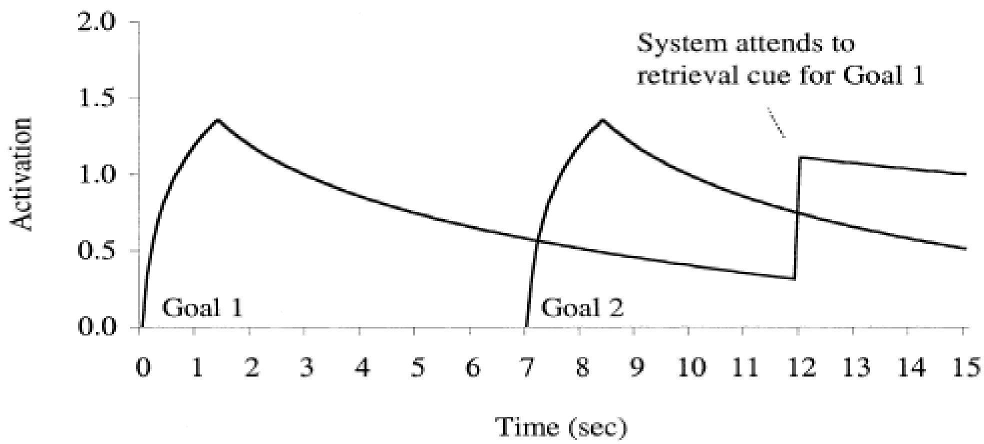

Fig. 3. Following the onboarding of a secondary task goal (i.e., goal 2), a cue is identified and strengthens the relative activation for Goal 1, allowing it to overcome the retroactive interference formed by Goal 2 and is now the most likely goal to be retrieved from memory. (adapted from Altmann & Trafton, 2002).

As discussed, the successful retrieval of a suspended task goal is dependent on its activation being strengthened via rehearsal during secondary task execution or from associative priming via contextual cues. This relationship between the strengthening of suspended goals and priming via contextual cues has important implications for explaining the differential effects of relevant and irrelevant interruptions on primary task resumption. Specifically, relevant interruptions (R) facilitate rehearsal (i.e., strengthening) of suspended task goals, whereas irrelevant interruptions do not. Furthermore, a critical difference exists between irrelevant interruptions that are similar in content (ICS) or dissimilar in content (ICD) to the suspended primary task. Specifically, while both types of interruptions lead to retroactive interference in memory, ICS interruptions provide associative activation for a suspended task goal via contextual cuing, whereas ICD interruptions do not. To illustrate the differences between these three types of interruptions, consider three separate situations in which a nurse is interrupted by R, ICS, or ICD secondary tasks while completing a data entry task. In the first situation, the nurse is interrupted by a task that requires him to fill out a supplemental report for an abnormally high blood pressure value that was being entered into the medical database in the suspended primary task. Since this interruption is requiring the nurse to recall aspects of the suspended task goal (i.e., the medical item that was being entered) and environmental context (i.e., characteristics of the medical database), MFG predicts that resumption should be relatively quicker, compared to ICS and ICD interruption. In the second situation, the nurse is interrupted by a task which requires him to report which medical items have already been entered or remain to be entered into the medical database in the suspended task. While this ICS interruption does not cause the nurse to reflect directly on the specific item that was being worked on like an R interruption, MFG predicts that the contextual cuing provides a boost in associative activation for the suspended task goal and will subsequently lead to a faster resumption, when compared to ICD interruptions. In the third situation, the nurse is interrupted by his charge nurse who has them fill out a form specifying which shifts he would prefer to work in the upcoming week. Since this interruption does not necessitate the nurse to reflect on the item that was being entered (i.e., the goal) or the general medical database from the suspended task (i.e., the task context), MFG predicts that task resumption will be relatively slower, when compared to both R and ICS interruptions.

Summary of MFG Model

As proposed by the MFG model (Altmann & Trafton, 2002), several factors are at play when operators attempt to retrieve, and subsequently resume, a suspended task goal. First, if secondary goals are encoded during the suspension of the primary goal, the increased activation from these nontarget goals interferes with the likelihood the primary goal will be retrieved when sampling declarative memory. During the period of suspension, the associated level of activation for the primary task goal will continue to decay in declarative memory in an asymptotic function. For this suspended task goal to be retrieved, and overcome the interference from newly formed goals, priming from cues can strengthen the activation of the suspended goal and direct future behavior. Taking these different factors together, the MFG model suggests that the deleterious nature of interruptions on task resumption may result from either general interference from newly encoded goals (i.e., the interruption task), decay of the primary task goal in declarative memory, and/or a lack of available associative contextual cues. However, while the MFG model has been shown to make predictions regarding the influence of secondary task relevance on primary task resumption (Gould et al., 2013), it cannot make specific predictions regarding the effects of interruptions that differ in complexity.

Time-based Resource-sharing Model

Another memory retrieval model, the Time-based Resource-sharing model (TBRS; Barrouillet et al., 2004; Plancher & Barrouillet, 2013) offers an alternate explanation of how interruptions affect task resumption. In general, the TBRS model proposes two separate components that operate within working memory: a mechanism for focusing (i.e., processing) on the highest activated task goal and a secondary mechanism for maintaining the activation levels of previously encoded task goals. However, because of attentional resource constraints on powering this dual-system, an assumption within the TBRS model is that only one mechanism can function at a time. Specifically, TBRS proposes that attentional processes switch between the two subsystems, that is, from managing a secondary task (e.g., an interruption task) to maintaining the activation for the primary task goal. A further assumption of TBRS is that as soon as attention is switched to a secondary task, the activation for the primary goal will experience time-related decay unless maintenance processes (i.e., reactivation) can occur. Barrouillet and colleagues (2007) noted that reactivation does not necessarily require a rehearsal process but can occur via covert attentional focusing (Cowen, 1992). Consequently, TBRS predicts that performance of primary task maintenance processes will be dependent on an operator's ability to rapidly shift attention back-and-forth between the newly encoded (i.e., interruption) goal to the primary task goal.

In general, TBRS proposes that the proportion of time available to perform maintenance during secondary task processing reflects the task's *processing load.* For example, the TBRS model predicts higher amounts of activation decay for a suspended task goal in situations when an interruption task inhibits task-switching (i.e., higher load), compared to situations that allowed switching (i.e., lower load). Barrouillet and colleagues (2007) conducted an experiment to examine the relationship between secondary task processing load and primary task maintenance. Participants were asked to remember an array of letters while concurrently performing a reading digit-span task (i.e., the interruption) in which the amount of time needed to read the digits was manipulated by changing their form (i.e., Arabic digits vs. dice-like configuration of dots).

As predicted by the authors, letter recall was significantly worse following the high processing load interruptions (i.e., dots), compared to the low load (i.e., Arabic numbers). This finding supported the TBRS model, such that secondary tasks that allow for less maintenance processing (i.e., higher processing load) experience higher levels of time-related decay, when compared to secondary tasks of lower load. However, previous work from Oberauer and Kliegl (2006) suggests that this finding may be confounded. Specifically, since the temporal interval between digit onset was held constant across load conditions, the additional amount of time to process secondary tasks in the high load conditions would inevitably leave less time for maintenance processing of the primary task.

To address this concern, Portrat and colleagues (2008) had participants complete a similar digit span task, except the amount of time available for primary task maintenance was held constant across conditions. Therefore, any differences in letter recall performance in the primary task would be the result of secondary task processing load and not differences in the availability of time for maintenance prior to the onset of the next digit. Even when holding maintenance time constant across conditions, results replicated those of Barrouillet et al. (2007). Specifically, the researchers found that the percentage of letters recalled in the correct order was significantly lower in the high processing load conditions, compared to the low load conditions. Therefore, these results support that it is not the amount of time available *after* secondary task processing that affects primary task maintenance, but rather the availability of maintenance opportunities *during* secondary task processing. Specifically, in the context of the TBRS model, there are fewer opportunities for rapid switching of attention between processing and maintenance subsystems during interruptions of high processing load (i.e., complexity).

Summary of TBRS

In general, the TBRS model is based on four core assumptions. First, it is assumed that two separate mechanisms operate within working memory: a mechanism for focusing (i.e., processing) on the highest activated task goal and a secondary mechanism for maintaining the activation levels of previously encoded task goals. Second, since both mechanisms make use of the same finite resource (i.e., attention), only one of the two mechanisms can execute at a given time. Third, to manage both mechanisms, processes in working memory rapidly switch attention between secondary task processing and primary task maintenance. Finally, the moment at which attention is shifted from one mechanism to another, the associated magnitude of activation will experience time-related decay.

Memory for Problem States

Whereas MFG (Altmann & Trafton, 2002) is focused on task goals and the ability to rehearse these goals during interruption, other models have been developed that also consider the specific cognitive requirements of the secondary interruption task. For example, *Memory for Problem States* (MFPS; Borst et., 2015) was developed within the ACT-R cognitive architecture and extends MFG by the adding a problem state module that is shared by both the primary and secondary interruption tasks. Originally proposed by Anderson (2005), the *problem state* is a cognitive module within ACT-R that is used to store task-relevant intermediate information. For example, when attempting to solve ‘6x+5=35’, an operator needs to store the intermediate solution ‘6x=30’ in the problem state, prior to calculating the final solution. Anderson (2005) proposed that within ACT-R, the problem state differs from the declarative memory module because problem state information is accessible without a time cost. Borst (2015) compared the problem state module with the *episodic buffer* (i.e., a limited capacity temporary storage system) in Baddeley's (1999) working memory model.

In general, the problem state module acts as a bottleneck when managing multiple tasks, as it can only hold intermediate information for one task at a time (Borst, 2015). Consequently, if the interruptive tasks require use of the problem state module, the information previously held in the problem state for the primary task is transferred to the declarative memory module, where it begins to exhibit time-based decay. Following completion of the interruption task, the primary task's problem state has to be retrieved from declarative memory. Similar to MFG, the longer the temporal interval of interruption the further the activation level of the information held in declarative memory will have decayed, and the longer resumption lag will be expected to take. Specifically, the initial activation from repeated sampling of the primary task goal will gradually decline due to an inability to maintain high rates of sampling when switching to execution of a secondary interruption task (Altmann & Trafton, 2002). However, in contrast to MFG, this increase in resumption lag will only occur if *both tasks* require a problem state. Specifically, if the secondary interruption task does not require use of the problem state module, it will not interfere with the problem state of the primary task. Therefore, MFPS leads to the prediction that the interruption task will only disrupt the primary task's problem state if it is complex enough to require its own problem state. Furthermore, MFPS makes the unique prediction that it does not matter how complex the interruption task, as long as it requires a problem state it will uniformly interfere with the primary task performance. Thus, two interruptions of differing complexity should not differentially impact primary task resumption, as long as they both require use of the problem state. As proposed by Borst and colleagues (2015), this attribute of MFPS can explain the results of Cades and colleagues (2007) who found that although a no-task interruption led to the quickest task resumption, there was no difference between a complex 1-back and a more complex 3-back interruption. Specifically, since both the 1- and 3-back interruptions required use of the problem state module, the effects on retrieving the primary task information from declarative memory following resumption were similar.

Previous research has supported this bottleneck view of the problem state module by showing that if the problem state is required by more than one task, performance is reduced in one or both tasks. For example, across two experiments, Borst and colleagues (2015) had participants solve math questions that required them to remember their position in the task following intermittent interruptions that varied in complexity. In their experiments, two types of math questions were provided: a low-complexity version that did not necessitate the participant to keep track of their position in the problem and a high-complexity version that did. Additionally, there were two types of interruptions: a 1-back task in which participants had to state if the presented letter was the same or different from the previously displayed letter (i.e., low complexity) or a 2-back task that required them to state if the presented letter matched the letter from two positions prior (i.e., high-complexity). Results found that resumption lag was significantly longer following the high-complexity 2-back task, when compared to the 1-back task. However, this difference was only found following resumption of the high-complexity math questions. Specifically, for the low-complexity math questions, resumption lag did not increase as the complexity of the interruption increased. The authors attributed this finding to the differing requirements of the problem state module for both the high complexity primary and secondary tasks. Specifically, primary task information being held in the problem state for low/low, low/high, high/low conditions did not have to be moved to declarative memory.

Therefore, in these three conditions, the problem state for the primary task did not experience time-based decay and subsequently lead to increases in resumption lag.

Additionally, Borst and colleagues (2013) investigated the effects of problem state use on resumption lag. Participants were asked to solve math questions and were periodically interrupted by a secondary text-entry task. Both the primary and interruption task varied in complexity. Each factor had two levels: either it required the participant to hold information in their memory (i.e., problem state) between tasks or not. Results found that resumption lags were significantly longer when both tasks required the user to hold information in their memory. The authors took this finding as additional support of the problem state resource originally described in ACT-R (Anderson, 2005). The authors also sought to investigate the effects of cuing support upon primary task resumption. Specifically, in some conditions, a cue was provided that was intended to help the participant recall the problem state for the suspended primary task. They found that when the cue was provided, it helped to mitigate the deleterious effects of when the both tasks require use of the problem state. While resumption lag was shorter than when no cue was provided, it did not completely eliminate the negative effects of problem state use by both tasks. Finally, it should be noted that this cue was provided upon resuming the primary task, not during the interruption. The effects of providing a task-relevant contextual cue during the period of interruption has not been previously investigated and will serve as an aim in the present study.

Summary of MFPS

In general, MFPS was developed to extend MFG by integrating findings from research aimed at the problem state bottleneck. MFPS differs from MFG because instead of focusing solely on task goal rehearsal, MFPS also considers the specific cognitive requirements for both the primary and interruptive tasks. As shown from previous research (Borst, 2015; Borst, 2013; Borst, 2010), the effect of complexity on prolonged resumption lag can be attributed to the problem state requirements of the interruption task. Specifically, the primary task's problem state will only be transferred to declarative memory and result in higher resumption costs if the interruption task also requires use of the problem state resource. Furthermore, when compared to TBRS, MFPS makes the unique prediction that two interruptions of different complexity should not differ in terms of their impact on primary task resumption, as long as they are both sufficiently complex to warrant use of the problem state to hold task-relevant intermediate information.

As previously mentioned, if the complexity of an interruption is low enough that it does not require use of the problem state resource, the primary task information currently being held in the problem state will not be transferred to declarative memory (Borst, 2013, 2015). Consequently, when complexity is low, the task goal for the suspended primary task should not experience time-based decay during relevant or irrelevant interruptions. Thus, it is expected that there will not be differences in resumption lag between relevant and irrelevant interruptions when the complexity is low (i.e., doesn't require the problem state module). Alternatively, when an interruption does require use of the problem state module, MFPS predicts that there will be differences in task resumption between relevant (R), irrelevant but similar in content (ICS), and irrelevant and content dissimilar (ICD) interruptions. Specifically, MFPS predicts that the rehearsal of task goal information during R interruptions will lead to significantly faster resumption, when compared to ICS and ICD interruptions. Additionally, MFPS predicts that task resumptions will be significantly faster following ICS interruptions, when compared to ICD interruptions. Specifically, while both types of interruptions lead to retroactive interference in memory, ICS interruptions provide associative activation for a suspended task goal via contextual cuing, whereas ICD interruptions do not (Altmann & Trafton, 2002).

Overview of Primary Task Resumption Models

Although the MFG, TBRS, and MFPS models (Altmann & Trafton, 2002; Borst et al., 2015; Barrouillet et al., 2004; Plancher & Barrouillet, 2013) share some predictions regarding task resumption following interruption, clear differences exist between the three models. For example, whereas all three models predict that a primary task goal will exhibit time-based decay following the onboarding of a secondary interruptive task, only the MFG and MFPS models make predictions regarding the availability of external associative cuing on resumption processes. Specifically, if a task interruption provides some type of cuing information that can refresh activation for the goal of the suspended primary task, it is predicted that resumption time should be quicker than when no such cue is provided.

The MFG model proposes that task resumption is affected by the magnitude of retroactive interference that has been generated by newly encoded interruption tasks. Specifically, if the relative activation of a newly formed goal (e.g., interruption task) is greater than the relative activation for a suspended primary task goal, then it is predicted that this interference will lengthen the time needed to reorient to the primary task goal and subsequently resume the task. Therefore, MFG would predict that interruptions irrelevant to the primary task will lead to greater interference and slower primary task resumption, when compared to relevant interruptions. Specifically, MFG predicts that relevant interruptions facilitate the strengthening of primary task goals. Alternatively, irrelevant interruptions lead to retroactive interference because they may reflect certain steps of the task that have either been completed or not yet performed (Gould et al., 2013). Additionally, irrelevant interruptions may hinder task resumption because they provide no cuing information that may facilitate rehearsal of suspended task goals, when compared to relevant interruptions (Altmann & Trafton, 2002). However, MFG does not make clear predictions regarding how altering the complexity of the interruption will affect this resumption process. Instead, it just implies that general interference will occur.

Alternatively, the TBRS model has been able to predict the effects of increased complexity on prolonged resumption lags (i.e., inhibited maintenance processing of suspended tasks). In general, the TBRS model assumes that efficient task resumption is dependent on the ability to execute rapid, sequential maintenance processes managing an interruption. For example, if the complexity of the interruption task is too high, TBRS suggests that primary task maintenance will be inhibited and result in prolonged task resumption. Thus, TBRS predicts that more complex interruptions will lead to longer task resumption times, when compared to less complex interruptions. While the TBRS model has been able to predict the effects of increased complexity on prolonged resumption lags (i.e., inhibited maintenance processing of suspended tasks), it cannot explain the effect of relevance.

Interestingly, it appears the MFPS model can offer a potential explanation for both the effects of complexity and relevance on resumption lag. In general, MFPS was developed to extend MFG by integrating research findings from the problem state bottleneck. MFPS differs from MFG because instead of focusing solely on task goal rehearsal, MFPS also considers the specific cognitive requirements for both the primary and interruptive tasks. As shown from previous research (Borst, 2013, 2015), the effect of complexity on prolonged resumption lag can be attributed to the problem state requirements of the interruption task. Specifically, the primary task's problem state will only be transferred to declarative memory and result in higher resumption costs, if the interruption task also requires a problem state. Furthermore, when compared to TBRS, MFPS makes the unique prediction that two interruptions of different complexity should not differ in terms of their impact on primary task resumption, as long as they are both sufficiently complex to warrant use of the problem state. Finally, since MFPS extends on MFG, it also holds promise for addressing the effects of relevance. Specifically, relevant interruptions (R) interruptions facilitate rehearsal (i.e., strengthening) of suspended task goals, whereas irrelevant interruptions do not. Additionally, while irrelevant interruptions lead to retroactive interference in memory, irrelevant interruptions of similar content (ICS) provide associative activation for a suspended task goal via contextual cuing, whereas irrelevant interruptions of dissimilar content to the primary task (ICD) do not. Therefore, whereas R interruptions may reduce the amount of time needed to resume the suspended task, ICS and ICD may increase the amount of time. However, MFPS predicts that ICS interruptions will have significantly faster resumption, when compared to ICD interruptions.

Goals of this Research

To investigate the interactive effects of interruption complexity and relevance on primary task resumption, this relationship was examined in the context of goal-based models (MFG; Altmann & Trafton, 2002), maintenance-inhibition models (TBRS; Barrouillet, 2007), and problem-state models (MFPS; Borst et al., 2015). While the theoretical explanations of interruption complexity and relevance on task resumption put forth by MFG, MFPS, and TBRS may not be mutually exclusive, previous research has yet to disassociate the relative magnitude of each on their predictions regarding task resumption following interruption. Therefore, the goal of the present study was to examine if manipulating characteristics of interruption relevance and complexity would lead to differential decrements in primary task resumption speed.

CHAPTER II

PRESENT STUDY

In the present study, undergraduate students completed a computer-based medical data entry task. Participants viewed medical patient charts (Appendix A) and used a keyboard to enter numerical values from these charts into a fictional medical record database (Appendix B). During execution of the primary task, participants were unexpectedly interrupted by secondary tasks that varied in task relevance and complexity. Following completion of the interruption, participants were tasked with resuming the data entry task exactly where they were working, prior to interruption. The present study employed a 3x3 within-subjects design. The first within-subjects factor was interruption complexity and had three levels: low (blank screen), moderate (1-back), and high (2-back). The second within-subjects factor was the relevance of the interruption to the primary task and had three levels: relevant (R), irrelevant but similar in content (ICS), and irrelevant and dissimilar in content (ICD). The primary dependent measures of interest were resumption lag and perceived mental demand.

The present study had six primary hypotheses. As suggested by the MFG (Altmann & Trafton, 2002) and MFPS (Borst, 2015) models, task interruptions generate retroactive interference and facilitate time-related decay of primary task goals in declarative memory. Moreover, if an interruption is irrelevant to the temporarily suspended primary task, MFG predicts that a greater magnitude of interference will occur, when compared to relevant interruptions. Therefore, the first hypothesis was that resumption lags would be significantly longer following ICS and ICD interruptions, when compared to R interruptions. Additionally, MFG predicts that ICD interruptions would lead to greater interference than ICS interruptions. Specifically, whereas interruptions that are similar in content to the primary task offer contextual information that may be used to boost associative activation of the suspended task goal, interruptions that are dissimilar to the primary task do not. Therefore, the second hypothesis was that resumption lags would be significantly longer following ICD interruptions, when compared to ICS interruptions.

The third hypothesis regarded the alternative predictions made by the Time-based Resource-Sharing (Barrouillet, 2007) and Memory for Problem States (Borst, 2015) models on the effects of interruption complexity. On the one hand, TBRS states that task interruptions limit the amount of opportunities for an individual to perform maintenance processing of suspended primary task goals. In general, the more attentional resources that an interruptive task requires, the less opportunities there will be for maintenance processing to occur. Thus, TBRS predicts that resumption lags would be significantly longer following high complexity interruptions, compared to low and moderate complexity interruptions. On the other hand, MFPS assumes that an interruption task will only disrupt the primary task's problem state if it is complex enough to require its own problem state. Specifically, it does not matter how complex an interruption task is, as long as it requires use of the problem state resource it will interfere with the primary task performance. Thus, according to MFPS, the fourth hypothesis is that moderate (1-back) and high (2-back) complexity interruptions would not significantly differ in their effects on resumption lag. Thus, the goal is to evaluate these competing hypotheses.

Next, based on the core assumption of TBRS that attention is rapidly switched between primary task goal maintenance and management of the interruptive task, it was predicted that greater perceived mental demand would occur following the management of complex interruptions. Specifically, since greater attentional demand would be placed on participants during secondary tasks that are higher in complexity, it was predicted that participants would report greater perceived mental demand following completion of the primary task trial. Therefore, the fifth hypothesis was that interruptions of high complexity would lead to significantly greater perceived mental demand scores, when compared to moderate and low complexity interruptions. Finally, as previously described, the MFPS model predicts an interaction between relevance and complexity. Specifically, if the complexity of an interruption is low enough that it does not require use of the problem state resource, the primary task information currently being held in the problem state will not be transferred to declarative memory (Borst, 2013, 2015). Consequently, when complexity is low, the task goal for the suspended primary task should not experience time-based decay during R, ICS, and ICD interruptions. Thus, it was expected that R, ICS, ICD interruptions *would not result* in significant differences in resumption lag when the complexity is low. Alternatively, it was expected that R, ICS, and ICD interruptions *would result* in significant differences in resumption lag when the complexity is moderate or high. Therefore, the sixth hypothesis was that the effect of interruption relevance on resumption lag would depend on the magnitude of complexity. Specifically, the R, ICS, and ICD conditions would not differ in resumption lag when the interruption task does not impose demands on working memory (i.e., low complexity), but would differ when the interruption requires working memory (i.e., moderate and high complexity).

CHAPTER III

METHOD

Participants

To determine an appropriate sample size for the present study, a power analysis was conducted using the G*Power software. Although an initial pilot test with 8 participants (see below) was sufficient for detecting main effects of interruption complexity and relevance on resumption lag, this sample size was not sufficient for achieving enough statistical power to find an effect for the predicted interaction. Thus, based on the results of this pilot test, a power analysis was conducted to allow for detection of the observed interaction effect (partial $\eta 2$ = .223) with $\alpha = .05$, power = .80, and a modest correlation among repeated measures = .25. The results suggested a sample size of 35. All participants were at least 18 years of age. All participants had normal or corrected-to-normal vision. Finally, all participants provided written informed consent and this study was approved by the Institutional Review Board at Old Dominion University.

Primary Task

In the present study, participants completed a computer-based medical data entry task. Specifically, participants used a mouse and keyboard to enter medical information from digital patient charts (Appendix A) into a medical record database (Appendix B). Both the patient chart and the database were visible on the same monitor (Appendix C). Participants completed nine trials of the data entry task, each lasting five minutes in temporal duration.

During execution of this primary task, participants were interrupted unexpectedly by secondary tasks that differed in both complexity and relevance to the primary task. A total of three interruptions occurred in each of nine primary task trials. Each interruption lasted for a total of eighteen seconds. The selection of this temporal duration was based on previous work that showed the majority of the "cost" of an interruption on working memory occurs within the first thirty seconds (Gillie & Broadbent, 1989; Altmann & Trafton, 2002). The onset of the interruption was controlled by the researcher and occurred when the participant was entering information into an item box. This moment of onset was selected based on previous research (Adamczyk & Bailey, 2004; Iqbal et al., 2005; Iqbal et al., 2006) which showed that interruptions are more detrimental to performance when they occur during completion of a task, when compared to interruptions that occur in between task steps. The temporal interval between the offset of the interruption and the selection of the item box that was being worked on prior to interruption (i.e., resumption lag), was the primary dependent measure.

Interruption Complexity

Interruption complexity has been defined as the processing demands placed on working memory that can facilitate or impair rehearsal of suspended task goals (Monk et al., 2008). In the present study, participants were interrupted with a modified n-back task (Borst, 2015; Kirchner, 1958). Specifically, they were interrupted by either a blank screen (low complexity), 1-back (moderate complexity), or 2-back (high complexity) task modeled on the procedure used by Monk et al. For the n-back task, participants were presented with a sequential stream of numbers, each for 1000ms followed by a mask of 1000ms. They responded vocally either "yes" or "no" if the current number matched the number either 1-back or 2-back, depending on the condition. Additionally, at the beginning of each n-back interruption, a title of “1-back” or “2-back” was presented for 2000ms to indicate which response was required. For each moderate and high complexity interruption, the interface displayed one title, eight digits and eight masks over the eighteen seconds of temporal duration. For the low complexity interruption, only a blank screen was visible, with the mask presented every 1000ms over the eighteen seconds of temporal duration. These values were adapted from Borst (2015) and were selected to allow for enough time to perceive the stimuli and respond vocally, but not so long as to provide additional opportunities to rehearse the suspended primary task goal and context. It should be noted that this instantiation of the n-back task differs slightly from previous research. Specifically, instead of waiting until the end of a string of digits for a participant to provide a response to a question (e.g., “what was the number shown two screens prior?”), the present study required participants to continually respond vocally to the presented stimuli throughout the entirety of the task. In general, the n-back method used in the present study allowed for greater control of the demand on working memory throughout the interruption task.

Interruption Relevance

In the present study, participants were interrupted by secondary tasks that were relevant (R), irrelevant but similar in content (ICS), or irrelevant and dissimilar in content (ICD) to the suspended primary task. This factor was varied by manipulating the mask which was displayed every 1000ms in each secondary interruption task.

For the R condition (Appendix D), the mask always displayed the name of the item box that was previously being worked on prior to interruption. For example, if a participant was interrupted following selection of the Oxygen item box, each mask displayed throughout the interruption displayed the word “Oxygen”.

For the ICS condition (Appendix E), the mask always displayed the name of an item box that had been or had not yet been completed. For example, if the participant selected the Oxygen item box prior to the onset of the interruption, the mask would cycle through the remaining eight item box categories (see Appendix A).

Finally, for the ICD condition (Appendix F), the mask always displayed an arbitrary name related to automobiles (e.g., tire). For example, if the participant selected the Oxygen item box prior to the onset of the interruption, the mask would cycle through eight words related to automobile characteristics (Appendix G).

Task Design

The priming constraint element of Memory for Goals (Altmann & Trafton, 2002) suggests that task steps serve as associative cues for the subsequent step. Thus, if the order of steps in the primary task is fixed, participants would be able to leverage this potential cue to aid task resumption. To address this, and the potential visual cuing confounds in Gould (2013) and Pankok and colleagues (2017), all potential associative cues in the interface were minimized or eliminated. Specifically, following the offset of an interruption task, any previously entered information in the item boxes was deleted and the mouse cursor was reset to the upper-left region of the screen. Therefore, following the interruption, participants had to identify the item category in the patient chart that they were about to enter into the database with limited aid from external visual cues.

Dependent Measures

The dependent measures of interest in the present study were resumption lag and perceived mental demand. First, to measure the amount of time needed to accurately resume the primary task following the offset of an interruption (i.e., resumption lag), screen recording software allowed for millisecond-level calculation of this time interval for each trial. Next, to assess perceived mental demand and frustration following each trial, participants were asked to complete a NASA-Task Load Index (Appendix H; NASA-TLX; Hart & Staveland, 1988). The present study chose not to examine subjective levels of physical demand, temporal demand, perceived performance and effort because there was no theoretical support that interruption relevance and complexity would affect these subscale measures. Participants were required to indicate their scores on an interval scale with values ranging from 1 to 20. The NASA-TLX has been shown to have strong internal, convergent, and concurrent validity (Rubio et al., 2004), along with high levels of test/re-test reliability (Hart et al., 1988).

Finally, as a manipulation check to verify that participants were completing the primary and secondary tasks accurately, the number of resumption errors (i.e., resuming the incorrect item) and interruption task errors (i.e., errors in the 1-back and 2-back tasks) were recorded. Specifically, all erroneous resumptions were excluded from the resumption lag dataset; thus, resumption lags were only measured for *correct* resumptions. Additionally, if a participant made three or more errors in the interruption task, that resumption was excluded from the resumption lag dataset. Although the present study did not make formal predictions regarding resumption errors and task interruption errors, it was expected that more errors would occur as the complexity of the interruption task increased.

Procedure

Participants first read and signed an informed consent form (see Appendix I) and a demographic questionnaire (Appendix K). To begin, participants were provided with written instructions (Appendix J) and time was given to clarify any potential questions. Next, participants completed a five-minute practice trial of the primary task, during which they could ask questions and gain familiarity with the data entry procedure. All participants were interrupted by every condition during the practice trial. Following the interruption, participants were instructed to use the mouse to select the item box that they were working on prior to the onset of the secondary interruption task. When the participant filled out all of the remaining item boxes in the database, they were instructed to press the “Submit” button. This action reset the entered values in the database and generated a new patient chart for the data-entry task to continue. After the practice session, participants were reminded of the importance of accurately completing any secondary tasks that may occur during the primary data-entry task and secondary task. Importantly, the task instructions did not describe these secondary tasks as “interruptions”, so as to not bias the participant into allocating more effort into the task than they would otherwise.

Participants then completed nine trials of the primary data entry task. During each trial, participants were interrupted three times, at predefined points, in which they were asked to complete the secondary tasks that differed in relevance and complexity. To control for potential order effects, the sequence of interruptions for the 36 participants was counterbalanced via a nine-element Latin square design that was repeated four times (Appendix L). Following each trial, participants completed a NASA-TLX questionnaire. Therefore, each participant was interrupted a total of twenty-seven times and provided nine NASA-TLX ratings over the course of the study. After completion of all trials, the researcher led a five-minute semi-structured interview (Appendix M) with the participant to gather additional qualitative data.

Pilot Testing

Employing the proposed methodology, a pilot test using eight undergraduate students was conducted to assess the effects of interruption complexity and relevance on task resumption lag and perceived mental demand. The effect of interruption complexity was shown to lead to significant differences in primary task resumption lag, F (2, 14) = 57.85, p <.001, partial η^2 = .891. Post hoc tests found that the low complexity condition (M=4.03) had significantly shorter resumption lags than the moderate complexity (M=5.72) and high complexity conditions (M= 5.99). The moderate and high complexity conditions were not found to differ significantly.

The effect of interruption relevance fell short of achieving significance in primary task resumption lag, F (2, 14) = 3.13, p = .075, partial η^2 =. 309. Post hoc tests found that relevant interruptions (M=4.80) reported faster resumption lags than the irrelevant but content similar interruptions (M=5.45) and irrelevant but content dissimilar (M= 5.48) interruptions.

The results also showed a trend toward an interaction between interruption relevance and complexity on resumption lag, F (4, 28) = 2.01, p = .120, partial η^2 =. 223. These preliminary results showed support for the hypothesis that the effect of interruption relevance on resumption lag depends on complexity. Specifically, the three relevance groups (R, ICS, ICD) should not differ in resumption lag when the interruption does not require working memory (i.e., low complexity). Regarding perceived mental demand, there was a significant effect of interruption complexity, F (2, 14) = 17.73, p < .001, partial η^2 = .717. Post hoc tests found that mental demand in the high complexity condition (M=10.00) was significantly higher than the moderate complexity condition (M=8.23), and the moderate complexity condition was significantly higher than the low complexity condition (M=5.43).

CHAPTER IV

RESULTS

Data Treatment

A total of 38 participants were recruited from undergraduate psychology classes at Old Dominion University. Two participants were excluded from data analysis because of failure to follow task instructions. The final sample of 36 participants consisted of 11 male and 25 female students with a mean age of 20.14 ($SD = 3.32$). Prior to statistical analyses, all data were checked for outliers and any extreme values (+/-3 SD from the mean) were replaced with the group mean. In total, two ICD moderate, two ICS moderate, and one ICD low trials were identified and replaced with the respective group mean. A Shapiro-Wilks test was used to assess normality and it was found that the data were unimodal and normally distributed. Finally, a Mauchly's test of sphericity was used to determine that the variability in the differences between all possible pairs of within-subject conditions were equal and Greenhouse-Geisser corrections were applied to all tests in which this assumption was violated. Finally, pairwise comparisons of any mean differences were also analyzed with Bonferroni-corrected degrees of freedom.

Statistical Analyses

To assess the effects of interruption relevance and interruption complexity on resumption lag and perceived mental demand, separate 3 x 3 repeated-measures analyses of variance (ANOVAs) were conducted. The independent variable of interruption relevance had three levels: relevant (R), irrelevant and similar in content (ICS), and irrelevant and dissimilar in content (ICD). The independent variable of complexity had three levels: low (i.e., blank screen), moderate (i.e., 1-back), and high (i.e., 2-back). The dependent variable of resumption lag was operationalized by the amount of time it took for participants to resume the primary data entry task following the offset of the interruption task. Perceived mental demand was reported via the NASA-TLX following the completion of each trial in the primary task. Separate 3 x 3 repeated-measures ANOVAs were also conducted for resumption errors and perceived frustration. Finally, a 2 x 3 repeated-measures ANOVA was conducted for interruption task errors.

Resumption Lag

The ANOVA for resumption lag is shown in Table 1 and the results are shown in Figure 4. In general, the analysis found a significant main effect for both interruption relevance and interruption complexity. The assumption of sphericity was violated for the relevance by complexity interaction term and the Greenhouse-Geisser correction was applied. The interaction between interruption relevance and complexity on resumption lag was not significant. These results suggest that the effect of interruption relevance on task resumption lag did not depend on task complexity. However, the statistical power for the interaction (*power* = 0.61) may have been insufficient for detecting the predicted effect.

Table 1

Results of the Analysis of Variance for Interruption Relevance and Complexity on Resumption Lag

	SS	df	MS	*F*	*p*	partial η^2
Relevance	8.27	2	4.13	5.60	*.006	0.14
Error	51.67	70	0.74			
Complexity	68.09	2	34.05	29.12	**.001	0.46
Error	79.672	70	1.14			
Relevance x Complexity	6.66	2.84	2.34	2.08	.111	0.56
Error	112.21	99.51	1.13			

Note. * $p < .05$, ** $p < .001$

The main effects were examined for differences among the means. Pairwise comparisons revealed that participants resumption lags were significantly longer ($p < .05$) following ICD interruptions (M = 4.43, SE = 0.10), when compared to R interruptions (M = 4.04, SE = 0.08). However, it was found that the ICS (M = 4.28, SE = 0.10) interruptions did not significantly differ from R ($p = .17$) and ICD ($p = .66$) interruptions in primary task resumption lag.

Regarding interruption complexity, pairwise comparisons revealed that participant resumption lags were significantly longer ($p < .05$) following high complexity interruptions (M = 4.82, SE = 0.12), when compared to moderate complexity (M = 4.24, SE = 0.12) and low complexity interruptions (M = 3.69, SE = 0.07). Additionally, participants resumption lags were significantly longer ($p < .05$) following moderate complexity interruptions, when compared to low complexity interruptions.

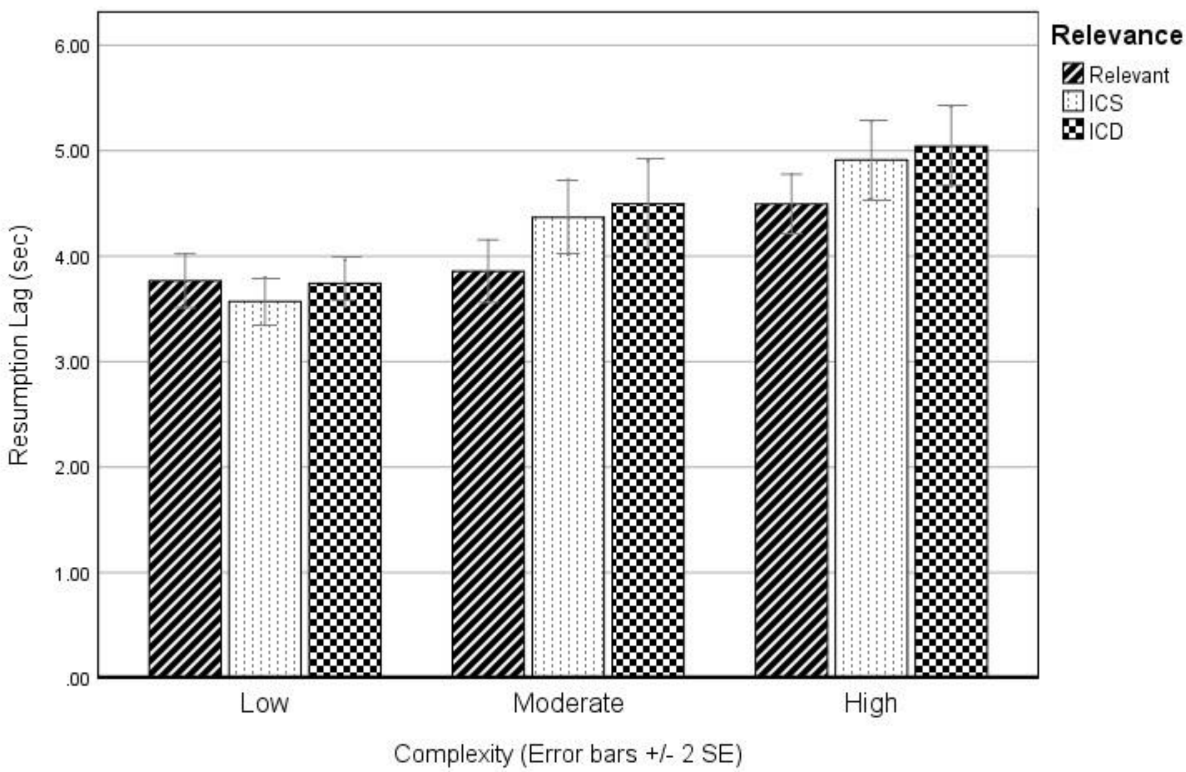

Figure 4. *Mean Resumption Lag (in sec) for Interruption Relevance and Complexity*

Finally, to examine if participants exhibited a speed-accuracy tradeoff in the present study, resumption lag times for correct and erroneous resumptions were compared. Although there were too few resumption errors to allow for statistical analysis, a comparison of the means for correct and erroneous resumptions for each complexity condition fell within overlapping SDs. Thus, there was no compelling evidence that participants sacrificed speed for accuracy across conditions in the present study.

Perceived Mental Demand

The ANOVA for perceived mental demand ratings from the NASA-TLX is shown in Table 2 and the results are shown in Figure 5. The assumption of sphericity was violated for both the complexity factor and the relevance by complexity interaction term and the Greenhouse-Geisser corrections were applied. In general, the analysis found a significant main effect for both interruption relevance and interruption complexity. The interaction between interruption relevance and complexity on perceived mental demand was not significant. Again, these results suggest that the effect of interruption relevance on perceived mental demand did not depend on interruption complexity.

A closer examination of the main effects was performed. Pairwise comparisons revealed that participants reported significantly higher ($p < .05$) perceived mental demand following ICS (M = 9.89, SE = 0.65) and ICD interruptions (M = 9.94, SE = 0.59), when compared to R interruptions (M = 8.89, SE = 0.65).

Table 2

Results of the Analysis of Variance for Interruption Relevance and Complexity on Perceived Mental Demand

	SS	df	MS	*F*	*p*	partial η^2
Relevance	74.77	2	37.38	6.99	*.002	0.17
Error	374.12	70	5.35			
Complexity	2201.15	1.42	1553.51	73.53	**.001	0.68
Error	1047.74	49.59	21.13			
Relevance x Complexity	5.24	3.25	1.61	0.29	0.84	0.01
Error	616.54	113.62	5.43			

Note. * $p < .05$, ** $p < .001$

However, the ICS and ICD interruptions did not differ (p =.99) in perceived mental demand ratings. Regarding interruption complexity, pairwise comparisons showed that participants reported significantly higher ($p < .01$) perceived mental demand following high complexity interruptions (M = 12.26, SE = 0.74), when compared to moderate complexity (M = 10.43, SE = 0.64) and low complexity interruptions (M = 6.05, SE = 0.65). Additionally, participants reported significantly higher ($p < .01$) mental demand ratings following moderate complexity interruptions, when compared to low complexity interruptions.

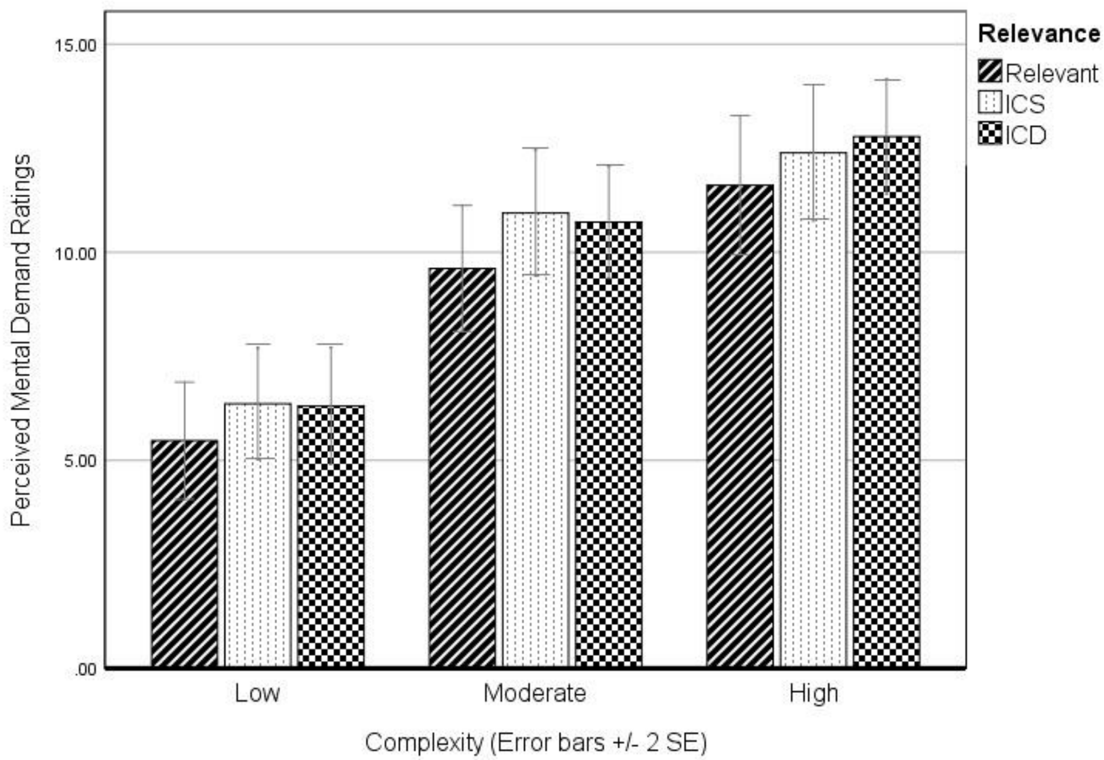

Figure 5. *Mean Perceived Mental Demand for Interruption Relevance and Complexity*

Resumption Errors

As a secondary analysis in the present study, the number of times that a participant resumed the data entry task in the incorrect location (i.e., resumption error) was assessed. The ANOVA for the amount on resumption errors is shown in Table 3. In general, the analysis found a significant main effect for interruption complexity. Interruption relevance did not significantly influence the amount of resumption errors. Additionally, the interaction between interruption relevance and complexity on resumption errors was not significant. Pairwise comparisons among the means for complexity revealed that participants, on average, committed significantly fewer resumption errors following low complexity interruptions ($M = 0.16$, $SE = 0.04$), when compared to moderate complexity (M = 0.58, SE = 0.09) and high complexity interruptions (M = 0.65, SE = 0.08). However, moderate and high complexity interruptions did not significantly differ in the amount of resumption errors.

Table 3

Results of the Analysis of Variance for Interruption Relevance and Complexity on Resumption Errors

	SS	df	MS	*F*	*p*	partial η^2
Relevance	1.71	2	0.86	3.05	0.05	0.08
Error	19.63	70	0.28			
Complexity	15.12	2	7.56	25.34	**.001	0.42
Error	20.88	70	0.30			
Relevance x Complexity	1.96	4	0.49	1.77	0.14	0.05
Error	38.71	140	0.28			

Note. * $p < .05$, ** $p < .001$

Interruption Task Errors

Interruption task errors were measured by the number of times participants committed an error in the 1-back and 2-back tasks (i.e., interruption task error). The ANOVA for interruption task errors is shown in Table 5. In general, the analysis found a significant main effect for interruption complexity. Interruption relevance was not found to significantly influence the number of errors made during the interruption task nor did relevance interact with complexity. Pairwise comparisons revealed that participants, on average, committed significantly fewer errors during the 1-back interruption task (i.e., moderate complexity; M = 0.34, SE = 0.07), when compared to the 2-back interruption task (i.e., high complexity; M = 0.50, SE = 0.09).

Table 5

Results of the Analysis of Variance for Interruption Relevance and Complexity on Interruption Task Errors

	SS	df	MS	*F*	*p*	partial η^2
Relevance	0.37	2	0.19	0.81	0.45	0.02
Error	16.11	70	0.23			
Complexity	1.42	1	1.42	5.78	*.02	0.14
Error	8.61	35	0.25			
Relevance x Complexity	0.08	2	0.04	0.13	0.88	0.04
Error	20.03	40	0.29			

Note. * $p < .05$, ** $p < .001$

Perceived Frustration

The ANOVA for perceived frustration ratings from the NASA-TLX is shown in Table 6. The assumption of sphericity was violated for the complexity factor and the Greenhouse-Geisser correction was applied. The analysis found a significant main effect for interruption complexity. Interruption relevance was found to not significantly influence perceived frustration ratings and the interaction between interruption relevance and complexity was not significant. A closer examination of the main effects for complexity was performed. Pairwise comparisons revealed that participants reported significantly lower ratings of perceived frustration following the low complexity interruption (M = 3.75, SE = 0.54) when compared to the moderate complexity (M = 7.01, SE = 0.65) and high complexity (M=8.12, SE = 0.73) interruptions. Moreover, participants reported significantly lower ratings of perceived frustration following the moderate complexity interruption, when compared to the high complexity interruption.

Table 6

Results of the Analysis of Variance for Interruption Relevance and Complexity on Perceived Frustration

	SS	df	MS	*F*	*p*	partial η^2
Relevance	32.67	2	16.34	2.15	0.12	0.06
Error	532.44	70	7.61			
Complexity	1132.89	1.41	803.55	41.76	**.001	0.54
Error	949.55	49.35	19.24			
Relevance x Complexity	19.46	4	4.86	0.72	0.58	0.02
Error	947.43	140	6.77			

Note. * $p < .05$, ** $p < .001$

Debrief Interviews

Following the completion of the full experimental session, a semi-structured interview (Appendix M) was conducted with each participant to gather additional qualitative data. In general, these interviews sought to identify the specific strategy that participants employed to aid task resumption and the perceived differences between the various relevance and complexity conditions. Participants reported a few different strategies for remembering where to resume the data entry task following interruption. The majority of participants (N=30) reported that they attempted to employ a rote rehearsal strategy throughout the interruption task. However, 24 participants reported that the high complexity interruptions significantly impaired their ability to remember where to resume the primary task, when compared to moderate and low complexity interruptions. Alternatively, a few participants (N=3) reported not using a rote rehearsal strategy. For example, one participant reported that she would continuously take deep breaths throughout the interruptions task if she had to resume at the "Oxygen" location. Finally, a few participants (N=3) reported that they relied on guessing where to resume the task.

In regard to the relevance manipulation, a majority of participants reported that they would tend to ignore the words (i.e., the mask) presented during the interruption task if it did not represent the item that they were working on prior to suspension of the primary task. Specifically, they would disregard the words shown during ICS and ICD interruptions. By contrast, participants reported that they would use the R interruption as an aid for remembering the item in the primary task where they were supposed to resume. Moreover, these participants reported that this aid improved their ability to resume the task in the correct location.

CHAPTER V

DISCUSSION

The purpose of the present study was to investigate the effects of interruption relevance and complexity on performance of a data entry task. Specifically, the goal was to examine if manipulating characteristics of interruption relevance and complexity would lead to differential decrements in primary task resumption speed and perceived mental demand. Additionally, the present study sought to employ a novel experimental design to address limitations and mixed findings from previous research. The following sections will discuss the main findings from the present study in relation to previous research and the a priori hypotheses.

Relevance and Resumption Lag

Previous research has documented mixed findings on the effects of interruption relevance on task resumption lag following interruptions. Thus, a primary aim of the present study was to examine this relationship. The effects of interruption relevance on resumption lag in the present study were informed by the Memory for Goals model (MFG; Altmann & Trafton, 2002). Specifically, MFG predicts that task interruptions generate retroactive interference of primary task goals in declarative memory. Moreover, if an interruption is irrelevant to the temporarily suspended primary task, MFG predicts that a greater magnitude of interference will occur when compared to relevant interruptions. Consequently, a greater level of activation for the suspended task goal would be required to overcome interference from task-irrelevant interruptions when compared to task-relevant interruptions. Therefore, the first hypothesis was that resumption lags would be significantly longer following irrelevant interruptions, when compared to relevant interruptions. This hypothesis was supported in the present study. Specifically, participants resumed the suspended data entry task significantly faster following relevant interruptions, when compared to interruptions that were irrelevant. This finding aligns with previous research conducted by Czerwinski and colleagues (2000) and Gould (2013) who both examined the effects of task-relevant and irrelevant interruptions on primary task resumption lag. In the study by Czerwinski and colleagues (2000), participants completed a computer-based task which required them to perform a web search for prespecified target content. During task execution, participants were interrupted by either a task-relevant message regarding the suspended task or a task-irrelevant message about the webpage they were currently viewing. Their results showed that the amount of time needed to resume the suspended primary task (i.e., resumption lag) was significantly longer for task-irrelevant messages. The authors proposed that task-irrelevant interruptions led to greater interference which required more time to reestablish activation for the task goal, when compared to task-relevant messages. Additionally, in the study by Gould and colleagues (2013), participants were unexpectedly interrupted by secondary tasks that were either relevant (e.g., “what subtask did you just complete?) or irrelevant (e.g., “which subtask label is this?) to the suspended primary task. They found significantly longer resumption lags following task-irrelevant interruptions, when compared to relevant interruptions. Within the context of MFG, these findings can be interpreted from a general retroactive interference account. Specifically, task-irrelevant interruptions generated greater retroactive interference, thereby increasing the amount of time needed to build activation for the suspended task goal and subsequently resume the primary task, when compared to relevant interruptions.

Additionally, the present study predicted that ICD interruptions would lead to greater interference than ICS interruptions. Specifically, interruptions that are similar in content to the primary task offer contextual information that may be used to boost associative activation of the suspended task goal. By contrast, interruptions that are dissimilar to the suspended task offer no such information. Therefore, the second hypothesis in the present study was that resumption lags would be significantly longer following ICD interruptions, when compared to ICS interruptions. This hypothesis, however, was not supported. Specifically, it was found that resumption lags following ICS and ICD interruptions did not differ significantly. Although this second hypothesis was not supported in the present study, this finding aligns with previous research by Latorella (1999) who investigated the effects of interruption similarity on performance of a simulated flight deck aviation task. In her study, there were no significant differences in resumption lag following similar and dissimilar interruption conditions. Moreover, Latorella (1999) found that the amount of errors between similar and dissimilar groups also did not differ. An analysis of errors in the present study also revealed that the number of errors made in both the primary task and the secondary interruption task did not differ between the content similar and dissimilar conditions.

It is important to note that other researchers have made alternative predictions regarding the effects of ICS and ICD interruptions on resumption lag. For example, Li and colleagues (2012) predicted that ICS interruptions should result in longer task resumption lags when compared to ICD interruptions. Specifically, the authors argued that greater interference should occur following ICS interruptions because they share task characteristics with the suspended primary task. Thus, when an individual attempts to retrieve a suspended task goal, the ICS interruption would to greater interference, when compared to an ICD interruption. For example, Li and colleagues (2012) would predict that resumption of the primary data entry task employed in the present study would be significantly slower following an interruption that shares task characteristics, when compared to a dissimilar task. However, since the present study found no differences between ICS and ICD interruptions on primary task resumption lag, this alternative prediction was also not supported.

Complexity and Resumption Lag

Previous research has documented mixed findings on the effects of interruption complexity on task resumption lag following an interruption. Thus, a primary aim of the present study was to re-examine this relationship. The expectations regarding interruption complexity on resumption lag were informed by the Time-based Resource-Sharing (TBRS; Barrouillet, 2007) and Memory for Problem States (MFPS; Borst, 2015) models. In general, the TBRS and MFPS models offered alternative predictions on the relationship between interruption complexity and resumption lag. On the one hand, TBRS proposes that task interruptions limit the amount of opportunities for an individual to perform maintenance rehearsal processing of suspended primary task goals. Moreover, the more attentional resources that an interruptive task requires, the fewer resources there will be for rehearsal. Thus, TBRS predicts that resumption lags would be significantly longer following high complexity interruptions, when compared to moderate and low complexity interruptions, because less attentional resources would be available to facilitate rehearsal in the former condition. On the other hand, MFPS proposes that an interruption task will only disrupt the primary task’s problem state if it is complex enough to require its own problem state. Specifically, it does not matter how complex an interruption task is, as long as it requires use of the problem state resource it will interfere with the primary task performance. Thus, MFPS predicts that moderate (1-back) and high (2-back) complexity interruptions would not significantly differ in their effects on resumption lag. In general, results from the present study support the predictions made by TBRS. Specifically, participants took significantly longer to resume the primary data entry task following high complexity interruptions, compared to moderate and low complexity interruptions. This finding aligns with previous research Monk and colleagues (2008) and Hodgetts and Jones (2005, 2006).

As noted earlier, Monk and colleagues (2008) found an effect of complexity on primary task resumption lag in their study in which participants were interrupted during a visuospatial VCR programming task. The interruptions in their study were either a blank screen (i.e., low complexity), a tracking task (i.e., moderate complexity), or a 1-back task (i.e., high complexity). Results showed that resumption lags were significantly longer following the high-complexity 1-back task. Moreover, resumption lags were longer following the moderate complexity tracking task, when compared to the low complexity blank screen interruption. The authors proposed that as the complexity of the interruption increased, there was a greater demand on attentional resources and subsequently fewer resources available to rehearse the suspended primary task goals. In similar studies, Hodgetts and Jones (2005, 2006) also found evidence for complexity effects on task resumption times following interruptions of a visuospatial task. Participants were unexpectedly interrupted by either a low complexity task (i.e., a mood questionnaire) or a high complex task (i.e., a verbal reasoning task). Their results showed that task resumption times were faster following the low complexity interruption, when compared to the high complexity interruptions. The authors proposed that the additional mental demand required by complex interruptions led to longer resumption lags. However, as noted by the authors, this result may have been confounded by not controlling for the duration of the interruption in both the simple and complex conditions. This potential confound was addressed in the present study by holding the duration of all interruption's constant. Specifically, the blank screen (i.e., low complexity), 1-back (i.e., moderate complexity), and 2-back (i.e., high complexity) interruptions were all held to 18 seconds in duration.

It is important to note that the effects of interruption task complexity on primary task resumption lag have not been consistent. For example, Pankok and colleagues (2017) found no evidence of prolonged resumption lags following interruptions of varying complexity in a procedural Lego assembly task. Specifically, participants were unexpectedly interrupted by an additional assembly task that used either one type of Lego brick (i.e., simple) or a variety of bricks (i.e., complex). Although results found that participants took significantly longer to complete the primary task following complex interruptions, compared to simple interruptions, the authors did not find a significant difference in the amount of time needed to resume the task (i.e., resumption lag). However, these findings may have been confounded by the availability of the primary task instructions on the computer monitor following management of the interruption. Again, to address this potential confound in the present study, all data entered into the task database were reset following the interruption.

Complexity and Mental Demand

Based on the core assumption of TBRS (Barrouillet, 2007), that attention is rapidly switched between primary task goal maintenance and management of the interruptive task, it was predicted that greater perceived mental demand would be reported during the management of higher complexity interruptions. Specifically, since a greater attentional resource demand would be placed on participants during higher complexity interruption tasks, they should report greater perceived mental demand. Therefore, the fifth hypothesis in this study was that high complexity interruptions would lead to significantly greater perceived mental demand scores, when compared to moderate and low complexity interruptions. This hypothesis was supported. Participants reported significantly greater perceived mental demand during high complexity interruptions, when compared to moderate complexity and significantly greater mental demand ratings for moderate complexity compared to low complexity interruptions.

This finding is consistent with previous research by Adamczyk and Bailey (2004) who interrupted participants either during a computer-based primary task or immediately after they had completed a previous task and were moving on to the next task. The authors predicted that the interruptions occurring within the primary task would lead to greater perceived mental demand, when compared to interruptions in between tasks. Their results showed that reported levels of mental demand were significantly reduced when the interruptions occurred in between tasks. This finding supports predictions made by the TBRS model that tasks which require greater attentional resource demands will result in higher perceived mental demand, when compared to less attentionally demanding tasks. Specifically, as interruption task demand increases, the amount of available resources will decrease, leaving fewer resources available for primary task maintenance.

Complexity and Frustration

A closer examination of the NASA-TLX ratings found that perceived frustration was also affected by interruption complexity. Specifically, participants reported significantly lower perceived frustration following low complexity interruptions, when compared to moderate and high complexity interruptions. While not predicted a priori, this finding is consistent with previous research by Adamczyk and Bailey (2004) and Iqbal and Bailey (2008).

As noted in the previous section, Adamczyk and Bailey (2004) interrupted participants either during a computer-based primary task or immediately after they had completed a previous task and were transitioning to the next task. Their results showed that reported levels of frustration were significantly reduced when the interruptions occurred in between tasks, when compared to interruptions during the task. The researchers proposed that participants may have reported less frustration when managing an interruption *in between* tasks because the demand on attentional resources was lower. In a similar study, Iqbal and Bailey (2008) found an effect of frustration when investigating the relationship between interruption onset point and primary task performance. Specifically, during the execution of a computer-based programming task, participants were interrupted by an on-screen notification either during execution of the primary task or during a breakpoint in between task sub-steps. Results showed that the onset of notifications during task breakpoints led to significantly less frustration when compared to notifications that occurred during the task. However, this finding may have been confounded because participants were told that interruptions would occur during completion of the primary task. Again, to address this potential confound in the present study, participants were not explicitly told that interruptions would occur during the data entry task.

Relevance and Complexity Interaction

Previous research has yet to investigate the interactive effects of interruption relevance and complexity on task resumption lag following an interruption. Thus, a primary aim of the present study was to examine this relationship. As previously described, the MFPS model predicted an interaction between relevance and complexity. Specifically, if the complexity of an interruption is low enough that it does not require use of the problem state resource, the primary task information currently being held in the problem state would not be transferred to declarative memory (Borst, 2013, 2015). Consequently, when complexity is low, the task goal for the suspended primary task should not experience time-based decay during R, ICS, and ICD interruptions. Thus, it was expected that R, ICS, ICD interruptions would not result in significant differences in resumption lag when the complexity is low. Alternatively, it was expected that R, ICS, and ICD interruptions would produce significant differences in resumption lag under moderate or high complexity. Therefore, the sixth hypothesis was that the effect of interruption relevance on resumption lag would depend on the magnitude of complexity. However, this prediction was not supported in the present study. In general, differences between ICS and ICD interruptions were not observed, regardless of the magnitude of complexity.

The a priori prediction was based on the assumption that interruptions similar in content to the primary task would offer contextual information from the suspended task that would subsequently boost associative activation for the suspended task goal. Alternatively, it was assumed that content dissimilar interruptions would not offer this contextual information. A possible explanation for this lack of effect was obtained during the participant debrief interviews. A majority of participants reported that they would tend to ignore the words presented during the interruption task if it did not represent the item that they were working on prior to suspension of the primary task. Specifically, they would disregard the words shown during ICS and ICD interruptions. Thus, the effects of time-based decay for the primary task goal were similar for both the ICS and ICD interruptions. By contrast, participants reported that they would use the R interruption as an aid for remembering the item in the primary task where they were supposed to resume. Moreover, these participants reported that this aid improved their ability to resume the task in the correct location. These subjective reports were corroborated by the objective resumption lag data. As previously discussed, task resumptions were significantly faster following relevant interruptions, when compared to irrelevant interruptions. An alternative explanation for the non-significant differences between ICS and ICD conditions on resumption lag may be due to participants inhibiting rehearsal of the words presented during the interruption task. Specifically, they may have strategically inhibited rehearsal of the words so that less interference would occur in working memory when they attempted to retrieve the suspended primary task goal. However, this alternative explanation is unlikely for two reasons. First, if participants were to inhibit rehearsal during the interruption task one would expect there to be no differences in resumption lag following R, ICS, and ICD interruptions. However, as previously discussed, R interruptions were resumed significantly faster than ICS and ICD interruptions. Second, no participants reported using this inhibition strategy, whereas many reported their tendency to ignore the ICS and ICD words shown during the interruption task.

Discussion of Theoretical Models

In general, the findings from the present study offered support for the MFG (Altmann & Trafton, 2002) and TBRS (Barrouillet et al., 2004) models, but not the MFPS (Borst et al., 2015) model. In the present study, the MFG model guided the prediction that interruptions that were not relevant to the primary task would lead to greater interference and slower primary task resumption, when compared to relevant interruptions. Specifically, MFG predicts that relevant interruptions facilitate the strengthening of primary task goals, whereas irrelevant interruptions should lead to retroactive interference because they may reflect certain steps of the task that have either been completed or not yet performed (Gould et al., 2013). Additionally, irrelevant interruptions may hinder task resumption because they provide no cuing information that could facilitate rehearsal of suspended task goals, when compared to relevant interruptions (Altmann & Trafton, 2002). In general, the predictions made by the MFG model were supported in the present study with the data showing significantly shorter task resumption lags following relevant interruptions, when compared to irrelevant interruptions.

The present study also employed the TBRS model to guide predictions regarding the effects of increased complexity on task resumption lags. In general, the TBRS model assumes that efficient task resumption is dependent on the ability to execute rapid, sequential maintenance processes when managing an interruption. For example, if the complexity of the interruption task is too high, TBRS suggests that primary task maintenance will be inhibited and result in prolonged task resumption. Thus, TBRS predicts that more complex interruptions would lead to longer task resumption times, when compared to less complex interruptions. In general, the findings from the present study provide further support for the TBRS model with data showing significantly longer task resumption lags following high and moderate complexity interruptions, when compared to low complexity interruptions.

Finally, the present study employed the MFPS model to guide the prediction of the joint effects of relevance and complexity on resumption lag. In general, MFPS extends MFG because it also considers the specific cognitive requirements for both the primary and interruptive tasks. As shown from previous research (Borst, 2013, 2015), the effect of complexity on prolonged resumption lag can be attributed to the problem state requirements of the interruption task. Specifically, the primary task's problem state will only be transferred to declarative memory and result in higher resumption costs, if the interruption task also requires a problem state. Thus, MFPS predicted an interaction between complexity and relevance. Specifically, if the complexity of an interruption is low enough that it does not require use of the problem state resource, the primary task information currently being held in the problem state will not be transferred to declarative memory (Borst, 2013, 2015). Consequently, when complexity is low, the task goal for the suspended primary task should not experience time-based decay during R, ICS, and ICD interruptions. Thus, it was expected that R, ICS, ICD interruptions would not result in significant differences in resumption lag when the complexity is low. Alternatively, however, it was expected that R, ICS, and ICD interruptions would result in significant differences in resumption lag when the complexity is moderate or high. In general, the present study did not find support for this prediction by MFPS, as there was no interaction between relevance and complexity. However, as previously discussed, the insufficient statistical power for detecting an interaction effect and limitations in the experimental manipulation of ICS and ICD interruptions may partially explain this nonsignificant finding. Thus, further research with a larger sample and enhanced experimental control is appropriate before any judgements can be made of MFPS.

Theoretical Implications

As previously discussed, findings for both interruption relevance and complexity have been mixed. However, this may be attributed to inconsistent definitions, and operationalizations, of each factor. For example, prior research on interruption relevance had not made clear distinctions between relevance and content similarity. Specifically, whereas Czerwinski and colleagues (2000) and Gould (2013) interrupted participants with secondary tasks that either did or did not aid performance on the primary task (i.e., relevant or irrelevant interruptions), Iqbal and Bailey (2008) and Latorella (1999) interrupted participants with tasks that were or were not similar in content to the suspended task. Although the differences between relevance and content similarity may not appear meaningful, the two impose different demands on memory. Specifically, while task-relevant interruptions may facilitate rehearsal of the suspended task goal or context, interruptions that are irrelevant may lead to the generation of retroactive interference (Altmann & Trafton, 2002). Therefore, whereas relevant interruptions may reduce the amount of time needed to resume the suspended task, irrelevant interruptions may increase the amount of time. This finding was supported in the present research with significantly faster task resumptions following relevant interruptions, when compared to irrelevant interruptions. The present research may offer an explanation for the mixed findings regarding interruption relevance. Specifically, since the present study was the first to investigate relevant, content similar, and content dissimilar interruptions the results suggest that only relevant interruptions aid task resumption, but both content similar and content dissimilar interruptions impair task resumption due to general retroactive interference.

However, it is important to note that the present study also predicted that the content similar and content dissimilar interruptions would differ. This prediction was guided by the MFG model which proposes that interruptions similar in content to the primary task offer contextual information which would boost associative activation for the suspended goal, whereas content dissimilar interruptions would not. This prediction was not supported in the present research. As previously noted, during the debrief interviews many participants reported that they would disregard the masks in the interruption task if they did not match the suspended item from the primary task. This tendency to ignore both the ICS and ICD masks may provide a possible explanation for the lack of significant differences in resumption lag. Specifically, while the ICS condition may have contained contextual information from the suspended task (i.e., item names), participants did not use this information to help maintain activation for the suspended goal. Thus, although the ICD interruptions did not provide contextual information by design, the contextual information in the ICS interruptions was not used. However, because this possible explanation was obtained during the informal debrief interviews, further empirical research is needed to address the nature of content similar and dissimilar interruptions.

Previous research on interruption complexity has also produced mixed results; however, this may be attributable to differences in how complexity was operationalized. For example, whereas Cades (2007), Hodgetts and Jones (2006), and Gillie and Broadbent (1989) manipulated complexity by altering the amount of mental operations (i.e., the number of mental steps required to reach a solution), Monk and colleagues (2008) manipulated the cognitive demands on working memory by using tasks that inhibited or facilitated rehearsal of suspended task goals. This latter definition of complexity was supported in the present study by participants reporting significantly higher ratings of perceived mental demand for the high and moderate complexity interruptions, when compared to the low complexity interruptions. This definition was further corroborated by participants in the debrief interviews. Specifically, a majority of participants reported that they attempted to rehearse during the interruption task, but that it was easier to do so during the low complexity interruption (i.e., blank screen).

Additionally, the present study employed a novel experimental design that addressed limitations in previous research. For example, Monk and colleagues (2008) noted that several unanticipated factors may have confounded their results. Specifically, upon resuming the suspended primary task, the cursor arrow on the monitor remained in the same location where the participant had been working prior to interruption. Also, previously selected buttons and display feedback from the suspended task remained on the monitor following the offset of the interruption task. Consequently, their participants may have utilized these cues to help identify the correct location for task resumption. To address these limitations, the present study was designed to eliminate all spatial cues from the task interface. Specifically, the task interface was programmed to reset the mouse to the top left-hand corner of the monitor and reset all previously entered data. Additionally, the experimental design used in this study was chosen to address a potential confound in the Pankok and colleagues (2017) experiment. Although these authors did not find a significant effect of interruption complexity on task resumption lag, they noted that their results may have been confounded by the availability of the primary task instructions on the computer monitor following completion of the interruption task. Again, to address this potential confound, all data entered into the task database in the present study were reset following interruption. Collectively, the experimental controls implemented in the present study overcame some of the limitations in the previous research by requiring participants to rely solely on their memory of the suspended task location following interruptions, without the aid of spatial cues.

Practical Implications

Findings from the present study also offer practical implications for healthcare settings. As previously discussed, prior research has found that interruptions are common in tasks such as surgery and medication administration. For example, following an observation of 56 general and orthopedic surgeries, Weigl and colleagues (2015) found that an interruption occurred about once every six minutes, on average. Additionally, in a study that observed medical workers as they prepared and administered medications, Westbrook et al. (2010) found that for every interruption, the risk of a subsequent medication error increased by an average of 12.7%. Moreover, these researchers found that if a medical worker was interrupted more than six times during their shift, this probability of medication error tripled for every additional interruption. It is important to note that these studies were observational and interruption characteristics such as relevance and complexity were not experimentally manipulated or even considered.

Results from the present study showed that the number of task-related errors was affected by interruption complexity. Specifically, results showed that when an interruption task required information to be held in working memory (i.e., high and moderate complexity), significantly more resumption errors were committed, when compared to interruptions that did not require working memory (i.e., low complexity). Further, more errors were made with in the high complexity interruptions, as compared to the moderate complexity interruptions.

Thus, while previous observational research on interruptions has documented the *prevalence* of errors in healthcare settings, results from the present study highlight important characteristics of interruptions that may *cause* errors. Not only are more errors committed during interruptions that are more complex (i.e., greater working memory demand), but more errors are also committed in the primary task following resumption. Therefore, it may be possible to reduce the prevalence of errors by modifying the ways in which healthcare workers are interrupted. For example, OR team members would be well advised to refrain from interrupting a surgeon in the middle of a task especially if that interruption will place a high demand on the surgeon's working memory. Results from the present study suggest that this precaution will reduce the likelihood that a surgical error is committed following resumption of the suspended procedure. However, further experimental research in a controlled or simulated setting is necessary to support this suggestion.

Finally, it is important to note that while the millisecond level differences in resumption lag observed in the present study may not pose a significant threat to the wellbeing of data entry professionals, these findings may be practically meaningful for other task domains. For example, in a simulated aircraft threat detection task, Miller (2002) had participants assess the threat level of incoming aircraft based on several characteristics (e.g., range, speed, altitude). During the task, participants were unexpectedly interrupted by task-related messages and were required to resume the primary task following the completion of the message. In general, the results showed that participants took significantly longer (i.e., 29% longer) to resume the threat detection task following interruptions, when compared to non-interrupted trials. Although these results were in a simulated experiment, similar findings in the real world could be disastrous. Unfortunately, as evident from the present study, interruptions greater in complexity and irrelevant to the suspended task can exacerbate this delay in task resumption. Although it is unclear if the findings from the present study would generalize to the aviation domain, cockpit designers and policy makers should seek to minimize the demand on attentional resources when interrupting individuals during the performance of visuospatial tasks, particularly when the interruption is irrelevant to the suspended task.

Limitations

The present study had a few limitations that bear consideration. The first limitation concerns the characteristics of the content similar (ICS) and content dissimilar (ICD) interruptions. The mask for the ICS interruption always displayed the name of an item box that had been or had not yet been completed. For example, if the participant selected the Oxygen item box prior to the onset of the interruption, the mask would cycle through the remaining eight-item box names throughout the interruption task (see Appendix A). Alternatively, for the ICD condition, the mask always displayed an arbitrary name related to automobiles (e.g., tire). For example, if the participant selected the Oxygen item box prior to the onset of the interruption, the mask would cycle through eight words related to automobile characteristics (Appendix G). In general, it was predicted that participants would resume the primary task significantly faster following ICS interruptions, when compared to ICD interruptions, because contextual information from the suspended task would boost associative activation for the suspended task goal. Alternatively, it was predicted that ICD would be resumed slower because they did not offer this contextual information. However, the present study showed that the ICS and ICD interruptions did not lead to significant differences in resumption lag. As previously noted, during the debrief interviews many participants reported that they would disregard the masks in the interruption task if they did not match the suspended item from the primary task. This tendency to ignore both the ICS and ICD masks may provide a possible explanation for the lack of significant differences. Specifically, although an attempt was made to enable associative activation for suspended task goals in the ICS conditions, participants may not have leveraged this aid. However, future research could potentially address this limitation by using items for the ICS condition that are spelled similarly or sound the same as the R condition. Thus, the ICS condition may enable lexical or acoustic associative activation that was not available in the present study.

Second, since the experiment used a within-subjects design, participants may have learned to anticipate the onset of interruptions. Although an effort was made to interrupt participants at inconsistent times across the full study, participants may have begun to anticipate that an interruption was imminent if they hadn't been interrupted in several minutes. For example, if they were not interrupted following the completion of a couple of patient charts, they may have learned to anticipate that another interruption would occur soon. Since the participants were not explicitly asked about this possibility in the debrief interview, it is unclear if anticipating an interruption had any effect on their strategies for maintaining items in memory.

The third limitation in the present study concerns the collection of the subjective data via the NASA-TLX. As noted earlier, participants completed the NASA-TLX following the completion of each primary task trial. However, since participants were not asked to fill out the TLX until *after* completion of the primary task trial, it is unclear it these ratings fully represent how participants felt *during* execution of the primary task. However, since participants filled out the TLX after the primary task for all within-subjects' trials, it was assumed that this potential limitation was controlled for. Moreover, since this TLX data corroborated the objective task resumption lag data, it was assumed that the subjective reports were representative of how participants felt during execution of the primary task.

The final limitation in the present study concerns participant recruitment. Specifically, the participants were undergraduate psychology students and not data entry professionals. Although students were given course credit for their participation, it is uncertain how well this method of compensation truly incentivized students to devote their full effort to the experimental task. However, as previously noted, only a few outliers were identified. Specifically, two participants were excluded because of an inability to follow task instructions. Additionally, any resumption lag, resumption error, or NASA-TLX data that exceeded three standard deviations from the mean were replaced with the respective group mean. Thus, while it remains uncertain if all participants applied their full effort through the entirety of the sessions, these data cleaning measures provide confidence that any effect of this potential issue was minimized.

Future Directions

Results from the present study offer a potential direction for future research. Specifically, it may be of interest to further explore the manipulation of content similarity. While the present study used incorrect item categories from the suspended task to manipulate the irrelevant but content similar (ICS) condition, future research might use items that are spelled similarly or sound the same as those in the R condition. For example, if the item categories in the primary data entry task (Appendix A) were replaced with names of medications, the ICS condition could be altered to similar sounding medications (e.g., acetazolamide vs. acetohexamide). This small change may impact the general interference effects that were observed in the present study. Specifically, changing the ICS interruption to a similar sounding item may potentially provide an acoustic associative activation for the suspended primary task that was not available in the present study. Consequently, as proposed by the MFG model (Altmann & Trafton, 2002) this associative activation from the ICS interruption may help reduce the amount of time needed for a participant to strengthen activation for the suspended task goal to overcome the retroactive interference set by the secondary task. Thus, a general prediction may be that ICS interruptions would be resumed faster than ICD interruptions.

Conclusion

The present research was conducted to provide clarification on the mixed findings regarding the relevance and complexity of task interruptions and address potential limitations from previous research. The main objectives were to explore how interruption relevance and complexity affect primary task resumption lag and perceived mental demand. Data from the present study revealed two important findings. First, relevant interruptions led to significantly faster resumption lag and lower perceived mental demand, when compared to irrelevant interruptions. Second, as interruption complexity increased, primary task resumption lag and perceived mental demand also increased. In general, the relevance findings were explained by interference effects described in the Memory for Goals model (Altmann & Trafton, 2002) and the complexity findings were explained by the inhibition of primary task maintenance (i.e., rehearsal) described in the Time-based Resource Sharing model (Barrouillet, 2007). In conclusion, the current research illustrates the importance of minimizing the demand on attentional resources when interrupting individuals during the performance of visuospatial tasks, particularly when the interruption is irrelevant to the suspended task.

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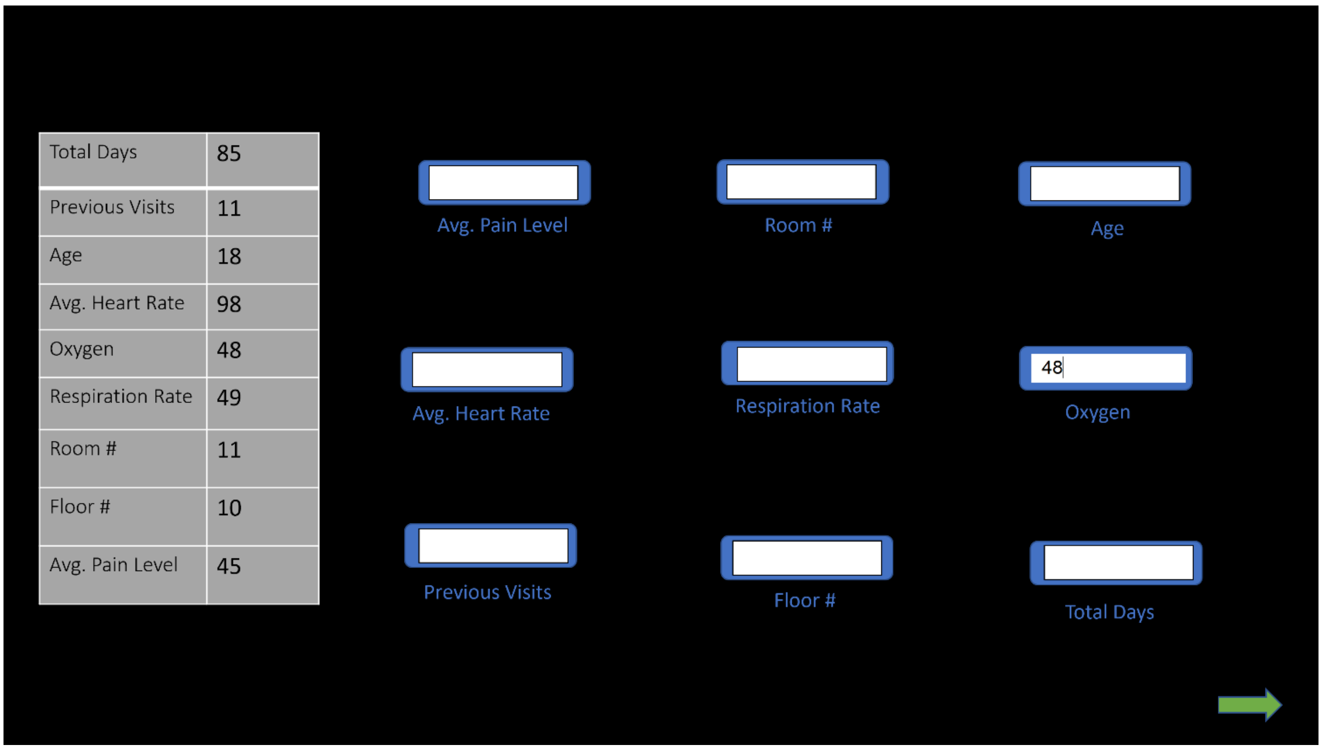
APPENDIX A

EXAMPLE OF A PATIENT CHART

Total Days	54
Previous Visits	10
Age	20
Avg. Heart Rate	10
Oxygen	40
Respiration Rate	50
Room #	20
Floor #	20
Avg. Pain Level	55

APPENDIX B

EXAMPLE OF A PATIENT CHART AND DATABASE ON A SINGLE MONITOR

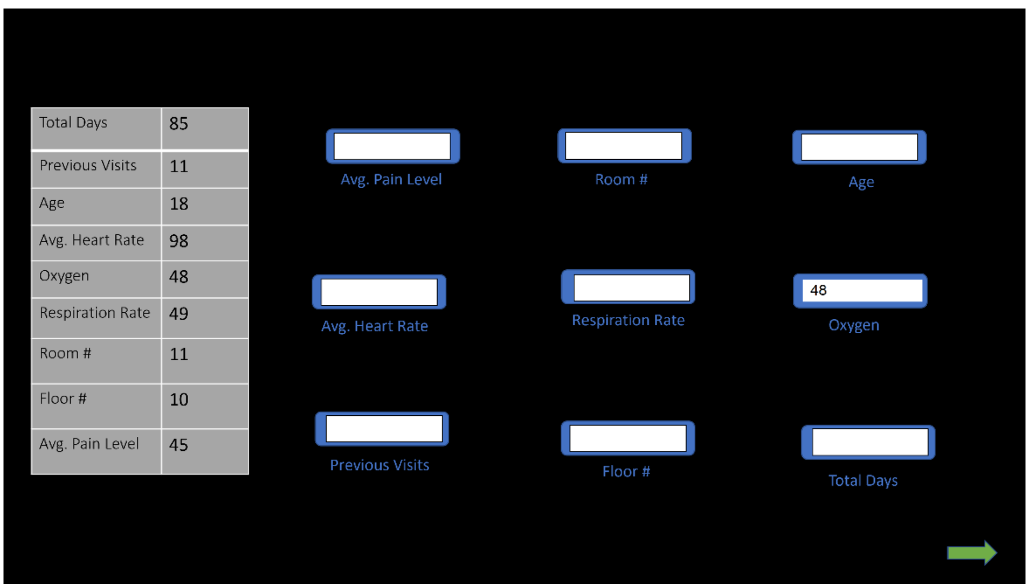


APPENDIX C

EXAMPLE OF MEDICAL DATABASE BEFORE AND AFTER INTERRUPTION

Participant is interrupted immediately after selecting O2 box in database.

Participant correctly resumes primary task at 02 box.



APPENDIX D

EXAMPLE OF A RELEVANT INTERRUPTION

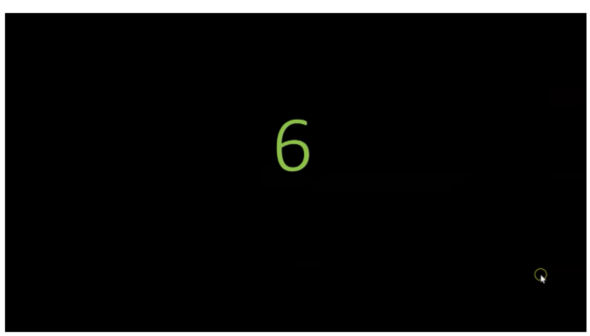
Participant was preparing to enter the value for Total Days in the database but was interrupted. The n-back task displayed a “6” followed by a “9” with the mask displaying the name “Total Days”

APPENDIX E

EXAMPLE OF ICS INTERRUPTION

Participant was preparing to enter the value for Oxygen in the database but was interrupted

The n-back task displayed a “9” followed by a “6” with the mask displaying the name “Blood Pressure”



APPENDIX F

EXAMPLE OF ICD INTERRUPTION

Participant was preparing to enter the value for Previous Visits in the database but was interrupted

The n-back task displayed a “3” followed by a “8” with the mask displaying the name “Brake”

APPENDIX G

ICD MAS WORDS- AUTOMOBILE CHARACTERISITICS

Exhaust
Tire
Windshield
Speed
Torque
Door
Drive
Bumper

APPENDIX H

NASA-TASK LOAD INDEX (TLX) WORKLOAD QUESTIONNAIRE

(Hart & Staveland, 1988)

MENTAL DEMAND

Low High

| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

PHYSICAL DEMAND

Low High

| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

TEMPORAL DEMAND

Low High

| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

PERFORMANCE

Low High

| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

EFFORT

Low High

| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

FRUSTRATION

Low High

| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |

APPENDIX I

INFORMED CONSENT FORM

PROJECT TITLE: Attention During Medical Data Entry Tasks

RESEARCHERS:

Mark W. Scerbo, Ph.D., Responsible Project Investigator, Professor, College of Sciences, Psychology Department

Co-investigators:

Brandon Fluegel, Graduate Student, College of Sciences, Psychology Department

DESCRIPTION OF RESEARCH STUDY

Data entry tasks are susceptible to a variety of human performance limitations. Specifically, human factors such as attention, vigilance and workload can be affected by computer-based tasks. Therefore, the goal of the present study is to assess these factors during completion of several trials of a computer-based medical data entry task.

If you decide to participate, then you will be one of approximately 70 undergraduate students involved in a study designed to identify how human attention functions during data entry tasks. You will be instructed in how to perform the data entry tasks on the computer then be given time to practice those tasks. Afterward, you will complete three trials of the task and will also be asked to complete brief questionnaires that ask you to rate the ease or difficulty of the tasks. The total amount of time for participation is approximately one hour.

EXCLUSIONARY CRITERIA:

To participate in this study, you must be an undergraduate student at ODU. You must be 18 years of age or older. You also must have normal or corrected-to-normal vision. If you wear contacts or glasses, you must have these with you when you participate

RISKS:

If you decide to participate in this study, then you may face a risk of slight physical fatigue. Both your arms and hands may become tired from interacting with mouse and keyboard. The researchers have tried to reduce these risks by incorporating frequent breaks and resting periods. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS:

There are no direct benefits for participation.

COSTS AND PAYMENTS:

If you decide to participate in the study, you will receive 1 Psychology department research credit, which may be applied to course requirements or extra credit in certain Psychology courses. Equivalent credits may be obtained in other ways, such as conducting library reports and online surveys. You do not have to participate in this study, or any Psychology Department study, in order to obtain this credit.

CONFIDENTIALITY:

The researchers will take reasonable steps to keep private information, such as questionnaires and laboratory performance and findings confidential. The researchers will remove all identifying information from questionnaires and store all data in a locked filing cabinet prior to its processing. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE:

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study – at any time. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation. If at any point during the study you wish to stop, simply tell the researcher and you will not be penalized in any way. Any data that has already been collected will be destroyed and will not be included in the final analysis.

COMPENSATION FOR ILLNESS AND INJURY:

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of injury, or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact the Faculty research advisor, and responsible principle investigator Dr. Mark W. Scerbo at 757-683-4217 or Dr. George Maihafer the current IRB chair at 757-683-4520 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT:

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Dr. Mark W. Scerbo, mscerbo@odu.edu, (757) 683-4217

Brandon Fluegel, bflue001@odu.edu, (508) 971-5520

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer, the current IRB chair, at (757) 683-4520, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

------------------------------------ ----------------------------------

Participant's Name Participant's Signature Date

INVESTIGATOR’S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

------------------------------------ ----------------------------------

Investigator’s Name Investigator’s Signature Date

APPENDIX J

TASK INSTRUCTIONS

"Once again, I want to thank you for coming in today. During today's study, you will be doing a task that requires you to transfer data from patient charts into a medical record database. When entering data, you must proceed in order from the top of the patient chart to the bottom--you cannot skip items. Just to confirm that you are going in order. **Show them task.** Any questions?

Next, when entering data, you may or may not be asked to complete secondary tasks. The format of these tasks will be memory-based. ***Show Example*.** If you are asked to complete a secondary task, you will be required to resume the data entry task exactly where you had left off, following resumption. For example, if you were about to enter a value for blood pressure, but were then presented with a secondary task, you will restart the data entry task by entering data into the blood pressure box. ***Show example*** Any questions?

You will be asked to complete the data entry task several times. Following each of the trials, you will be asked to complete a questionnaire that allows you to tell us how the task made you feel. ***Show Example***

In a few moments you will have a chance to practice this task before the study begins. During this time, you will be able to ask me any questions that may come to mind. However, when the study begins, you will no longer be able to ask me any questions. Keep in mind that your accuracy in completing these tasks is more important than speed. Essentially, you want to enter data as quick as possible, without sacrificing accuracy. Any questions?”

APPENDIX K

PARTICIPANT BACKGROUND INFORMATION FORM

Participant #:_____ Group:_____ Date:_____ Time:_____

The purpose of this questionnaire is to obtain background information on the participant that will be used for research purposes only.

1. Age______

2. Gender______

    0 = Female

    1 = Male

3. Do you have normal or corrected-to-normal vision?_____

    0 = Yes

    1 = No

APPENDIX L

COUNTERBALANCING CHART

Complexity (L, M, H) X Relevance (R, ICS, ICD)

ID	1	2	3	4	5	6	7	8	9
1	M—R	L—ICD	L—R	H—ICD	H—R	H—ICS	M—ICS	M—ICD	L—ICS
2	L—R	H—ICD	L--ICD	M—ICS	L—ICS	M—R	H—R	H—ICS	M—ICD
3	L—ICD	H—R	L—ICS	M—ICD	L—R	M—ICS	M—R	H—ICD	H—ICS
4	M—ICD	H—ICS	M—R	L—R	M—ICS	H—R	H—ICD	L—ICS	L—ICD
5	M—ICS	L—ICS	H—ICD	M—R	M—ICD	L—ICD	H—ICS	H—R	L—R
6	H—ICD	M—R	M—ICD	L—ICS	H—ICS	L—R	L--ICD	M—ICS	H—R
7	H—ICS	M—ICD	H—R	L—ICD	H—ICD	L—ICS	L—R	M—R	M—ICS
8	H—R	L—R	M—ICS	H—ICS	M—R	M—ICD	L—ICS	L--ICD	H—ICD
9	L—ICS	M—ICS	H—ICS	H—R	L--ICD	H—ICD	M—ICD	L—R	M—R
10	M—R	L—ICD	L—R	H—ICD	H—R	H—ICS	M—ICS	M—ICD	L—ICS
11	L—R	H—ICD	L—ICD	M—ICS	L—ICS	M—R	H—R	H—ICS	M—ICD
12	L—ICD	H—R	L—ICS	M—ICD	L—R	M—ICS	M—R	H—ICD	H—ICS
13	M—ICD	H—ICS	M—R	L—R	M—ICS	H—R	H—ICD	L—ICS	L—ICD
14	M—ICS	L—ICS	H—ICD	M—R	M—ICD	L—ICD	H—ICS	H—R	L—R
15	H—ICD	M—R	M—ICD	L—ICS	H—ICS	L—R	L--ICD	M—ICS	H—R
16	H—ICS	M—ICD	H—R	L—ICD	H—ICD	L—ICS	L—R	M—R	M—ICS
17	H—R	L—R	M—ICS	H—ICS	M—R	M—ICD	L—ICS	L--ICD	H—ICD
18	L—ICS	M—ICS	H—ICS	H—R	L--ICD	H—ICD	M—ICD	L—R	M—R
19	M—R	L—ICD	L—R	H—ICD	H—R	H—ICS	M—ICS	M—ICD	L—ICS
20	L—R	H—ICD	L—ICD	M—ICS	L—ICS	M—R	H—R	H—ICS	M—ICD
21	L—ICD	H—R	L—ICS	M—ICD	L—R	M—ICS	M—R	H—ICD	H—ICS
22	M—ICD	H—ICS	M—R	L—R	M—ICS	H—R	H—ICD	L—ICS	L—ICD
23	M—ICS	L—ICS	H—ICD	M—R	M—ICD	L—ICD	H—ICS	H—R	L—R
24	H—ICD	M—R	M—ICD	L—ICS	H—ICS	L—R	L--ICD	M—ICS	H—R
25	H—ICS	M—ICD	H—R	L—ICD	H—ICD	L—ICS	L—R	M—R	M—ICS
26	H—R	L—R	M—ICS	H—ICS	M—R	M—ICD	L—ICS	L--ICD	H—ICD
27	L—ICS	M—ICS	H—ICS	H—R	L--ICD	H—ICD	M—ICD	L—R	M—R
28	M—R	L—ICD	L—R	H—ICD	H—R	H—ICS	M—ICS	M—ICD	L—ICS
29	L—R	H—ICD	L—ICD	M—ICS	L—ICS	M—R	H—R	H—ICS	M—ICD
30	L—ICD	H—R	L—ICS	M—ICD	L—R	M—ICS	M—R	H—ICD	H—ICS
31	M—ICD	H—ICS	M—R	L—R	M—ICS	H—R	H—ICD	L—ICS	L—ICD
32	M—ICS	L—ICS	H—ICD	M—R	M—ICD	L—ICD	H—ICS	H—R	L—R
33	H—ICD	M—R	M—ICD	L—ICS	H—ICS	L—R	L--ICD	M—ICS	H—R
34	H—ICS	M—ICD	H—R	L—ICD	H—ICD	L—ICS	L—R	M—R	M—ICS
35	H—R	L—R	M—ICS	H—ICS	M—R	M—ICD	L—ICS	L--ICD	H—ICD
36	L—ICS	M—ICS	H—ICS	H—R	L--ICD	H—ICD	M—ICD	L—R	M—R

APPENDIX M

DEBRIEF INTERVIEW

Subject ID: __________

Group Code:________

Date: ______________

What strategy or strategies did you take to remember where you were in the primary task?

____

____

Do you have any additional comments about the task? Please explain:

____
____

Brandon Allan Fluegel

Department of Psychology
Old Dominion University
Norfolk, VA 23529

RESEARCH EXPERIENCE

Old Dominion University
Simulation Usability Research Facility, Human Factors Ph.D. Candidate Researcher
August 2015-May 2020

- Worked on the development and evaluation of an augmented reality interface to help both normal sighted and visually impaired operators control unmanned aerial vehicles. Also investigating the cognitive and physical effects of interruptions and distractions on human performance during complex visuospatial tasks.

Uber
Vehicles, User Experience Ph.D. Intern
June 2019-September 2019

- Planned and executed mixed-methods research in North & South America to guide design and foster social impact on the Vehicles team.

NASA Langley
Space Mission Analysis Branch, User Experience & Human Factors Ph.D. Candidate Intern
June 2018-December 2018

- Used virtual reality (Oculus Rift & HTC Vive) to design/evaluate medical workstation prototypes for astronaut use on the Deep Space Gateway, transport, and planetary surface habitats. Led both the human-in-the-loop VR evaluation and metric definition.

Mercedes-Benz Research and Development
User Research and Innovation Group, User Experience Ph.D. Student Intern
June 2017-August 2017

- Worked on a variety of human-centered research projects applying both qualitative and quantitative methods. Select projects include a study on the psychological effects of being driven by autonomous vehicles and the development and execution of a case study that investigated noise and vibration in the passenger cabin of a next-generation vehicle.