PROSPECTIVE MEMORY IN DYNAMIC ENVIRONMENTS: THE ROLE OF UNCERTAINTY

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PROSPECTIVE MEMORY IN DYNAMIC ENVIRONMENTS: THE ROLE OF UNCERTAINTY

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Prospective memory (ProM) refers to remembering to perform a task in the future. Successfully remembering a ProM task entails remembering not only *that* something has to be done, but also *when* it has to be done, and *what* has to be done. Busy operational environments may require operators to rapidly switch between multiple safety-critical tasks. In dynamic environments, an operator's inability to predict upcoming tasks may interfere with any or all aspects of ProM (i.e., remembering *that* something needs to be done, *when* it needs to be done, and *what* needs to be done). However, previous research has not manipulated uncertainty about the context of ProM execution influences ProM.

The current dissertation uses a task-switching paradigm to investigate whether uncertainty about the context in which ProM tasks are executed would affect ProM success. In the certain condition, participants could predict the order of upcoming tasks. In the uncertain condition, participants experienced tasks in a random, unpredictable order. In Experiment 1, the ProM task consisted of remembering to perform an action after being presented with the ProM cue, but only after completing the current (0 delay), next (1 delay), or next two (2 delay) ongoing tasks. Participants in the certain condition were expected to use knowledge about the order of upcoming tasks to imagine the specific context in which the ProM response had to be executed. In contrast, participants in the uncertain condition were unable to encode a more specific context of ProM execution. Results showed that participants in the certain condition were significantly better at remembering when the ProM task had to executed, as well as what action had to be undertaken to execute the ProM task for the longest delay (2 delay). Encoding the specific context of execution seems

to have helped automatize detection of the context for ProM execution, thus boosting ProM performance in the certain condition.

Experiment 2 investigated whether specifying a concrete context of execution would similarly help ProM for participants in the uncertain condition. In contrast to Experiment 1 in which participants were told to remember to execute a ProM task after a specific number of ongoing tasks, in the second experiment, participants were told to remember to execute a ProM task, but only after they had completed a specific ongoing task (e.g., dose calculation). As in Experiment 1, Experiment 2 also varied the delay between ProM instruction and ProM execution: the specific ongoing task after which the ProM response had to be made was either the current task that participants were working on, or the next task, or two tasks later. Unlike Experiment 1, however, there was no difference on ProM performance between the certain and uncertain task order groups. Whereas Experiment 1 found that performing tasks in a predictable order helped in remembering ProM tasks that had to be performed after a specific number of tasks, Experiment 2 suggests that task order did not affect ProM execution if details about the context of execution were well-specified at the time of ProM encoding. The results of the dissertation may help inform how uncertainty at the time of encoding influences ProM in operational environments that are characterized by frequent and unpredictable task switching. Specifically, changing the framing of ProM so that the context of execution of future tasks is encoded in terms of details about the retrieval context rather than completing a specific number of tasks helps support ProM in unpredictable environments.

CHAPTER 1. INTRODUCTION

In our daily lives, we often encode tasks that have to be performed in the future. Although remembering to perform tasks such as returning borrowed items or taking medication has long been a common feature of human life, only recently have cognitive psychologists devised an experimental paradigm to study such tasks (Einstein, Holland, McDaniel, & Guynn, 1992), as well as formulated theories that shed light on the cognitive processes underlying how people may remember to perform future tasks (Ellis & Freeman, 2008; Ellis, 1996; McDaniel & Einstein, 2000; Smith, 2003). Remembering to execute a future intention is called prospective memory (ProM).

One characteristic that distinguishes ProM from retrospective memory is the nature of memory retrieval. Retrieval in ProM is self-initiated (Graf & Uttl, 2001), meaning that the operator must remember to execute the ProM task within the correct window of opportunity, but without of an explicit reminder to do so. Owing to this feature of ProM, some researchers have argued that self-initiated retrieval always requires resource-demanding cognitive processes such as preparatory attention to detect the opportunity to perform the ProM task (Smith, 2003; Smith & Bayen, 2004; Smith, Hunt, McVay, & McConnell, 2007). The resource-intensive nature of self-initiated retrieval may make it difficult to remember to perform ProM tasks (Einstein et al., 1992). Without an externally-generated reminder, operators may forget to perform the ProM task altogether. Alternatively, they may remember to perform the ProM task, but after the opportune moment of execution has passed. In either case, failure of self-initiated retrieval leads to ProM failure.

CHAPTER 2. PROSPECTIVE MEMORY IN DYNAMIC ENVIRONMENTS

Forgetting to execute ProM tasks may have serious consequences, especially in safety-critical and dynamic operational environments such as healthcare. For example, a physician who forgets to add allergy information in a patient's chart may inadvertently place the patient at risk of being prescribed a medication that may result in an adverse effect or even be potentially life-threatening. Therefore, it is important to understand how ProM operates in dynamic environments.

Dynamic environments may be embedded with uncertainty. Very generally, uncertainty may be thought of as lack of information (Shannon, 1948), and may arise from various sources. One source of uncertainty is a rapid rate of change in events in the environment. Operators in environments such as the emergency department (ED) may have to contend with rapidly changing events while performing important patient care tasks. For example, a physician in the ED may be diverted from caring for her or his current patient by an incoming trauma patient, or by interruptions from other healthcare providers seeking consults.

Even when operational environments require rapidly task switching, operators may still be able to plan when to execute future tasks if they always perform tasks in a predictable, routine order. Consider an ED physician who has to defer performance of a particular task to the future, for example, remembering to order labs for patient X in the next five minutes. If the physician knows the task that he or she will be working on in the upcoming five minutes, then that knowledge could be used to envision the context of executing the task of ordering labs.

However, rapidly changing events in busy operational environments could also lead to an inability to predict the future state of the environment (i.e., state uncertainty; Milliken, 1987). If initiating a ProM task requires controlled processes (e.g., preparatory attention) to predict the opportunity of execution (McDaniel & Einstein, 2000; Smith, 2003), but if operators are unable to predict the context in which the ProM task has to be executed, then they may not know when to strategically devote resources to monitor for the occurrence of the opportunity to execute the ProM task. In this way, operators working in unpredictable and dynamic environments may be at a higher risk for ProM failure (Nowinski & Dismukes, 2005).

Unstructured environments that impose a rapid change in events may result in frequent task switching. For example, a physician in the ED may have to switch between performing different tasks. These tasks may include conducting physical examinations on patients, ordering lab tests, coordinating with other healthcare providers to diagnose the patient, prescribing medication, and maintaining a record of diagnosis, labs, and treatment in the electronic health record. The physician may have to simultaneously manage multiple patients. This may result in the physician having to interleave different tasks for different patients.

Task switching may contribute to state uncertainty in at least two ways. First, the operator may be unable to predict when he or she may be required to switch between tasks. In the example above, the ED physician may not be able to predict when exactly he or she would experience a disruption to the current task. Second, the operator may be unable to predict the upcoming task. It is possible, for example, that while the physician is in the midst of performing a physical exam on a patient, there may be any number of tasks that may have to be performed next: ordering medication for a different patient, or responding to another physician requesting a consult. The dynamic nature of work in the ED may make it difficult to anticipate the upcoming task. Lack of knowledge about upcoming tasks means that it may be difficult for the physician to imagine the specific context in which ProM task may have to be executed. The primary research question of this dissertation concerns whether uncertainty in task switching will have an effect on ProM.

CHAPTER 3. STAGES OF PROSPECTIVE MEMORY

Ellis and Freeman (2008; Ellis, 1996) described five stages of ProM. The first stage involves forming an intention and encoding the ProM task. After encoding the ProM task, there is usually a delay before encountering the context in which the ProM task has to be executed. This is called the retention interval. During the retention interval, the operator may be engaged in activities that are unrelated to the ProM task; these are called filler tasks. The third stage is the performance interval, which signals the beginning of the opportunity to execute the ProM task. This is followed by the fourth stage: initiation and execution of the ProM action. Finally, the last phase involves evaluating whether the ProM task has been correctly performed.

Ellis' model describes ProM progression in the standard paradigm to study ProM. Each stage involves different types of cognitive demands (Dobbs & Reeves, 1996; Ellis & Freeman, 2008; Ellis, 1996). It is possible to apply Ellis' stage model to understand how ProM operates in operational environments. We can use knowledge about the cognitive demands at each stage to predict how uncertainty may influence ProM in dynamic environments. The current dissertation focuses on the stages of encoding the ProM task, and the performance interval (i.e., the first and third stages, respectively).

3.1 Encoding the ProM task

The first stage of ProM involves forming an intention to perform a task in the future and encoding the ProM task. Encoding a ProM task involves remembering multiple components. People have to remember *that* a task has to be executed in the future, the window of opportunity *when* the task has to be performed (the cue, i.e., at what the time or after which event), and *what* has to be done to execute the task.

Take for instance an ED physician who has to remember to execute the ProM task of ordering labs for patient X but only after receiving consult notes from patient X's cardiologist. In this example, the ED physician has to remember *that* some task has to be done for patient X in the future, *when* that task has to be performed (after receiving consult notes), and *what* has to be performed (i.e., order labs for patient X). The *that* and *when* aspects are termed the "intent" of ProM; the *what* aspect is called the "content" (Einstein et al., 1992; Vortac, Edwards, & Manning, 1995). Remembering ProM content requires retrospective memory (Smith & Bayen, 2004), whereas remembering the intent may be automatic, or require preparatory attention to notice the opportunity of execution. (McDaniel & Einstein, 2000; Smith, 2003).

ProM failure may occur despite remembering the individual elements of ProM. This is because successful ProM requires associating the individual components with each other. There may be ProM failure, for example, when the physician remembers *that* something has to be done (e.g., do something for patient X) but forgets *when* it has to be done (e.g., after receiving consult notes). In this example, the ProM failure occurred because of missing the appropriate window of opportunity for executing the ProM response.

Any factors that influence encoding will affect ProM at later stages. For example, a physician in the ED may face time pressure due to rapid task switching; this may reduce the amount of time available to plan the execution of ProM tasks. Similarly, if the order of upcoming tasks is uncertain then the physician may be unable to imagine details about the context in which the ProM task has to be executed.

3.1.1 ProM Encoding in the Standard ProM Paradigm: Implementation Intentions

ProM using the standard paradigm usually present ProM tasks in the form of implementation intentions (Gollwitzer, 1999). Implementation intentions identify all components of ProM at the time of encoding: the specific ProM cue, the opportunity to execute the task, and the ProM action. For example, participants may be assigned the ProM task of remembering to press the spacebar key whenever they see a particular cue word (e.g., *tiger*). Implementation intentions may improve ProM because they specify the exact context in which the ProM task will be executed (Gollwitzer, 1999). Once participants encounter the context in which the ProM task has to be performed, the ProM task is automatically triggered.

In dynamic operational environments, however, there may be considerable variation in encoding and executing ProM tasks (Holbrook & Dismukes, 2009). Because the standard ProM paradigm presents ProM tasks in the form of implementation intentions, it is possible that the failure rate of ProM tasks encoded and executed in operational environments exceeds the rate of ProM failures obtained by the standard paradigm.

3.1.2 ProM Encoding in Operational Environments

In dynamic environments ProM tasks may not use implementation intentions (Holbrook & Dismukes, 2009). There may be uncertainty associated with any of the three aspects of ProM (i.e., *that, when, what)*. Uncertainty in encoding ProM components may negatively affect whether the ProM task is successfully maintained over time, as well as whether it is recalled. Holbrook and Dismukes (2009) illustrated the variability and richness of everyday ProM tasks. They instructed participants to keep track of their everyday ProM tasks over the span of a week. While encoding, most participants did not specify the context in which they would execute future intentions. For example, participants may determine that a task had to be performed at some time in the future (e.g., “remember to email some files to a colleague”) but fail to specify whether it had to be executed at a specific time, in a specific place, or after a specific event. Such intentions thus did not specify the cue (or *when)* that would prompt them to execute the ProM task.

Even when the ProM cue is encoded, there may variability in the details specified at the time of encoding. We may encode the general category to which a cue belongs (e.g., an animal name) instead of the specific instance of the category (e.g., *tiger*). Cues that indicate a general category are remembered less well that specific cues (Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995; Ellis & Milne, 1996).

Another variation in *when* may be with regards to the precise time window during which the task has to be executed. In the standard ProM paradigm, the opportunity of execution is marked by the occurrence of the ProM cue. Once the cue occurs, participants are usually expected to immediately execute the ProM action. However, in dynamic operational environments there may occasionally be a delay between seeing the ProM cue and executing its associated action. In the example of the ED physician earlier, it may be possible that the physician receives consult notes from the cardiologist but is unable to immediately execute the ProM action of ordering labs for patient X. The physician may have to complete the current task before executing the ProM task. This example illustrates a delay between receiving the ProM cue, and reaching the opportunity to execute the task.

An additional source of uncertainty in ProM has to do with the number of actions with which a cue is associated. This may lead to uncertainty with the *what* component. Cook, Marsh, Hicks, and Martin (2006) found that cues that were associated with more actions resulted in less successful ProM than cues associated with fewer actions. Thus, an ED physician who associates the cue of working on patient records on the computer with multiple ProM actions such as ordering labs for patient X, updating allergy information for patient Y, and ordering medication for patient Z, may be less successful in remembering all three actions as compared to someone who associates the cue with only one action, for example, updating allergy information for patient Y.

Related to this, a cue may be associated with different actions at different points in time. For example, an ED physician may use the cue of entering patient notes to order labs for the patient at one time, and to prescribe medication for the patient at another time later in the day. In such a case a ProM failure may occur when the cue triggers the wrong action at the wrong time. Thus, even though the physician may remember *that* something has to be done and *when* it has to be done, he or she may not correctly remember *what* has to be done. In this way, variations in ProM may manifest as different types of ProM errors.

3.2 Performance Interval

The performance interval is the third stage of ProM (Ellis, 1996) and signals the beginning of the opportunity to execute the ProM task. The activities in the midst of which the ProM cue is expected to appear are called ongoing tasks. During the performance interval, the operator must self-initiate the execution of the ProM task. This involves several steps: detecting the ProM cue, recognizing it as a signal to execute the ProM task, and self-initiating the retrieval of the ProM action. There is currently a debate about the extent to which resource-demanding cognitive processes are required during the performance interval (McDaniel & Einstein, 2000; Smith, 2003). This debate is discussed below.

3.2.1 Cognitive Resources Underlying the Performance Interval

The multiprocess theory (McDaniel & Einstein, 2000) states that remembering *that* a task has to be performed in the future does not inevitably consume cognitive resources. Specifically, detection of the ProM cue is automatic when the cue is distinctive and when it engages focal processing. Focal processing is recruited when performing the ongoing task also entails processing the primary features of the ProM cue. According to the multiprocess theory, a distinctive ProM cue is automatically noticed and leads to spontaneous retrieval of the ProM action.

Smith and colleagues (Smith, 2003; Smith et al., 2007) have challenged the spontaneous nature of retrieval proposed by the multiprocess theory. They found that remembering to perform a ProM task was associated with slowed responding on the ongoing task, compared to participants who were not holding a ProM task in memory during the ongoing task (Smith & Bayen, 2004; Smith et al., 2007; Smith, 2003). The phenomenon of slowed responding on the ongoing task is referred to as ProM task costs, or costs to the ongoing task (Smith, 2003). According to the preparatory attention and memory (PAM) processes theory (Smith, 2003), slowed responding on the ongoing task occurs because the operator is strategically monitoring for the occurrence of the ProM cue and the opportunity to execute the ProM task. Thus, according to the PAM theory, successful performance on the *that* aspect of ProM requires dedicating resources to detect the occurrence of the ProM cue. Although the exact nature of such resources are unclear, Smith (2003) hypothesizes that they may involve preparing to execute the ProM task, or preparatory attentional processes

The debate between the PAM theory and the multiprocess theory has implications for the success of ProM tasks in uncertainty-laden operational environments. In dynamic environments, operators may have to contend with several demands on their cognitive resources. Operators may have to maintain high performance on safety-critical tasks while switching between different types of tasks that have differing cognitive demands. Because cognitive resources may be focused on managing uncertainty and the demands of the ongoing tasks in the operational environment, operators may be unable to devote resources to monitor for, or to detect, the ProM cue during the performance interval. In fact, it has been argued that it may be difficult and impractical to dedicate resource-demanding preparatory attentional processes to detect the ProM cue (Harrison & Einstein, 2010), and that ProM tasks are occasionally automatically triggered on seeing the ProM cue (McDaniel & Einstein, 2000). However, if preparatory attentional processes are necessary to ProM success, then the PAM theory predicts that environments characterized by high resource demands may leave insufficient resources for operators to dedicate to monitoring the environment for the ProM cue. Therefore, demanding environments may lead to greater failures in correctly executing the *when* aspect of ProM tasks.

3.2.2 Uncertainty During the Performance Interval

Any factor that affects the context of execution may also affect ProM at the performance interval stage. Uncertainty in specifying the context of ProM execution may lead to difficulties in identifying the beginning or the end of the performance interval, or both. One of the ways in which uncertainty may operate during the performance interval is by frequent and unpredictable task switching. When operators have to frequently switch between tasks, they may be unable to define the exact context in which the ProM task will be executed. For example, a physician in the ED may encode the ProM task of remembering to order labs for patient X in the next five minutes. However, because of the dynamic nature of work, the physician may be unable to predict which task he or she will be working on in the next five minutes. As a consequence, the physician may be unable to anticipate characteristics of the retrieval context in which labs will have to be ordered, or even the cognitive resources that may have to be interrupted to monitor for the opportunity to order labs (i.e., after 5 minutes have passed). Difficulty in encoding the features of the ProM opportunity that will be encountered during retrieval may result in ProM failure (encoding specificity, Tulving, 1983).

A failure to anticipate the retrieval context of ProM may have other consequences, too. It is possible that the resources required by the ongoing task during the performance interval (e.g., text comprehension) may be different from those required to detect the ProM cue (e.g., categorization). In this case, the ProM cue would be non-focal and may require engagement of resource-demanding controlled processes for detection. However, being unable to anticipate the resource demands to detect the ProM cue at the time of encoding may hamper cue detection and subsequent ProM success (McDaniel & Einstein, 2010; Smith, 2010).

The principle of encoding specificity can also be invoked to explain how uncertainty induced by task switching may affect ProM. Encoding specificity states that when information that is present during encoding is also present at retrieval, it results in an improvement in memory compared to when the contexts differ (Thomson & Tulving, 1970). When a task is encoded within a larger context, it may create “hooks” to the context. If the same context is present during retrieval, then the hooks created during encoding may trigger retrieval.

However, dynamic environments may result in frequent changes in the context of execution due to task switching. Therefore, it is possible that even if the ProM task was encoded in the context of a specific task, the operator may no longer be working on that task during the performance interval. Operators may find it difficult to recognize the performance interval if the ProM task has not been associated with a specific ongoing task at the time of encoding (Nowinski & Dismukes, 2005), which may hurt ProM performance.

CHAPTER 4. UNCERTAINTY IN PROSPECTIVE MEMORY

Very generally, uncertainty may be thought about as lack of information (Shannon, 1948). Lack of information may lead to uncertainty through an inability to anticipate or predict the future (Milliken, 1987). Switching between tasks in dynamic operational environments may contribute to uncertainty by bringing about a change from the context experienced at ProM encoding to execution. This section will present a brief overview of task switching and its relationship to ProM, and will present a special case of task switching in ProM through the delay-execute paradigm.

4.1 Cognitive Processes Involved in Task Switching

When switching between tasks, the task set associated with an old response has to be inhibited (Koch, Gade, Schuch, & Philipp, 2010) and the mental set or schema to execute the new task has to be initiated. Each new stimulus or task may afford multiple responses. Which response is selected depends on several factors: the goal of the person, the context in which the action has to be executed, and the availability, frequency, and recency of alternative responses to the stimulus (Monsell, 2003). Executive control is used to activate the set associated with the upcoming task (Altmann, 2004), and to select the action that best meets task goals. If an operator has associated the beginning of a particular task with the execution of a ProM response, and if the order in which tasks are switched is not predictable, then the operator must have two possible response sets at the time of switching: that associated with performing the upcoming task, and the ProM response.

Task switching has been associated with performance costs (Monsell, 2003). Switching to a new task may result in greater time to respond to the new task, and errors in responding. This is because the cognitive system takes time to initiate a change in the mental set to respond to the new task (Monsell, 2003). Reduced speed and accuracy in responding to new tasks because of task switching are called switch costs. Switch costs are reduced when people know in advance which task they will be switching to. Even though switch costs reduce with advance preparation to anticipate the switch and the type of task to be switched over to, the costs persist, even after a few seconds are given to prepare for the switch (Monsell, 2003).

4.1.1 Task Switching and ProM

Switching between different types of tasks has been found to interfere with ProM (Finstad, Bink, McDaniel, & Einstein, 2006). This is because task switching may interfere with the context of ProM response execution. If the ProM task has been associated with a particular ongoing task at the time of encoding, then frequent task switching may mean that that task may no longer be present during ProM retrieval. In case of such a dissociation between the ProM task and the ongoing task, the ProM task may not be activated until operators begin working on the specific ongoing task within which the ProM task was encoded. A change in the context from encoding to execution has been found to result in ProM failure (Nowinski & Dismukes, 2005, Experiment 1).

The failure of ProM in safety-critical dynamic environments characterized by task switching such as healthcare may have troublesome consequences. For example, a physician may encode a ProM task of remembering to enter important allergy information in the electronic health record after finishing the physical exam. However, if the physician is forced to switch to another task after the physical exam, then the association between completing the physical exam and entering allergy information is severed. A failure to complete the ProM task may result in the patient being given unsuitable medication, possibly worsening the patient's health and prolonging the patient's hospital stay.

Performance on ongoing tasks may also be negatively impacted by having to remember ProM tasks during task switching (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003). When engaging in task switching, participants are likely to show slower and less accurate responding on new tasks because of switch costs (Kiesel et al., 2010; Monsell, 2003). If the predictions of the PAM theory hold true, then remembering a ProM task may further lower performance on new tasks. This is because resources may be devoted to monitoring for the ProM cue and the opportunity to execute the ProM action (Smith, 2003). On the other hand, if the ProM cue is salient and if the predictions of the multiprocess theory hold true, then performance on ongoing tasks may not be worse when holding a ProM task along with task switching (McDaniel & Einstein, 2000).

It is possible to test the predictions of the PAM theory and the multiprocess theory by comparing performance on ongoing tasks between ProM and non-ProM trials. If ongoing task performance is slower or less accurate on ProM trials than non-ProM trials, then it is possible that participants are monitoring for the ProM cue and opportunity to execute the ProM response; this would lend support to the PAM theory that ProM tasks are resource-demanding. On the other hand, comparable performance between the ProM and non-ProM trials may mean that ProM tasks may not require monitoring that results in slowed and worse responding on ongoing tasks; this could be interpreted as support for the multiprocess theory.

4.2 Delay-Execute ProM: A Special Case of ProM Uncertainty Through Task Switching

In the standard paradigm to investigate ProM, detection of the cue and execution of the action occur closely in time. As soon as the participant detects the ProM cue (e.g., a particular word), he or she has to immediately execute the ProM action (e.g., pressing the spacebar key). In dynamic environments, however, operators may not be able to perform the ProM action immediately after seeing the cue. The delay between cue recognition and ProM action execution may occur because insufficient environmental resources are available to perform the action immediately. Delayed response execution may also result from having insufficient cognitive resources to execute the ProM task because of being engaged in another important task at the moment of perceiving the ProM cue. ProM tasks characterized by a delay between cue presentation and execution of ProM content are called *delay-execute ProM* (McDaniel et al., 2003). In the standard delay-execute paradigm, participants are instructed to remember to execute a response after they have seen a cue. However, response execution has to be deferred until they finish working on their current ongoing task.

A task-switching paradigm is often used to investigate delay-execute ProM. Einstein et al. (2003) investigated whether attention demands of ongoing tasks and the delay between cue presentation and action execution would influence delay-execute ProM. Every 60 seconds, participants switched between eight different ongoing tasks. The ongoing tasks differed in the extent to which they recruited complex cognitive processes.

Some tasks such as solving mathematics problems or choosing synonyms were more complex and resource demanding compared to tasks requiring simple judgments such as pleasantness rating or similarity rating. In addition, for half of the participants, attention was divided in the first half of performing each ongoing task by simultaneously performing the digit monitoring task.

The ProM cue was a red screen that appeared when participants were in the midst of working on ongoing tasks. The ProM task consisted of remembering to press a key after seeing the red screen, but only after finishing the current ongoing task. The delay between presentation of the ProM cue (the red screen) and the opportunity to execute the ProM action (reaching the end of the current ongoing task) was 5, 15, or 40 seconds. Occasionally, participants would also experience an interruption during the 40-second delay condition.

Einstein et al. (2003) found that ProM performance suffered when participants had to perform the digit monitoring task along with the ongoing tasks. When participants' attention was divided between working on the ongoing tasks and performing the digit monitoring task, they may have had insufficient cognitive resources to actively rehearse the ProM task. There was no effect of delay on ProM; however, experiencing an interruption during the delay resulted in worse ProM. These results were replicated by McDaniel, Einstein, Graham, and Rall (2004). These studies on delay-execute ProM suggest that interfering with active maintenance of the ProM action (as evidenced by an inability to rehearse the ProM task during the divided attention task or during the interruption) hurts ProM.

CHAPTER 5. LIMITATIONS OF THE STANDARD DELAY-EXECUTE PARADIGM

5.1 Fixed duration of ongoing tasks

Although the studies described above have helped shed light on the difficulties associated with executing ProM tasks, there are some limitations in previous research on ProM using the delay-execute paradigm. One limitation concerns the fixed durations of ongoing tasks (Einstein et al., 2003; McDaniel et al., 2004). Each trial of the experiments by McDaniel and Einstein comprised one ongoing task. Participants solved 12 consecutive 5-second problems of one ongoing task on each trial. Thus each ongoing task lasted for one minute.

Because of the predictable duration of ongoing tasks, participants may have been able to anticipate when to devote resources to monitor for the opportunity to execute the ProM task. In dynamic environments, however, it may be difficult to predict when task switches may occur, as well as how much time may be available to work on any given task before being forced to switch to the next task. Uncertainty about the timing of task switching as well as the duration of working on tasks may consequently lead to difficulty in predicting the occurrence of the window of opportunity of executing the ProM task. The current dissertation varied the duration of ongoing tasks, as well as the moment of task switch. Making the duration of the ongoing tasks unpredictable helped in closely mirroring the unpredictable nature of task switching in dynamic operational environments. The ProM cue was a red screen that appeared when participants were in the midst of working on ongoing tasks. The ProM task consisted of remembering to press a key after seeing the red screen, but only after finishing the current ongoing task. The delay between presentation of the ProM cue (the red screen) and the opportunity to execute the ProM action (reaching the end of the current ongoing task) was 5, 15, or 40 seconds. Occasionally, participants would also experience an interruption during the 40-second delay condition.

5.2 Nature of Cognitive Activities of Ongoing Tasks

A second limitation of the standard delay-execute paradigm concerns the nature of ongoing tasks. With some exceptions, current research investigating delay-execute ProM uses ongoing tasks that impose relatively easy cognitive demands such as answering vocabulary or trivia questions, rating the pleasantness of words, categorizing objects, etc. (McDaniel et al., 2004). Although such tasks may mimic the processes required for some types of routine work, participants may also be more likely to engage in rehearsal of the ProM task while performing them because the tasks may require relatively few resources.

Switching between the relatively simple tasks in the standard delay-execute paradigm on ProM may also not mimic the complexities of task switching in operational environments. For example, a physician in the ED may have to switch between patient examination, a task requiring problem solving and decision making, to charting, a task that requires retrospective memory to match patient diagnoses to appropriate prescription drugs, to planning, for example, by scheduling follow-up examination.

An additional criticism about the nature of the tasks used in previous studies concerns mundane realism. Many ongoing tasks involve similar cognitive processes (e.g., decision making). However, these tasks are not logically connected to each other because often they do not share a higher-order goal. The types of ongoing tasks used in current delay-execute experiments lack the connection that may be inherent between ongoing tasks in operational environments.

To address these criticisms about the nature of ongoing tasks, the current dissertation used ongoing tasks that were modeled after the type of activities that are performed by healthcare providers. The ongoing tasks were developed in consultation with an ED physician. These tasks included reading and recalling patients' histories, reading and interpreting medical charts, calculating the probability of disease, and calculating the dosage of medication based on the weight of patients. Because these tasks involve cognitive processes such as reading and graph comprehension, recall, decision making, and mathematical reasoning, they may be considered to be at least as resource demanding as ongoing tasks used in previous research. In addition, because the tasks shared the common goal of managing patients and providing healthcare services, they had greater mundane realism than tasks used in previous research in the delay-execute paradigm.

5.3 Lack of Variation in ProM Cue and its Associated Action

A third criticism of research using the standard delay-execute paradigm involves the ProM cue. Participants are usually given a single ProM task that may have to be performed multiple times during the experiment. The cue triggering the ProM action is always the same (e.g., a red screen), as is the ProM response (e.g., press the spacebar key). Even though the ProM action has to be made at the end of the ongoing task in which the ProM cue has occurred, it may be possible for participants to occasionally respond from remembering the ProM cue from a previous trial. However, in the standard delay-execute paradigm it is unclear whether the ProM response has occurred after seeing the most recent (and correct) cue, or after having recalled a previously presented cue. This issue was addressed in the current dissertation by presenting a distinct ProM task on each ProM trial. Each ProM task was associated with a different window of opportunity of execution, as well as a different response to execute the ProM task.

5.4 Brief Delays Between Cue Presentation and Response Execution

A fourth limitation of current delay-execute research concerns the delay between cue presentation and response execution. This delay is usually brief, ranging from a couple of seconds to under a minute. McDaniel, Einstein, and colleagues (Einstein et al., 2003; McDaniel et al., 2004) have found that ProM performance did not significantly differ when the delay between cue presentation and response execution ranged between 5 – 40 seconds. Current research using the delay-execute paradigm has not investigated the effect of longer cue-execution delays on ProM.

In addition, in busy operational environments, the cue-response delay may be longer than those investigated in the standard delay-execute paradigm due to unpredictable availability of physical or cognitive resources to execute the task. One of the objectives of the current dissertation was to investigate the effect of extended delays on ProM in the delay-execute paradigm. Specifically, participants experienced delays ranging from a few seconds to a couple of minutes between presentation of the ProM instruction and execution of the action.

Previous research on the effect of delays on ProM may be used to guide hypotheses about delays. Because this research was not conducted using the delay-execute paradigm, the delays investigated do not occur between cue presentation and ProM task execution. Instead, delays have been manipulated in two ways: 1) by inserting a task unrelated to the ongoing task (a "filler" task) between encoding of the ProM task and beginning the ongoing task in which the ProM cue appears; 2) by increasing the time spent working on the ongoing task until when the ProM cue is encountered.

Martin, Brown, and Hicks (2011) investigated whether the duration of the delay as well as the tasks performed during the delay would affect ProM. After encoding the ProM task, participants experienced one of four types of delays: short filler task/short ongoing task (6 minutes delay before ProM cue presentation); short filler task/long ongoing task (21 minutes delay); long filler task/short ongoing task (21 minutes delay); and long filler task/long ongoing task (36 minutes delay). Martin et al. found a significant interaction between the length of the ongoing tasks and length of the filler tasks on performance: a longer filler task followed by a shorter ongoing task resulted in the best ProM performance. Participants in the long filler task/short ongoing task condition may have engaged in rehearsal of the ProM task while performing the filler task. Once participants reached the context in which the ProM task had to be executed, i.e. the ongoing task, a longer duration until encountering the ProM cue may have resulted in forgetting of the ProM task. Therefore, it is important to consider whether delays afford an opportunity to rehearse the ProM task.

Hicks, Marsh, and Russell (2000) also investigated whether manipulating delay by varying the nature of filler tasks would affect ProM. Participants performed one of three types of filler tasks: a continuous 15-minute filler task; a 15-minute filler task with periodic unfilled intervals; and five trials of different filler tasks, each of which lasted three minutes.

ProM performance was highest with filler tasks that allowed periodic self-reminders or rehearsal of the ProM task. The second highest ProM performance occurred in the condition in which participants switched between five different filler tasks. Hicks et al. attributed higher ProM performance in this condition to self-reminders when participants were transitioning between tasks.

In the study by Hicks et al. (2000), the greater the number of task switches prior to reaching the opportunity to perform the ProM task was associated with a higher number of chances to rehearse the ProM task, and consequently increased the chances of ProM success. However, it is possible that rehearsing the ProM task is difficult once participants begin the ongoing task (and enter the window of opportunity to perform the ProM task). Finstad et al. (2006) found that ProM was lower when participants switched between different types of tasks than if they performed the same task on subsequent trials. Therefore, delays through task switching may have different effects on ProM based on similarity of the cognitive activity in the tasks.

The memory for goals theory (Altmann & Trafton, 2002) can also be used to inform predictions about the effect of delays. Suppose the ProM task is considered the primary task and the ongoing tasks between the ProM cue and action execution are considered to be the secondary, interrupting tasks. The memory for goals theory predicts that lengthy interruptions result in decay of the primary task unless the primary task is rehearsed or reinforced by environmental stimuli. Therefore, the greater the length of the interval separating the ProM cue from the opportunity to perform the ProM task, the greater will be the likelihood of decay of the goal of performing the ProM action.

However, the memory for goals theory also predicts that resumption lags will be smaller when there is an opportunity to rehearse the primary task. Previous research in ProM has also found that ProM improves when participants experience a chance to rehearse the ProM task (Hicks, Marsh, & Russell, 2000; Martin, Brown, & Hicks, 2011). In the current experiment, the greater the interval between the presentation of the ProM cue and the opportunity to perform the ProM action, the greater will be the times that the participants switch between tasks. If participants use the opportunity of switching between tasks to rehearse the ProM task, then longer delays between cue presentation and response execution should not affect ProM performance.

However, there is some evidence suggesting that the moment of task switching may be used to activate cognitive structures to respond to the upcoming task (Altmann, 2004). In addition, frequent task switching is associated with switch costs (Monsell, 2003). If this is true, then participants who experience a greater number of task switches between experiencing the ProM cue and executing its associated action may be cognitively slowed by the switch costs and fail to use the interval between tasks to rehearse the ProM task. In the current dissertation, participants switched between different types of tasks and were expected to experience switch costs. In this case, the memory for goals theory would predict that ProM performance would be worse with greater number of task switches (and greater lengths of delay) between the cue and the opportunity to execute the ProM task, unless participants rehearsed the ProM task during switching.

In summary, past research can be used to guide competing predictions about the effect of delay on ProM performance. In the current dissertation, length of the delay was varied by changing the number of ongoing tasks that separated instruction on the ProM task from the opportunity to execute the task. Longer delays therefore resulted in more switches between tasks involving different types of cognitive activities as compared to shorter delays.

5.5 No Change in the Context From Cue Presentation to Response Execution

A fifth criticism of the current delay-execute paradigm, related to the previous section on delay, involves the activity during the interval separating presentation of the ProM cue and the execution of the associated action. In previous research, the cue-response delay has not extended over multiple tasks. The ProM response has to be made at the end of the same ongoing task in which the ProM cue appeared. The cue and the response are part of the same context. Thus, there is no variability in the context in which the cue occurs and the one in which the response has to be executed. In environments characterized by task switching, however, this context may frequently change. The opportunity of response execution may occur when the current task is no longer active; thus, the context of encoding the ProM task may be different from the context of its execution. If task switching is unpredictable in terms of when the switch will occur as well as what the upcoming task will be, then operators may be unable to anticipate the specific task in whose context they will encounter the opportunity to execute the ProM task. Thus, task switching may induce uncertainty about the context of execution at the time of encoding the ProM task. Current delay-execute paradigms do not investigate such variation in ProM response encoding, and its ensuing effect on ProM execution. The primary research objective of this dissertation is to investigate whether uncertainty experienced at the time of ProM encoding will have an effect on ProM performance.

In summary, the standard paradigm of delay-execute ProM has numerous limitations. Ongoing tasks are of a fixed duration, and task switches appear at predictable intervals. The ongoing tasks recruit relatively simple cognitive processes. A single ProM cue is associated with the ProM response, making it difficult to uncover whether ProM responses were made after seeing the most recent cue, or after having recalled a previous occurrence. Finally, participants make the ProM response at the end of the same ongoing task in which the cue appears. Thus, there is no change in the context from presentation of the ProM cue, and there is a very brief delay from cue presentation to ProM execution. These limitations make it difficult to capture the nature of cognitive work in operational environments.

CHAPTER 6. DESCRIPTION OF CURRENT EXPERIMENTS

In the standard delay-execute paradigm, participants are instructed to remember to execute the ProM content, but only after finishing the current ongoing task (McDaniel et al., 2004). However, there is no uncertainty with regards to the opportunity of response execution because the response has to always be made at the end of the current ongoing task. In dynamic operational environments, however, the opportunity to execute the ProM task may be more unpredictable. It may be possible to think about two aspects that constitute the opportunity of response execution. The first relates to the time duration until which the opportunity may occur. This aspect may be defined in terms of time (e.g., execute the ProM task after 10 minutes), or number of tasks (e.g., execute the ProM task after the next two tasks) until encountering the window of opportunity.

The second aspect of the opportunity of response execution has to do with clarifying the context of execution. One way to do this is by specifying the characteristics about the target ongoing task that will constitute the context in which the ProM response has to be executed (e.g., after finishing patient examination). It may be possible for uncertainty in this latter type of response execution opportunity to exist even if the operator has information about the former aspect. Thus, even if the operator knows that a ProM task has to be executed after 10 minutes or after finishing the next two tasks, he or she may still not know the specific task at the end of which the ProM response has to be made. This would be especially true when the operator may be unaware about the order in which tasks are arranged.

The current dissertation uses a modified delay-execute paradigm to investigate the effect of response opportunity uncertainty on ProM execution. In the modified delay-execute paradigm, participants had to remember to execute a ProM task after seeing the ProM cue. However, ProM response execution was deferred until participants reach a pre-specified context for the execution. In Experiment 1, the context of execution was the end of a given number of ongoing tasks. In Experiment 2, the context of execution was the end of a specific ongoing task.

Participants switched among four ongoing tasks. These tasks were developed in consultation with an ED physician and were expected to engage cognitive processes that a healthcare provider would need to engage in to perform the relevant tasks. The tasks included text comprehension, calculating the probability of disease, interpreting graphs about medical information, and dose calculation. In Experiment 1, the ProM task comprised remembering to order labs for a patient, but only after completing the current, next, or next two ongoing tasks.

Suppose the ongoing tasks are performed in the following order: reviewing the history of the patient – probability of disease calculation – graph interpretation – dose calculation. Suppose also that the ProM instruction occurs during the second ongoing task (i.e., probability of disease calculation). The ProM instructions identify after how many tasks participants would have to remember to execute the ProM response (e.g., after the next task). After having received the instruction, participants would have to suppress execution of the ProM response until reaching the end of the third ongoing task, (i.e., graph interpretation, the next task after the current task). After finishing performance on the graph interpretation task, the participant would have to self-initiate performance of the ProM action.

In the current dissertation, participants experienced one of two levels of environmental unpredictability: ongoing tasks either followed a known order (certain task order), or had an unpredictable order (uncertain task order). Even though participants in both groups were told the number of tasks after which the ProM response would have to be made, only the participants in the certain condition could make use of task order to additionally encode the features of the ongoing task associated with ProM response (e.g., they knew that the "next task" would be graph interpretation, and could encode their ProM intention using this specific context). Thus, the retrieval context of the ProM task could be more concretely encoded for participants in the certain task order condition.

In addition to using the order of ongoing tasks to vary uncertainty between subjects, uncertainty was also varied within subjects. Specifically, all three aspects of ProM (*that*, *when*, *what*) were associated with uncertainty. Uncertainty with the *that* component varied because participants completed ProM as well as non-ProM trials in each of the three experimental blocks. Thus, on some blocks, participants did not have to execute a ProM task.

Uncertainty with the *when* aspect was varied by varying the number of intervening tasks after which the ProM response had to be made. Thus, participants had to remember to respond after the current, next, or the next two tasks.

Uncertainty with the *what* aspect was varied by associating a different key press with the execution of the ProM task. Each ProM trial identified the *when* and *what* aspects; thus, these uncertainties were presented to participants at the stage of ProM encoding.

CHAPTER 7. HYPOTHESES

7.1 ProM Performance

7.1.1 Hypothesis 1 (when)

Participants in the certain task order condition will execute more ProM tasks in the correct window of opportunity (or *when)* compared to participants in the uncertain condition.

7.1.1.1 Rationale

At the time of ProM encoding, participants in the certain condition would be able to use knowledge about task order to associate the *when* aspect of ProM with the specific ongoing task that would be encountered at the time of executing the ProM response. In contrast, the retrieval context will be relatively undefined for participants in the uncertain condition because they would not be aware about the order in which tasks are arranged. Therefore, even though they would know the number of intervening tasks after which the ProM response has to be executed, they would not be able to imagine features of the retrieval context at the time of encoding.

7.1.2 Hypothesis 2 (that)

Participants in the certain task order condition will remember to perform more ProM tasks (or have a higher average score on the *that* aspect of ProM) compared to participants in the uncertain condition.

7.1.3 Hypothesis 3 (what)

Participants in the certain task order condition will have a significantly higher average ProM score on the *what* aspect of ProM (i.e., they will press the correct key) compared to participants in the uncertain condition.

7.1.3.1 <u>Rationales for hypotheses 2 and 3</u>

Participants in the certain condition should be able to anticipate the upcoming ongoing tasks. Knowledge about task order may leave them with more resources to engage in controlled processes that are required to detect non-focal ProM cues (in this case, the end of the target ongoing task after which the ProM response has been made), as well as remember the ProM content (or the *what* aspect of ProM).

7.1.4 Hypothesis 4 (delay)

The memory for goals theory and Finstad et al. (2006) would predict that longer delays between ProM instruction and the opportunity for execution that do not allow ProM rehearsal will result in goal decay, accumulation of switch costs, and frequent changes in the cognitive activity engaged by the ongoing task; this would lead to worse ProM performance compared to shorter delays.

However, Hicks et al. (2000; 2011) would predict that if longer delays allow for greater task switches, and subsequently, greater chances to rehearse the ProM task, then longer delays would result in a significantly higher ProM performance than shorter delays that do not allow for ProM rehearsal or active maintenance of the ProM task in working memory. Thus, participants may perform better in longer delays that allow for more chances of rehearsal of the ProM task.

7.2 Ongoing Task Performance

7.2.1 Hypothesis 5 (monitoring costs)

Participants will have higher average accuracy and lower response time on the ongoing task on non-ProM trials as compared to ProM trials.

7.2.1.1 Rationale

Being engaged in monitoring for a ProM task may result in costs to the ongoing task in the form of greater response time and lower accuracy in responding to the ongoing task (Smith, 2003). Costs to the ongoing task occur because of the decision-making process involved when encountering each stimulus of the ongoing task: making the ongoing task response vs. the ProM response. Such monitoring costs may be especially high whenever participants may be unaware of the upcoming task, for example, when participants in the uncertain condition switch to a new task.

CHAPTER 8. EXPERIMENT 1: METHOD

8.1 Participants

Forty-four participants (Females = 18; Males = 26; Age: *M* = 20 years, *SE* = 1.8) were drawn from the undergraduate subject pool at the Georgia Institute of Technology. Participants were compensated by extra credit.

8.2 Materials, Design, and Procedure

8.2.1 Ongoing Tasks

Participants switched among four resource-demanding ongoing tasks. At any given point in time, participants worked on only one ongoing task. Each ongoing task lasted between 50 and 80 seconds. Because of the uncertain duration of each ongoing task, participants were unable to anticipate the end of the current task and consequently, the amount of time until the beginning of the upcoming task.

Even though undergraduate students were recruited for the experiment, tasks were designed in order to engage cognitive processes that a healthcare provider would need to perform the relevant tasks.

The ongoing tasks were modeled after the types of tasks in a dynamic healthcare setting such as the ED. These tasks were chosen in consultation with an ED physician who indicated them to be common tasks that healthcare providers would engage in. The four tasks included: reading and answering questions about the medical history of patients; calculating the probability of disease; interpreting graphs about medical information; and calculating the dosage of medication. In this sense, the tasks were connected to each other through the higher-order goal of effectively managing a patient.

8.2.1.1 Patient History

The four ongoing tasks intentionally engaged a variety of cognitive processes including text and graph comprehension, arithmetic reasoning, problem solving, and decision-making. The patient history task involved text comprehension and recall. Participants read a passage about the medical history of a patient. The passage included five to eight facts about the patient. The facts included symptoms, vital signs, past and current medical conditions, current medication, and adverse reactions to medications. Participants then answered four multiple-choice questions about the passage. Questions included recalling patient symptoms, dose of medication, and change in vital signs due to medication.

8.2.1.2 Disease Calculation

The disease calculation task involved arithmetic reasoning and drew upon Bayes' theorem. Participants were told that a laboratory test for a specific illness was positive. They were then provided with three additional pieces of information: the reliability rate of the test in detecting the illness, the false positive rate of the test, and the prevalence of the illness in the general population. Using this information, participants had to calculate the likelihood that the patient may actually have the illness. The formula to calculate disease probability was continually present on the screen.

8.2.1.3 Graph Interpretation

The graph interpretation task presented a graph with data that would be present on bedside patient monitors. This included body temperature, pulse rate, respiration rate, and blood pressure. A line graph was used to represent the data for each vital sign. Participants then answered three multiple-choice questions about the graph. The graphs were continuously present on the screen while participants answered the questions. Example questions included interpreting the data at different time points, trends in the patient's status, and the relationship between the variables over a period of time.

8.2.1.4 Dose Calculation

The dose calculation task involved problem solving. Participants calculated the dose of tablet or intravenous medication. Participants were given the available strength of a medication, e.g., 500 milligrams, and the dose at which a patient was required to take the medication (e.g., 1.5 grams). Using this information, participants calculated the quantity of medication that the patient would have to consume (for this example, 3 tablets).

8.2.2 ProM Task

A modified delayed-execute paradigm was used to measure ProM. A ProM task comprised remembering to perform an action after seeing a cue, but only after finishing the current, the next, or the next two ongoing tasks. Specifically, participants were instructed to remember to order labs for a patient by pressing a key, but only after finishing a previously-identified number of ongoing tasks. Even though the ProM action always involved remembering to press a key, each ProM task identified a different key to be pressed.

Participants received the ProM instruction as an interruption while performing the ongoing tasks. ProM instructions could be received while performing any ongoing task; thus, the ProM response was not tied to any particular ongoing task. This ensured that when participants executed the ProM action, they would do so in response to the cue from the trial that they were currently working on, and not from recalling the cue from a previous trial. As mentioned previously, the ProM action would also change from trial to trial.

To mark the ProM instruction as distinct from the ongoing task, it always appeared on a screen that had a different colored background as compared to the ongoing task. The ProM instruction identified the number of tasks after which the participant had to make the response, as well as the key to be pressed to make the response. The key was any letter except the responses for the ongoing task (i.e., any key besides a, b, c, or d). Participants could take as long as they wished to encode the ProM task. They pressed the "9" key to return to the ongoing task.

8.2.3 Post-Experiment Questionnaire

This questionnaire asked participants different details about the task, and their performance on it. Participants were asked to recall the structure of the ProM task, and to estimate the number of tasks that intervened between presentation of the ProM instruction and execution of the ProM response. Participants were also asked to recall any strategies they may have used to perform the ProM task during the experiment, and whether these strategies changed throughout the experiment.

8.2.4 Design

A 2 (task order: certain vs. uncertain; between-subjects) x 3 (delay interval between ProM cue presentation and response execution: no intervening task delay vs. one delay vs. two delays; within-subjects) x 3 (experimental block number: 1 vs. 2 vs. 3; within-subjects) factorial mixed design was used in the experiment.

A trial comprised a sequence of the four ongoing tasks. In the uncertain condition, each trial comprised the four ongoing tasks occurring in random order (without replacement). In the certain condition, the four ongoing tasks were always presented in the same, pre-determined order. In both conditions, the ongoing tasks immediately followed each other; there was no break between subsequent ongoing tasks on the same trial. Tasks within each trial referred to different patients. Each task lasted between 50 – 120 seconds. The duration of each task was approximately between four to five minutes.

Each participant performed three blocks. Each block contained six trials. Within each experimental block, four trials presented a ProM task to the participant. Two ProM trials within each block had the same delay level (i.e., either 0, 1 or 2). The remaining two ProM trials in each block presented the two other delay levels. Thus, throughout the experiment, each participant performed four ProM trials of each delay level for a total of 12 ProM trials. Order of the experimental blocks were randomized.

In addition to the four ProM trials, each experimental block also had two trials in which participants were not assigned a ProM task. One purpose of the non-ProM trials was to test whether participants would make the ProM response despite not having been presented the ProM instruction. Specifically, it was possible for participants to remember ProM instructions from a previous trial but make its associated response on a later trial.

Thus, the purpose of the non-ProM trials was to test for commission errors. The order of ProM and non-ProM trials within each block was randomized.

ProM performance was measured by three dependent variables (DV). The first DV measured whether participants remembered that they had to perform a ProM task in ProM trials. The second DV measured whether participants remembered to perform the ProM task in the correct window of opportunity, that is, within 10 seconds of finishing the target ongoing task (or when). Finally, participants were also tested on whether they remembered what key they had to press to make the ProM response.

Ongoing task performance was also measured. Specifically, the speed with which participants advanced through the description of each problem, and the speed and accuracy with which they answered the ongoing task questions, was measured. Performance on the ongoing tasks was used as a measure of ProM costs.

ProM costs were measured by comparing participants' performance on the ongoing tasks during the ProM trials and the non-ProM trials. It should be noted that the nominal ProM cue in Experiment 1 was the completion of a specific number of ongoing tasks. The cue was not salient. Both the multiprocess and the preparatory attention and memory (PAM) processes theories hold that costs may be incurred to the ongoing task if the ProM cue is not salient (Smith, 2003; Smith et al., 2007). Therefore, worse performance on ongoing tasks on ProM trials compared to the non-ProM trials may reflect that participants devoted resources to engaging cognitive processes to detect the ProM cue and execute the ProM task.

8.2.4.1 Uncertainty

Figure 1 shows an example of each of the four trial types in the certain condition. The trials are arranged in increasing level of delay; the last trial illustrates the “non-ProM” condition. Each trial consists of four distinct ongoing tasks: patient history; calculating disease probability, graph interpretation; and dose calculation. In the certain condition the ongoing tasks always occur in a predictable order. Participants were told that there would be a 100% probability that each type of ongoing task would be followed by a specific type of ongoing task. In the case of Figure 1, for example, the ongoing tasks always occurred in the order patient history – disease calculation – graph interpretation – dose calculation. A trial could begin with any one of the four possible ongoing tasks. However, the figure illustrates how the progression of tasks within each trial would always follow a pre-learned order. In the condition of delay of one ongoing task, for example (row 2), the tasks would be arranged in the order disease calculation – graph interpretation – dose calculation – patient history. If participants see disease calculation as the first task then they could expect with 100% probability that the next task will be graph interpretation, followed by dose calculation, and finally, task patient history.

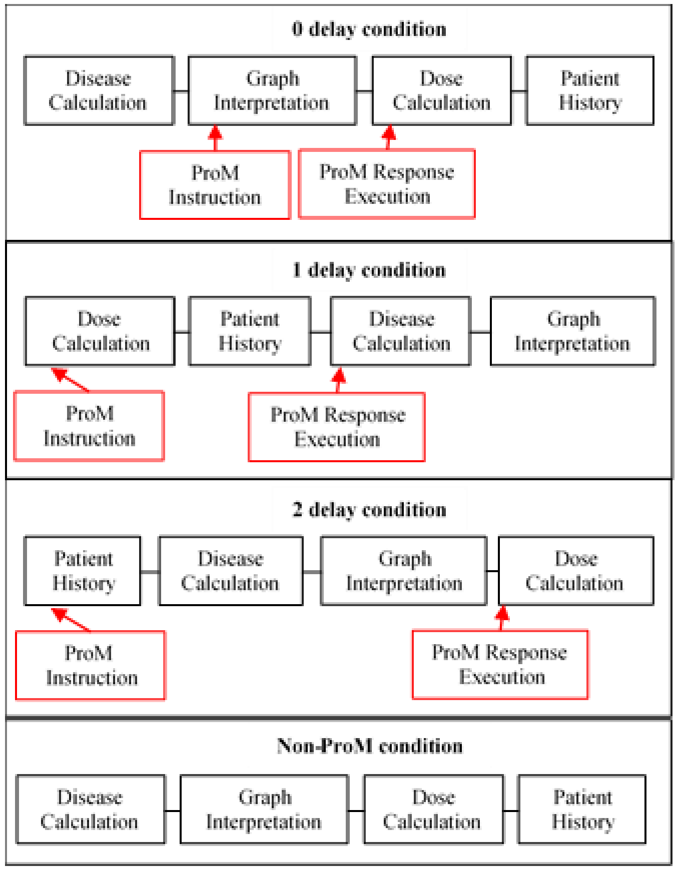

Figure 1. Four types of trials in the certain task order condition.

As noted earlier, each trial could begin with any one of the four possible ongoing tasks. After participants had completed one iteration of the four ongoing tasks (or one trial), they saw the words "END OF TRIAL." Thus, the trials were made distinct from each other so that participants in the certain condition could use the first task of each trial to predict the order of the next ongoing tasks. Signaling the end of each trial was especially important in differentiating consecutive trials in which one trial may end with a particular ongoing task (for e.g., dose calculation) and when the next trial may begin with the same ongoing task (i.e., dose calculation).

In ProM trials the ProM instruction identified the specific number of ongoing tasks after which the participants had to execute the ProM response. If participants in the certain condition used information about the order in which ongoing tasks were arranged, they could identify the appropriate opportunity to perform the ProM task with relative ease. For example, in row 2 of Figure 1 the ProM cue occurs at the beginning of the dose calculation task. Since this is the one-intervening-task delay condition, participants in the certain condition can use knowledge about the current task to predict the upcoming task. They could thus encode that the ProM action has to be executed at the end of the patient history task.

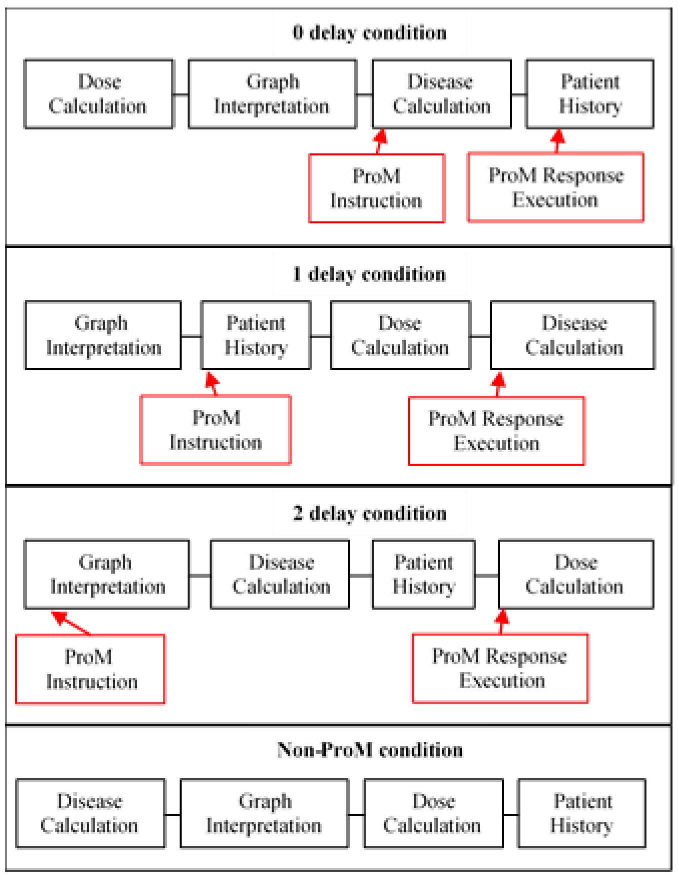

Figure 2. Four types of trials in the uncertain task order condition.

In the uncertain condition, ongoing tasks were not arranged in a predictable order.

In order to parallel the trials in the certain condition in which each task could only be followed by a different type of task (and not by itself), there was zero probability that a task would appear in succession on any given trial. That is, the experiment was constructed so that the same tasks did not appear consecutively after each other. Participants in the uncertain condition were instructed that each ongoing task could be followed by a different type of ongoing task with equal probability. Thus, participants were not able to use knowledge about the current ongoing task to predict the upcoming ongoing task.

Figure 2 shows an example of the four distinct trial types in the uncertain condition. In each trial the ongoing tasks are arranged in random order. In the condition of a delay of one ongoing task (row 2), for example, participants may see the ProM instruction during patient history, but would not be able to use this information to predict the task after which the ProM response had to be executed, that is, dose calculation.

8.2.4.2 Intervening Task Delay

In all ProM trials, the ProM instructions could occur as an interruption during the beginning of any ongoing task. In the no delay (or 0 delay) trial (row 1 in Figures 1 and 2), participants had to make the ProM response at the end of the same task in which the ProM instruction had occurred. In the 1- and 2- intervening task delay conditions the ProM response would have to be made at the end of the next, or the next two ongoing tasks, respectively. Because knowledge about the order of tasks was the main experimental manipulation, presenting the ProM instruction for the uncertain condition on the penultimate ongoing task with the expectation of the ProM action being performed on the upcoming (and last) ongoing task of the trial meant that there would be no uncertainty with respect to the context of ProM execution. Therefore, the 1-delay condition never occurred on the penultimate ongoing task in either the certain or the uncertain condition.

8.2.5 Procedure

Participants were tested individually. The experiment was presented to the participants through E-Prime and Psychopy software (Peirce, 2007, 2009) on a computer in an individual testing room in the Cognitive Ergonomics Lab. After providing consent, participants were randomly assigned to one of the two task order conditions.

8.2.5.1 <u>Training on Ongoing Tasks</u>

Participants were first trained on performing each of the four ongoing tasks. They were told to imagine themselves as physicians working in the emergency department of a hospital. As part of their responsibilities, they had to switch among four different tasks: reading a passage about a patient's history and recalling facts about the patient; calculating the probability of disease; interpreting graphs about medical information; and calculating dosage of medication.

Participants were trained on individually performing each of the four ongoing tasks. For each task, participants first read a description of the task and reviewed some worked examples of the task. Next, participants were tested on their understanding of the task. Task instructions emphasized speed and accuracy. Participants were given feedback about accuracy and response time on each problem. This process of instruction on the task, worked examples with the task, and testing followed by feedback on performance was repeated for each of the four ongoing tasks.

8.2.5.2 Training on Task Order

Participants in the “certain task order” condition were told that the ongoing tasks would always be arranged in the following order: patient history (Task A), calculating the probability of disease (Task B), graph interpretation (Task C), and dose calculation (Task D). A trial could begin with any of the four tasks. However, the task order would always proceed in the A-B-C-D repeating pattern. For example, if the trial began with Task C, then the order of the remaining tasks would be in the order D-A-B. Having received instructions about task order, participants in the certain condition were then made to recall the order. Any mistakes in recalling the order were corrected, and the experiment proceeded only after participants had learned the order of the ongoing tasks.

8.2.5.3 Practice on Ongoing Tasks

After learning the ongoing tasks by themselves, participants practiced performing the four tasks together in two sample trials. Depending on the condition, participants saw the four tasks in the learned order, or in a random order.

8.2.5.4 ProM Task Instructions and Practice

After participants had learned the ongoing tasks, they were given instructions for the ProM task: they would need to remember to press a key after completing a given number of ongoing tasks. Participants were told that they could receive ProM instructions when they were in the midst of any ongoing task. They were also informed about the three levels of delay that could occur between receiving the ProM instruction and executing the ProM action. The three delay levels were illustrated through examples.

Participants were also informed about non-ProM trials. Specifically, they were told that executing the ProM action in the absence of the ProM cue would be considered an error. Finally, participants were told that it would be important that they maintain accuracy in responding to the ongoing tasks while also remembering to perform the ProM task.

After receiving instruction about the ProM and non-ProM trials, participants performed a practice block. The block contained four ProM trials and two non-ProM trials. The ProM and non-ProM trials were randomly ordered. At the end of the practice block, participants received feedback about their accuracy on the ongoing tasks on each trial.

8.2.5.5 Main Experiment

The main experiment began after ensuring that all participants were familiar with the ongoing tasks and the structure of the ProM task, and that participants in the certain condition were proficient in the task order. Participants were reminded to work through as quickly and as accurately as possible through the ongoing tasks on each trial. They were encouraged to maintain as high accuracy levels as possible on each of the four ongoing tasks.

All participants completed three blocks of the experiment. Each block comprised six trials, four of which gave ProM instructions. Over the course of the experiment participants performed a total of 18 trials. After participants finished all three blocks of the experiment, they were administered the post-task questionnaire, and then debriefed.

CHAPTER 9. EXPERIMENT 1: RESULTS AND DISCUSSION

9.1 Ongoing Task Performance

The certain and uncertain conditions were compared on ProM costs. ProM costs refer to an increase in reaction time or a decrease in accuracy on ongoing tasks that are associated with a ProM response (Smith, 2003). These costs are thought to reflect resources taken away from the ongoing task to monitor for the ProM cue (Smith, 2003, Smith et al., 2007). ProM costs were measured by comparing average accuracy and response time on ProM trials with the non-ProM trials. If ProM costs exist, then participants would be expected to take longer time and show worse accuracy on ProM trials compared to non-ProM trials.

There were no significant effects for the DV of accuracy (see Table 1 in Appendix for F-values). However, participants on the certain condition took longer to answer questions associated with ongoing tasks than those in the uncertain condition [F (1, 43) = 4.66, p = 0.04, partial η^2 = 0.10, see Table 2 in Appendix for other F-values). If interpreted from the perspective of ProM costs, the slowing of the certain condition may indicate that participants in this condition may likely have engaged in monitoring for the opportunity to perform the ProM task. In addition, there was a failure to replicate costs associated with remembering ProM tasks: participants took longer to process information associated with ongoing tasks on non-ProM trials than on ProM trials [F (1, 43) = 5.98, p = 0.02, partial η^2 = 0.13, see Table 3 in Appendix for other F-values].The main experiment began after ensuring that all participants were familiar with the ongoing tasks and the structure of the ProM task, and that participants in the certain condition were proficient in the task order.

Participants were reminded to work through as quickly and as accurately as possible through the ongoing tasks on each trial. They were encouraged to maintain as high accuracy levels as possible on each of the four ongoing tasks.

9.2 ProM Task Performance

ProM performance was measured through three dependent variables:

1) whether participants remembered *that* a ProM task had to be executed,

2) whether participants remembered to execute a ProM task during the correct window of opportunity (or *when* the ProM task had to be executed), and

3) whether participants remembered *what* was the correct response (i.e., the correct key to press) to execute the ProM task.

Each of these DVs was examined by a 2 (task order: certain vs. uncertain; between-subjects) x 3 (delay between ProM instruction and opportunity for execution: 0 task delay vs. 1 task delay vs. 2 tasks delay) x 3 (experimental block: 1st vs. 2nd vs. 3rd) mixed ANOVA. The results of each DV will be separately discussed below. The critical alpha level was set at 0.05 for all analyses.

9.2.1 DV 1 = Whether Participants Remembered That a ProM Task Had to be Executed

The first measure of ProM performance considered whether participants remembered *that* they had to execute a ProM task (see Table 4 for descriptive statistics). Participants earned a point for execution of each ProM task as long as they remembered to press a non-ongoing task key (i.e., any key besides the letters *a, b, c,* or *d)* before executing a subsequent ProM task. Each ProM task had to be executed during a specific window of opportunity, and its response was associated with a unique key press. However, because this scoring scheme only considered whether participants remembered *that* they had to execute a ProM task, participants received credit for execution even when they made a ProM response late, i.e., outside of the appropriate window of opportunity, and even if they pressed the wrong key to indicate the ProM action.

Table 4

Descriptive Statistics for Participants Who Remembered That They had to Execute the ProM Task for Each Delay Level for Experiment 1

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	1.0 (0.03)	0.91 (0.04)	0.96 (0.03)	0.96 (0.02)	0.96 (0.03)	1.0 (0.04)	1.0 (0.03)	0.99 (0.02)
	1	0.93 (0.06)	0.86 (0.07)	1.0 (0.03)	0.93 (0.04)	0.91 (0.06)	0.89 (0.07)	0.93 (0.04)	0.91 (0.04)
	2	0.96 (0.03)	0.89 (0.07)	0.96 (0.08)	0.93 (0.04)	0.96 (0.03)	0.89 (0.07)	0.77 (0.08)	0.87 (0.04)
	Means (Block)	0.96 (0.03)	0.89 (0.04)	0.97 (0.04)	0.94 (0.03)	0.94 (0.03)	0.92 (0.04)	0.90 (0.04)	0.92 (0.03)

Note. Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity. Standard errors are in parentheses

Contrary to the task order hypothesis, there was no effect of task order for this DV, either by itself [F (1,42) = 0.24, p = 0.63, partial $\eta 2$=0.006], or in interaction with delay [F (2,126) = 1.04, p = 0.37, partial $\eta 2$=0.02], or experimental block [F (2,126) = 1.74, p = 0.18, partial $\eta 2$=0.04], or delay and experimental block [F (4, 210) = 1.27, p = 0.29 partial $\eta 2$=0.03] on whether participants remembered that they had to execute a ProM task (see Table 5 in Appendix for F-values).

There was also no effect of delay, either by itself [$F(2, 84) = 2.41$, $p = 0.10$, partial $\eta 2=0.05$], or in interaction with task order, or block [$F(2,168) = 1.54$, $p = 0.19$, partial $\eta 2=0.04$] on whether participants remembered that they had to execute the ProM tasks. Even though there seemed to be a trend towards better memory for remembering that the ProM task had to be executed for the shortest delay level (M 0 delay = 0.97, SE 0 delay = 0.01) compared to ProM tasks with the longest delay M 2 delay = 0.90, SE 2 delay = 0.03), the difference was not statistically significant [$F(2, 84) = 2.41$, $p = 0.10$].

The Memory for Goals theory states that goals that are not refreshed undergo decay (Altmann & Trafton, 2002). In fact, on the post-task questionnaire, participants across both task order conditions often mentioned periodic rehearsal of the ProM task during task switches. Such rehearsal may have staved off decay of the goal of executing the ProM task over longer delay levels and suggests that rehearsal may be an effective tool at maintaining ProM task over at least a few minutes, even when the environment requires frequent and unpredictable task switching.

9.2.2 DV 2 = Whether Participants Remembered to Execute the ProM Response During the Correct Window of Opportunity, (i.e., When)

For the second measure of ProM (see Table 6 for descriptive stats), participants earned a point for execution of each ProM task if they remembered to press a non-ongoing task key (i.e., any key besides the letters *a, b, c,* or *d)* within the correct window of opportunity (i.e., within 10 seconds of the end of the target ongoing task). Hence, unlike the previous DV of *that*, ProM tasks that were remembered late were counted wrong. This analysis could thus be interpreted as whether participants remembered *that* at the correct time.

Table 6

Descriptive Statistics for Participants who Remembered to Execute the ProM task During the Correct Window of Opportunity for Each Delay Level for Experiment 1

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	0.80 (0.08)	0.75 (0.07)	0.82 (0.08)	0.79 (0.05)	0.82 (0.08)	0.91 (0.07)	0.86 (0.08)	0.86 (0.05)
	1	0.64 (0.10)	0.52 (0.10)	0.68 (0.64)	0.61 (0.07)	0.48 (0.10)	0.41 (0.10)	0.57 (0.10)	0.49 (0.07)
	2	0.61 (0.10)	0.66 (0.10)	0.64 (0.10)	0.64 (0.07)	0.46 (01.)	0.41 (0.10)	0.27 (0.10)	0.38 (0.07)
	Means (Block)	0.68 (0.06)	0.64 (0.06)	0.71 (0.06)	0.68 (0.05)	0.58 (0.06)	0.58 (0.06)	0.57 (0.06)	0.58 (0.05)

Note. Standard errors are in parentheses

As predicted for this DV, the significant main effect of delay [F (2, 84) = 20.92, p = .001, partial η^2 = 0.33) was qualified by a significant interaction with task order [F (2, 126) = 4.94, p = .009, partial η^2 = 0.11; see Table 7 in Appendix for other F-values]. Post-hoc Bonferroni tests revealed that participants in the certain condition had higher mean ProM performance on delay until reaching significance at the longest delay level (i.e., a delay of two ongoing tasks between ProM instruction and opportunity for ProM execution ($M_{\text{certain-2 delay}}$ = 0.64, $SE_{\text{certain-2 delay}}$ = 0.07) as compared with participants in the uncertain condition ($M_{\text{uncertain-2 delay}}$ = 0.38, $SE_{\text{uncertain-2 delay}}$ = 0.07, see Figure 3).

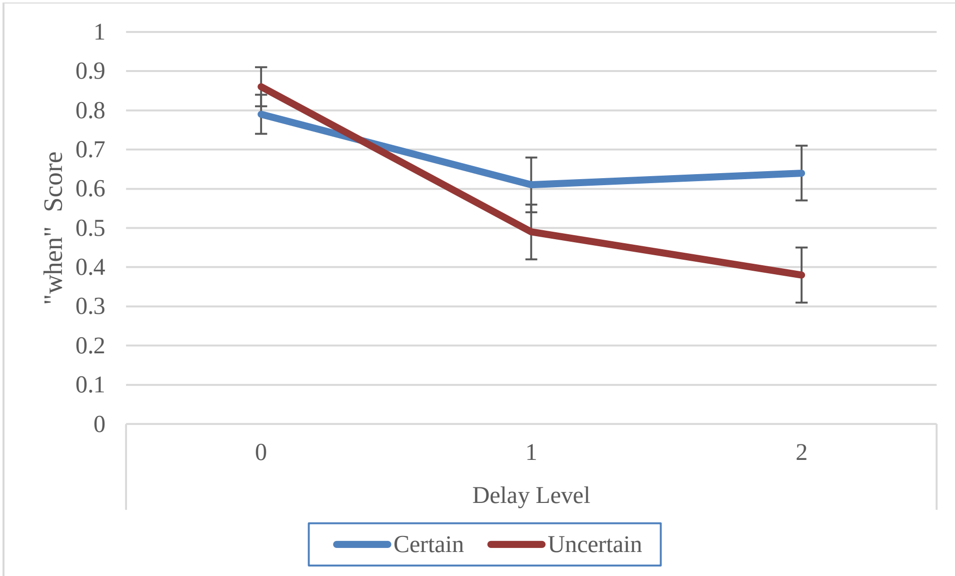

Figure 3. Mean score on the "when" DV for the two task order conditions under the three types of delay levels. Error bars represent standard error.

Data from the post-experiment questionnaire about strategy use in ProM helped shed light on the significant interaction. The ProM cue in the current experiment was the end of some given number of ongoing tasks. Participants in the certain condition could predict the order of upcoming tasks. They could use information about task order to encode features of the actual ongoing task after which they were to make the ProM response. Thus, participants in the certain condition could use two attributes to encode the opportunity of execution: 1) the number of tasks after which they had to execute the ProM response, and 2) the features of the specific ongoing task after they had to execute the ProM response. In contrast, participants in the uncertain condition were only able to maintain a count of the ongoing tasks until they would have to execute the ProM response. Thus, participants in the certain condition could presumably encode a more concrete opportunity of execution than those in the uncertain condition.

9.2.3 *DV 3a= Whether Participants Remembered to Press the Correct Key to Execute the ProM Task, (i.e., What)*

Participants earned a point for execution of each ProM task if they remembered to press the correct key to execute the action. They could earn the point as long as the ProM action was executed before executing the action for the subsequent ProM task (see Table 8 for descriptive statistics). This scoring scheme is termed “lenient” because it permitted participants to receive credit for execution even when they made a ProM response late, i.e., outside of the appropriate window of opportunity, but only as long as they pressed the specific key that had been identified in the instructions.

Table 8

Descriptive Statistics for Participants who Remembered to Execute the Correct ProM Action for Each Delay Level for Experiment 1

		Certain				Uncertain			
		Block 1	Block 2	Block 3	Mean (Certain-Delay)	Block 1	Block 2	Block 3	Mean (Uncertain-Delay)
Delay level	0	0.77 (0.08)	0.77 (0.06)	0.96 (0.05)	0.83 (0.04)	0.91 (0.08)	0.98 (0.06)	0.93 (0.05)	0.94 (0.03)
	1	0.89 (0.07)	0.73 (0.09)	0.91 (0.07)	0.84 (0.06)	0.89 (0.07)	0.75 (0.09)	0.84 (007)	0.83 (0.06)
	2	0.91 (0.05)	0.82 (0.07)	0.82 (0.09)	0.85 (0.05)	0.91 (0.05)	0.89 (0.07)	0.66 (0.09)	0.82 (0.05)
	Mean (Block)	0.86 (0.04)	0.77 (0.04)	0.89 (0.05)	0.84 (0.03)	0.90 (0.04)	0.87 (0.04)	0.81 (0.05)	0.86 (0.03)

Note: Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity. Standard errors are in parentheses

Although task order or delay did not have a significant effect by themselves or in interaction with each other, their effects come forth in interaction with experimental block (see Table 9 in Appendix for *F*-values). In Block 3 participants had significantly higher mean ProM performance on the 0-delay condition ($M_{0\ delay}$= 0.94, $SE_{0\ delay}$ = 0.03) as compared to the 2-delay condition ($M_{2\ delay}$ = 0.74, $SE_{2\ delay}$ = 0.06, F (2, 126) = 3.81, p = .005, partial η^2 = 0.08, see Figure 4).

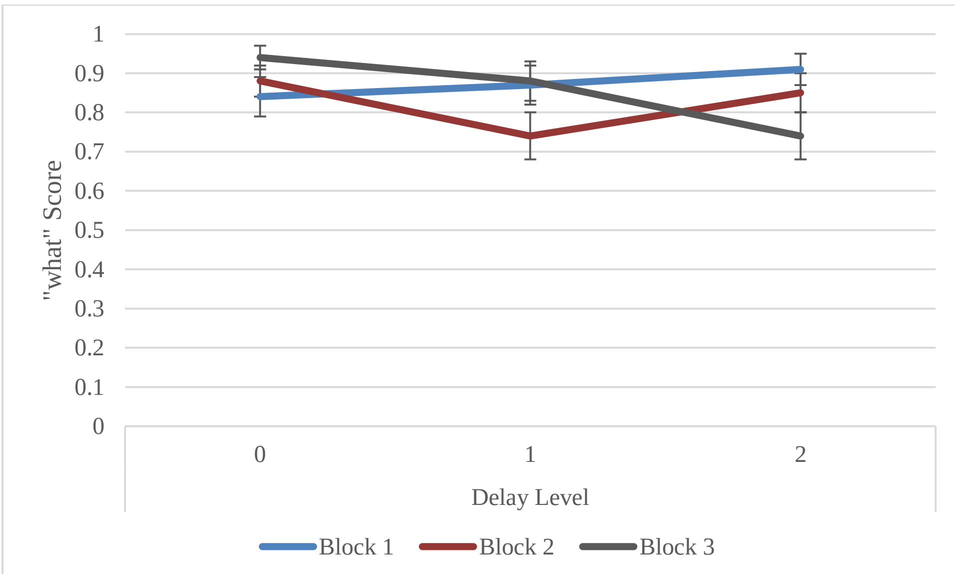

Figure 4. Mean score on the "what" DV for the three types of delays for each experimental block. Error bars represent standard error.

Task order also appeared in interaction with experimental block [F (2, 126) = 3.14, p = 0.05, partial η2 = 0.07]. However, none of the follow-up pairwise tests confirmed the interaction.

9.2.4 DV 3b: "What" Conditionalized on the DV "When"

In the previous discussion of the DV of what, participants could receive credit even if they remembered that they had to press a particular key, but after the opportunity of execution had passed. However, ProM tasks are completely correct only if they are remembered within the correct window of opportunity, and if they elicit the correct action as the response. Indeed, ProM in operational environments may often be time critical, such as remembering to take medication at a certain time of the day or after finishing a certain task, e.g., after breakfast. In our daily lives we may remember ProM tasks after the moment of opportunity has passed; however, by then, it may be too late to execute the task. Similarly, we may remember the ProM task within the correct window of opportunity, but fail to execute the appropriate action to complete the ProM task. For example, we may remember that we need to take one of three medications at 2 PM, but forget to take the correct type of medication. Therefore, for the next set of analyses, a ProM task was counted as correct only when the participant remembered to press the correct key in the correct window of opportunity (see Table 10 for descriptive statistics). This will be termed as the "stringent" scoring scheme.

Table 10

Descriptive Statistics for Participants Who Remembered to Execute the Correct ProM Action During the Correct Window of Opportunity for Each Delay Level for Experiment 1

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	0.66 (0.09)	0.68 (0.08)	0.82 (0.09)	0.72 (0.06)	0.77 (0.09)	0.89 (0.08)	0.80 (0.09)	0.82 (0.06)
	1	0.59 (0.10)	0.43 (0.09)	0.64 (0.10)	0.55 (0.07)	0.46 (0.10)	0.36 (0.09)	0.57 (0.10)	0.46 (0.07)
	2	0.52 (0.10)	0.59 (0.10)	0.57 (0.10)	0.56 (0.08)	0.46 (0.10)	0.41 (0.10)	0.28 (0.10)	0.36 (0.08)
	Mean (Block)	0.59 (0.06)	0.57 (0.06)	0.67 (0.06)	0.61 (0.05)	0.56 (0.06)	0.55 (0.06)	0.53 (0.06)	0.55 (0.05)

Note: Standard errors are in parentheses

Under the stringent scoring criterion a significant main effect of delay [$F(2, 84) = 18.06$, $p = .001$, partial $\eta 2 = 0.30$) was qualified by a significant interaction between task order and delay [$F(2, 126) = 3.39$, $p = 0.03$, partial $\eta 2 = 0.08$, see Table 11 in Appendix for other F-values)] was obtained. Specifically, there was a shallow, insignificant decay function for the certain condition (see Figure 5), there was a substantial decay function for the uncertain condition.

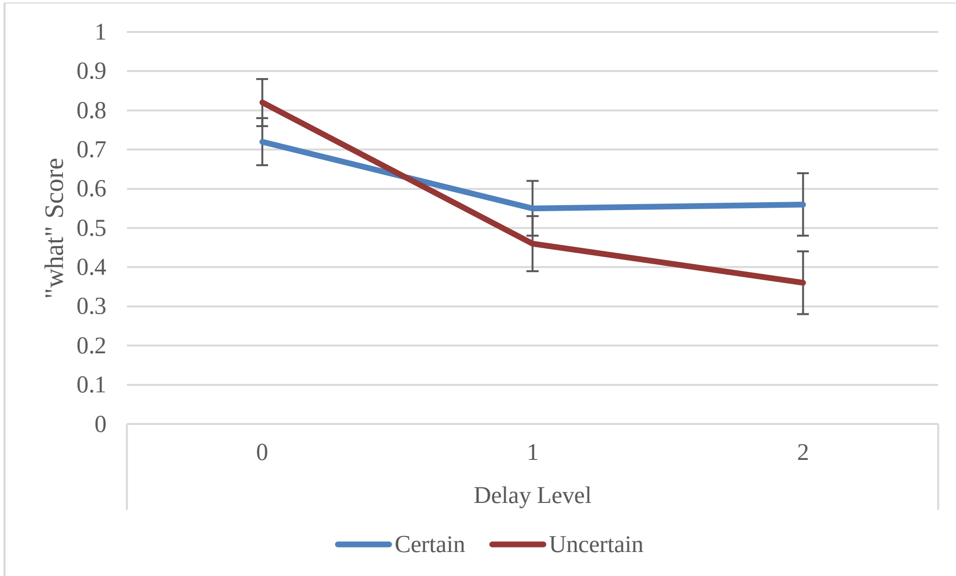

Figure 5. Mean score on the "what" DV for the two task order conditions under the three types of delay levels. Error bars represent standard error.

In summary, Experiment 1 found that although there was no effect of task order, delay level, or experimental block on whether participants remembered that they had to execute a ProM task, participants in the certain condition performed significantly better than those in the uncertain condition on remembering when they had to perform ProM tasks that had the longest interval (2 ongoing tasks) between receiving the ProM instruction and opportunity to execute the ProM action. If a pure measure of ProM success was taken where participants received points only if they correctly remembered that they had to perform a future task, when they had to exactly perform the task, and what action they had to do to execute the task, then participants in the certain condition again outperformed those in the uncertain condition at ProM execution at the longest delay levels.

The superior performance of the certain group at the longest delay level may be attributed to them being able to encode a concrete context of ProM execution. Specifically, participants in the certain condition could make use of knowledge about the order of tasks to predict the specific task after which they would have to execute the ProM task. It is possible that encoding the ProM task in terms of the specific features of the task that would be encountered during execution helped to automatize ProM execution at longer delays and guard against decay of the ProM goal. Specifying the context of ProM execution may thus have worked through multiple ways in helping improve performance of the certain group.

If associating the moment of execution with the features of the specific task after which the ProM action has to be executed helps in strengthening the context of execution, then supplying this information to the uncertain group should help make the context of execution more concrete. Experiment 2 tested this hypothesis.

Specifically, in contrast to Experiment 1 which framed the ProM task as remembering to perform an action after completing a specific number of tasks, Experiment 2 reframed the ProM task in terms of the name of the ongoing task after which participants would have to execute the ProM action. Knowing the specific task after which the ProM task had to be executed would enable participants to encode features of the task that they may expect during ProM retrieval.

Objectively, ProM encoding in the certain condition in Experiment 1 would be similar to ProM encoding for both the certain and uncertain conditions in Experiment 2. As in Experiment 1, participants would still experience ProM tasks with 3 delay levels. Thus, the ProM task after which the ProM action would have to be executed would either be the ongoing task during which the ProM instructions were received (i.e., 0 delay), or the next ongoing task in the trial (i.e., 1 delay), or the next two ongoing tasks in the trial (i.e., 2 delays). Participants in the certain order condition would thus be able to also encode the number of tasks after which they would have to execute the ProM action, in addition to the name of the ProM task and its accompanying features. In contrast, because participants in the uncertain condition would not be aware about the order of tasks, they would be unable to predict the number of tasks after which the opportunity of ProM execution would occur.

If encoding the opportunity of ProM execution in terms of multiple attributes (features of the target task + number of tasks) helps in strengthening the context of execution then participants in the certain condition would be expected to perform better on the when aspect of ProM. However, if encoding the task name is sufficient in specifying the context of execution then there should be no difference between the certain and the uncertain conditions.

CHAPTER 10. EXPERIMENT 2: METHOD

10.1 Participants

Forty-two participants (Females = 22; Males = 20; Age: M = 19.88 years, SE = 2.05) were drawn from the undergraduate subject pool at the Georgia Institute of Technology. Participants were compensated by extra credit.

10.2 Materials, Design and Procedure

A 2 (task order: certain vs. uncertain; between-subjects) x 3 (delay interval between ProM cue presentation and response execution: no intervening task delay vs. one intervening task delay vs. two intervening tasks delay; within-subjects) x 3 (experimental block number: 1 vs. 2 vs. 3; within-subjects) factorial mixed design was used in the experiment. Recall that in Experiment 1, the ProM task instructed participants to remember to execute an action after completing a given number of tasks. In Experiment 2 the only change was in the phrasing of the ProM task: participants were told to remember to execute the ProM action after they had completed a specific ongoing task. For example, participants may be given the following instruction: remember to press the “y” key to order labs for patient X, but only after finishing the DOSE CALCULATION task. Each ProM task identified a different ongoing task after which the ProM response had to be executed.

Participants again switched among four ongoing tasks modeled after the work performed by healthcare providers in the ED: reviewing and answering questions about the medical history of patients; calculating the probability of diseases; reading and interpreting graphs on vital signs; and calculating the dose of medication. All participants were trained on each of the four ongoing tasks. Participants in the certain condition were additionally trained on the order in which the tasks would appear.

In the main experiment participants again completed three blocks of the experiment. Each block comprised four ProM trials and two non-ProM trials. Two ProM trials in each block presented two distinct delay levels; the remaining delay level was presented in the other two ProM trials. Non-ProM trials did not present a ProM task to participants. Participants completed 12 ProM tasks over the course of the three experimental blocks

Each trial presented one iteration of the four ongoing tasks. A trial could begin with any ongoing task. In the certain condition the tasks followed the repeating order of patient history-disease-calculation-graph interpretation-dose calculation. After participants had finished the three experimental blocks they completed a post-task questionnaire that quizzed them about strategies they had used to perform the ongoing tasks, and remember the ProM task. Participants were debriefed after completing the post-task questionnaire.

CHAPTER 11. EXPERIMENT 2: RESULTS AND DISCUSSION

11.1 Ongoing Task

As with Experiment 1, ProM costs were measured by comparing average accuracy and response times on the ProM and non-ProM trial between the certain and uncertain task order conditions. There were no significant findings (see Table 12 in Appendix for F-values for the DV of accuracy, Table 13 in Appendix for the DV of response time for ongoing task questions, and Table 14 in Appendix for response time for processing the information slides), indicating the absence of ProM costs (Harrison & Einstein, 2010, McDaniel & Einstein, 2010).

11.2 ProM Task Performance

Experiment 2 also measured ProM performance through the following three dependent variables:

1) whether participants remembered *that* a ProM task had to be executed,

2) whether participants remembered to execute the ProM task during the correct window of opportunity (or *when* the ProM task had to be executed), and

3) whether participants remembered *what* was the correct response (i.e., the correct key to press) to execute the ProM task.

Each of these DVs was examined by a 2 (task order: certain vs. uncertain; between-subjects) x 3 (delay between ProM instruction and opportunity for execution: 0 tasks vs. 1

task vs. 2 tasks) x 3 (experimental block: 1st vs. 2nd vs. 3rd) mixed ANOVA. The results of each DV will be separately discussed below. The critical alpha level was set at 0.05 for all analyses.

11.2.1 DV 1 = Whether Participants Remembered That a ProM Task Had to be Executed

There was no effect of task order, either by itself, or in interaction with any other variable on whether participants remembered *that* they had to execute a ProM task (see Table 15 for descriptive statistics, and Table 16 in Appendix for *F*-values). Similarly, there was no effect of delay, either by itself, or in interaction with task order or experimental block on whether participants remembered to execute the ProM tasks. There was no interaction between task order, delay, and experimental block. Thus, it appears that neither the order in which tasks are arranged, nor the delay between ProM instruction and ProM execution affect remembering *that* a task has to be completed in the future when the context of ProM execution is defined by the task name after which ProM had to be executed.

Table 15

Descriptive Statistics for Participants who Remembered That They had to Execute the ProM Task for Each Delay Level for Experiment 2

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	0.86 (0.06)	0.86 (0.06)	0.98 (0.02)	0.88 (0.04)	0.95 (0.06)	0.95 (0.06)	1	0.97 (0.04)
	1	0.86 (0.06)	0.86 (0.06)	0.93 (0.07)	0.88 (0.05)	0.95 (0.06)	0.93 (0.06)	0.83 (0.07)	0.91 (0.05)
	2	0.86 (0.05)	0.95 (0.04)	0.95 (0.03)	0.92 (0.03)	0.98 (0.05)	0.93 (0.04)	1 (0.03)	0.97 (0.03)
	Mean (Block)	0.86 (0.04)	0.89 (0.05)	0.95 (0.03)	0.90 (0.03)	0.96 (0.04)	0.94 (0.05	0.94 (0.03)	0.95 (0.03)

Note: Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity. Standard errors are in parentheses.

11.2.2 DV 2 = Whether Participants Remembered to Execute the ProM Response During the Correct Window of Opportunity, (i.e., When)

There was a significant interaction between experimental block and delay level [*F* (4,160) = 2.75, *p* = .03, partial $\eta^2 = 0.06$; see Table 17 for descriptive statistics, and Table 18 in Appendix for other F-values] on whether participants remembered to execute the ProM task during the correct window of opportunity.

Table 17

Descriptive Statistics for Participants who Remembered to Execute the ProM task During the Correct Window of Opportunity for Each Delay Level for Experiment 2

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	0.69 (0.10)	0.79 (0.08)	0.86 (0.07)	0.78 (0.06)	0.60 (0.10)	0.88 (0.08)	0.88 (0.07)	0.79 (0.06)
	1	0.67 (0.09)	0.69 (0.09)	0.79 (0.09)	0.71 (0.05)	0.79 (0.09)	0.74 (0.09)	0.60 (0.09)	0.71 (0.05)
	2	0.69 (0.08)	0.55 (0.10)	0.79 (0.09)	0.68 (0.06)	0.81 (0.09)	0.69 (0.10)	0.76 (0.09)	0.75 (0.06)
	Mean (Block)	0.68 (0.06)	0.68 (0.06)	0.81 (0.06)	0.72 (0.04)	0.73 (0.06)	0.77 (0.06)	0.75 (0.06)	0.75 (0.04)

Note: Standard errors are in parentheses

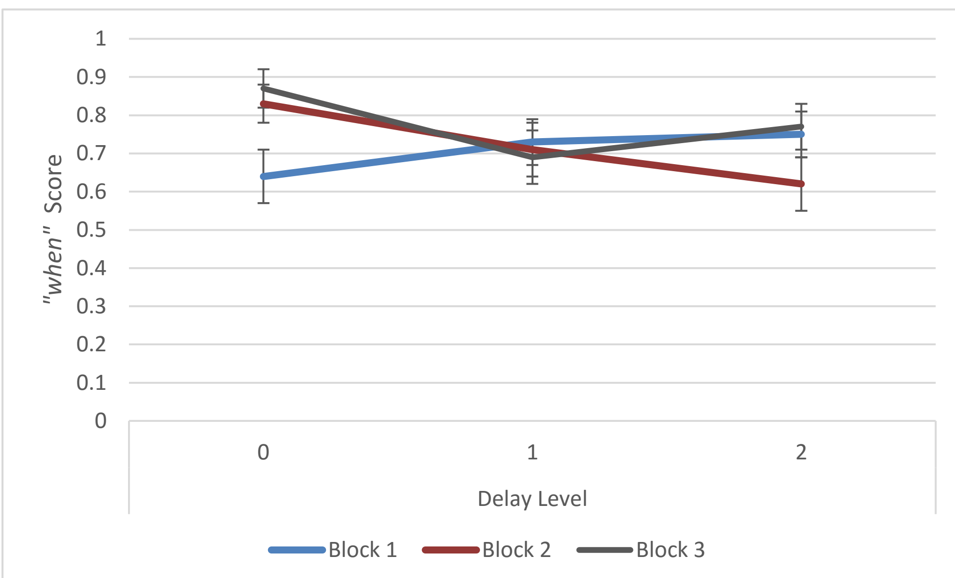

Figure 6. Mean score on the “when” DV for the three types of delays for each experimental block. Error bars represent standard error.

11.2.3 DV 3a = Whether Participants Remembered to Press the Correct Key to Execute the ProM Task, (i.e., What)

Using the lenient scoring scheme of granting a point for pressing the correct key to execute the ProM task (even if the key press was made outside of the window of opportunity) yielded a significant effect of delay [F (2, 80) = 4.60, p = .01, partial η^2 = 0.10, see Table 19 for descriptive statistics and Table 20 in Appendix for other F-values].

Table 19

Descriptive Statistics for Participants who Remembered to Execute the Correct ProM Action for Each Delay Level for Experiment 2

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	0.83 (0.08)	0.81 (0.08)	0.93 (0.06)	0.86 (0.05)	0.81 (0.08)	0.81 (0.08)	0.88 (0.06)	0.83 (0.05)
	1	0.86 (0.08)	0.74 (0.09)	0.79 (0.10)	0.79 (0.06)	0.86 (0.08)	0.76 (0.09)	0.69 (0.10)	0.77 (0.06)
	2	0.83 (0.07)	0.91 (0.05)	0.86 (0.07)	0.87 (0.05)	0.91 (0.07)	0.93 (0.05)	0.93 (0.07)	0.92 (0.05)
	Mean (Block)	0.84 (0.06)	0.82 (0.06)	0.86 (0.05)	0.84 (0.04)	0.86 (0.06)	0.83 (0.06)	0.83 (0.05)	0.84 (0.04)

Note: Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity. Standard errors are in parentheses

11.2.4 DV 3b = "What" Conditionalized on the DV "When"

The stringent criterion was used to re-score the DV of *what.* In this criterion, participants could receive a score on correct execution of *what* only if they had also remembered to make the ProM action within the appropriate window of opportunity (i.e., correct *when,* see Table 21 for descriptive statistics*)*. The resulting score would be a "pure correct" ProM because all three aspects of ProM would be correct.

Table 21

Descriptive Statistics for Participants Who Remembered to Execute the Correct ProM Action During the Correct Window of Opportunity for Each Delay Level for Experiment 2

		Certain				Uncertain			
		Block 1	Block 2	Block 3	*Mean (Certain-Delay)*	Block 1	Block 2	Block 3	*Mean (Uncertain-Delay)*
Delay level	0	0.69 (0.10)	0.74 (0.09)	0.86 (0.08)	0.76 (0.06)	0.48 (0.10)	0.79 (0.09)	0.79 (0.08)	0.68 (0.06)
	1	0.67 (0.09)	0.62 (0.10)	0.64 (0.10)	0.64 (0.06)	0.79 (0.09)	0.57 (0.10)	0.52 (0.10)	0.63 (0.06)
	2	0.69 (0.09)	0.48 (0.10)	0.74 (0.10)	0.64 (0.06)	0.76 (0.09)	0.69 (0.10)	0.67 (0.10)	0.71 (0.06)
	Mean (Block)	0.68 (0.06)	0.61 (0.07)	0.75 (0.06)	0.68 (0.05)	0.68 (0.06)	0.68 (0.07)	0.66 (0.06)	(0.67 (0.05)

Note: Standard errors are in parentheses

Upon re-scoring the *what* responses using the stringent analysis, an uninteresting interaction between experimental block and delay level emerged [F (4, 160) = 3.53, p = 0.003, partial η^2 = 0.08, see Table 22 in Appendix for other F-values, see Figure 7].

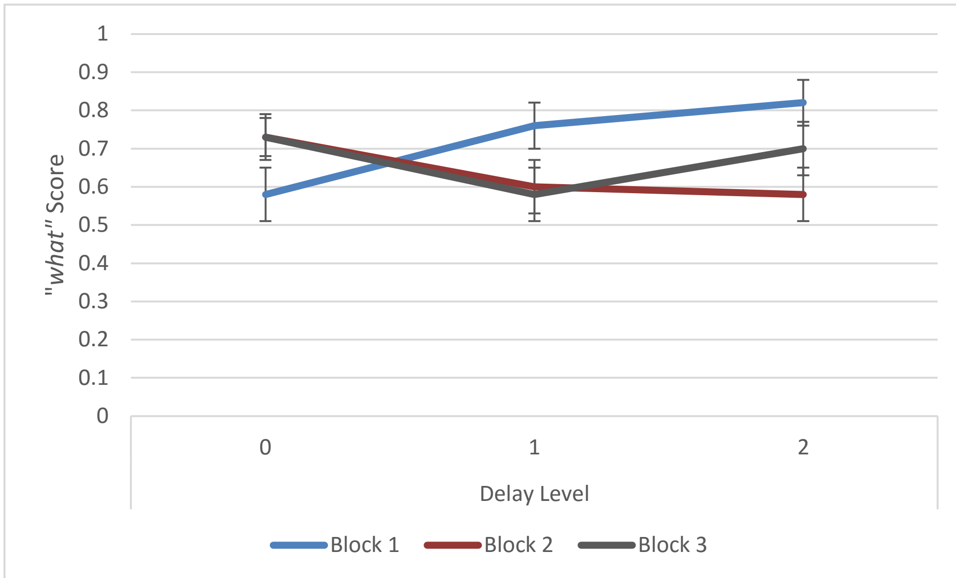

Figure 7. Mean score on the "what" DV for the three types of delays for each experimental block. Error bars represent standard error.

CHAPTER 12. GENERAL DISCUSSION

The current dissertation explored whether uncertainty affects ProM. Uncertainty was manipulated by varying *when* a ProM task had to be executed, as well as *what* action had to be performed to execute it; the experiment also varied whether participants had to remember *that* they had to execute a ProM task. Although Einstein et al. (1992) enumerated these three aspect of ProM (i.e., *that*, *when*, and *what*), most of the previous research on ProM has not analyzed the three DVs separately. By measuring the *that*, *when*, and *what* aspects of ProM separately and in conjunction with each other, the current dissertation was able to estimate ProM failures at all three aspects. In this way, the current dissertation was able to capture a nuanced, complex measure of ProM performance.

In both experiments, participants switched among four ongoing tasks. In Experiment 1, the ProM task was framed as remembering to execute a future action after having completed either the current, the next, or the next two ongoing tasks. Participants in the certain condition could predict the order in which they would perform the ongoing tasks. Thus, the certain condition could use knowledge about task order to predict the specific task after which they would have to execute the ProM action. This information enabled participants in the certain condition to encode the features of the context that would be encountered during ProM retrieval. When information that is present during encoding is also present at retrieval, it results in an improvement in memory compared to when the contexts differ (Nowinski & Dismukes, 2005; Thomson & Tulving, 1970). Thus, participants in the certain condition were able to encode a rich context in which they would execute the ProM action.

In contrast, participants in the uncertain condition experienced the ongoing tasks in random order. Because of being unable to predict which task would occur when, participants in the uncertain condition were unable to encode a concrete context of ProM execution. Indeed, the post-experiment questionnaire revealed that the only strategies used by participants in the uncertain condition were rehearsing the ProM task, and counting down ongoing tasks until reaching the opportunity of ProM execution.

However, the superior performance of the certain condition manifests at the longest delay level. When there was a delay of two ongoing tasks between ProM instruction and execution, participants in the certain condition were not only better at remembering *when* to execute the ProM task, but also *what* action had to be performed to execute the ProM task. A longer interval between ProM instruction and execution meant that the goal of accomplishing the ProM task had a higher chance of decay; mere rehearsal or counting down until reaching the opportunity of execution did not seem to be sufficient at maintaining the ProM task for the uncertain group.

In contrast to the strategies used by the uncertain group, participants in the certain condition were able to encode specific features of the ongoing task after which they had to execute the ProM action. Encountering the end of the target ongoing task whose features they had encoded could serve as a cue to trigger the ProM action. In this way, an ability to predict the upcoming tasks helped participants in the certain condition define and anticipate the opportunity of ProM execution. If specifying the context of execution helps ProM performance, then providing context information should also help participants in the uncertain group. Therefore, in Experiment 2, both the certain and the uncertain groups were told the name of the task after which they had to execute the ProM action. Participants could presumably use this information to imagine specific features of the target ongoing task, and associate these features with ProM execution. As predicted, participants in both the certain and uncertain groups were equally likely to remember to execute the ProM task. Thus, Experiment 2 illustrated that uncertainty does not affect ProM as long as the context of ProM execution is well-specified at the time of encoding the ProM task.

Taken together, the two experiments help illustrate the support that predictable environments provide to ProM, as well as the limits of that support. Weaving the context of execution within the ProM instructions was an effective foil against ProM failure in an unpredictable environment involving frequent task switching between resource-demanding tasks.

12.1 Methodological Contributions

The current dissertation proposed and tested a novel modification of the standard methodology to investigate delay-execute ProM. Tasks in the standard delay-execute paradigm have certain limitations that may make it difficult to extend their findings to operational environments. In dynamic work environments, operators may have to often switch unpredictably between several tasks. However, ongoing tasks utilized in standard delay-execute studies are usually of a predictable, fixed duration (McDaniel et al., 2003). Further, with a few exceptions, the ongoing tasks in previous research recruit relatively simple decision processes; this may not reflect the more complex processes that are required to perform safety-critical tasks in busy operational environments.

Another additional difference is with regards to the goal of performing the ongoing tasks. Tasks in operational environments such as healthcare may be geared towards a larger goal such as improving the safety and efficiency of the healthcare system. However, the tasks performed in the standard delay-execute paradigm are not connected by a higher order goal.

Another important difference is the delay between appearance of the ProM cue and execution of the ProM response. In the standard delay-execute paradigm participants have to make their response at the end of the same task in which they had received the ProM instruction. This is because the ProM cue is usually an event (e.g., a screen with a red color), that directs participants to make their response at the end of the ongoing task in which it appeared. This design does not lend itself to understanding ProM performance during longer delays that are interspersed by multiple ongoing tasks. Switching between different types of ongoing tasks may mean that the ProM cue was seen in a different context from when the response has to be executed.

Because the ProM cue remains the same throughout the experiment, an addition drawback that is tied to the standard delay-execute paradigm is that participants may make their ProM response after having remembered a previous ProM cue. However, there is no way to uncover the timing of the event that may have elicited the participants' ProM response.

The current dissertation addressed these limitations by developing a modified version of the standard delay-execute paradigm of ProM. In order to simulate work in dynamic operational environments that are characterized by frequently switching between different types of safety-critical tasks, the ongoing tasks in the current dissertation were based on tasks that may be performed by healthcare providers. Thus, all ongoing tasks were tied together by the higher-order goal of patient care. The ongoing tasks recruited a variety of complex cognitive processes such as decision making, recall, chart interpretation, etc.

Another contribution of the modified delay-execute paradigm was its ability to investigate the effect of different durations of delay between ProM instruction and ProM execution. The standard delay-execute paradigm can only investigate the effect of relatively short delays in which participants perform the same ongoing task from the time that they are presented with the ProM cue to when they execute the ProM action. In the current dissertation, however, the interval between ProM instruction and ProM execution could be filled by different types of ongoing tasks. This not only allowed inserting different lengths of delays before ProM execution, but also changed the context from which the ProM task was encoded to when it was executed. The change in cognitive context from ProM encoding to its execution helps mirror work in ambulatory settings in which the environment in which a task is encoded may be different from the one in which it is executed. Thus, the current dissertation proposed a novel method of investigating how a change in context from encoding to retrieval may affect ProM.

In this way, the current dissertation proposed a methodology that enables the simulation of features of dynamic operational environments. It is possible to systematically vary features of this new methodology to investigate how specific features of dynamic environments may influence ProM. For example, because all ongoing tasks are unified by an overarching goal, it may be possible to vary the extent to which each ongoing task is related to this higher goal. Thus, it will be possible to investigate how varying the strength of the relationship between ongoing tasks and the overall task goal may influence ProM. It is similarly possible to imagine varying other features such task switching, time pressure, duration of ongoing tasks, etc. Thus, the modified delay-execute paradigm can contribute to theory development in ProM by enabling the systematic investigation of key features of dynamic operational environments in a controlled setting.

12.2 Theoretical Contributions

Previous research (Nowinski & Dismukes, 2005) has shown that associating the ProM task with the ongoing task during which it will be executed benefits ProM performance. Nowinski and Dismukes evoked context effects as the mechanism underlying their findings: encountering the ongoing task that was associated with the ProM task helped cue ProM. The current dissertation demonstrates the resilience of context effects in ProM. Specifically, knowledge about the context helped support ProM, even in an uncertain task environments. Being unable to predict the order of upcoming task did not hinder ProM as long as participants were able to encode the features of the context in which they would have to execute the ProM task.

Encoding the context of ProM execution alerted participants to the *when* aspect of ProM. That is, knowledge about context alerted participants to the appropriate window of opportunity in which the ProM task had to be executed. This suggests that uncertainty exerts its effects by influencing our experience of the dimension of time.

Experiment 1 provides evidence for the broad-based effects of the temporal dimension of uncertainty. In Experiment 1, the certain condition performed better than the uncertain condition on the *when* DV for the longest delay interval. In addition, the *when*

DV also appears to have driven the significant uncertainty effects obtained with the *what* DV. Specifically, uncertainty effects did not show up on the *what* DV if it was scored correct without taking into consideration whether participants made a timely ProM response (i.e., the lenient criterion). However, if ProM was counted correct only if participants made the correct action during the correct time, then uncertainty effects were apparent again. Thus, in dynamic operational environments, uncertainty affects ProM by impacting the dimension of time.

12.3 Applied Contributions

Results from the current dissertation can help in developing a multi-step approach towards improving ProM in dynamic operational environments. First, the results suggest that performing tasks in a predictable order support ProM. This is especially helpful when ProM tasks are framed as “remember to do something after finishing X number of tasks”, or “remember to do something after 10 minutes.” If the operator knows the order in which tasks have to be performed and can estimate how long each task will take, then he or she can imagine the context that will be encountered after finishing X number of tasks.

Consider, as an example, a physician in the ED. As part of his or her job, the physician may have to perform different tasks: performing a physical examination of patients, ordering tests and medication, consulting with patients’ families and other healthcare providers to construct the medical history of the patient, updating medical charts, and so on.

Sometimes, the physician may expect to perform the tasks in a predictable order. For example, patients’ previous medical history may always be reviewed first, followed by a physical examination of the patient, perhaps ordering additional tests, consulting with other healthcare providers to fill in the history of the patient, and finally, patients may be prescribed medication. In fact, it is possible that completing one task may cue the physician about beginning the next task in the order.

If the physician has to remember to perform a ProM task along with other routine patient care tasks, then it may be possible to use knowledge about the order of tasks to plan ProM execution. For instance, if the physician has to remember to order labs for a patient after 10 minutes, and knows that he or she will be reviewing patient charts at that time, then he or she could imagine the context of executing the labs ordering task. The physician may update his or her task model so that completing the patient charts task will now also cue the beginning of the labs ordering task. Thus, an operational environment that enables the operator to predict the order in which tasks are performed may support ProM because operators can anticipate specific details about the context in which the ProM task has to be retrieved and executed. In this case, predictable operational environments may support ProM by aiding the *when* aspect of ProM.

Operators in dynamic environments may not always be able to predict the order in which tasks have to be performed. In such a case, operators should try to specify details about the context in which the ProM will have to be executed. This may mean restructuring ProM tasks that may have been phrased as “remember to do something after X number of tasks” in terms of “remember to do something after you finish task Y.” The latter phrase would help in identifying specific features about the environment that will help in cuing ProM during the appropriate window of opportunity.

It is possible to imagine uncertainty about task order in the previous example of the ED physician. During peak patient flow times, for example, the physician may face frequent interruptions. The interruptions may interfere with the routine order of performing tasks. The completion of specific tasks may no longer cue the physician to begin with another task. If the physician has to remember to execute a ProM task after a specific number of tasks when faced by such type of unpredictability, he or she may no longer know details about which task will be performed during the opportunity of ProM execution. In this case, the physician may no longer be able to anticipate the retrieval context in which a ProM task has to be executed. Of course, it is possible that the physician still remembers *that* some task had to be performed in the future, but may no longer be able to remember *when* exactly it has to be performed. In this case, specifying as many details about the context in which ProM has to be executed may help the physician in remembering the ProM task.

Re-structuring ProM tasks to emphasize details about the context of execution during encoding may be a particularly helpful strategy when ProM tasks have to be executed without external reminders. This may be especially beneficial in alarm-heavy environments such as healthcare. Training healthcare providers on these strategies to improve ProM may help avoid create a new and potentially intrusive alarm.

However, it may still be necessary to program reminders for ProM. In the current dissertation, even though participants were able to predict the order of upcoming tasks, or knew the context of execution, the average ProM performance in these conditions was well below ceiling. Specifically, the average ProM performance in these conditions ranged from 0.56 – 0.71. As discussed earlier, the *when* aspect of ProM drove ProM success. This suggests that it may be worthwhile to employ aids that alerts participants to execute ProM tasks during the appropriate window of opportunity.

In summary, in uncertain operational environments, the framing of ProM tasks affects their success. Encoding a ProM task in terms of finishing a specific number of tasks may not be an effective strategy of remembering the task over long intervals. Instead, operators may be better off if they were to define the retrieval context of ProM. Thus, tying ProM response to the occurrence of a specific event in the environment can help ProM performance in uncertain environments. In addition to re-structuring ProM tasks to emphasize context, it may also be beneficial to consider aids that alert operators to execute ProM tasks when they encounter the appropriate opportunity of ProM execution.

12.4 Limitations and Future Research

In the current studies ProM performance was lower than what has been found in previous research. Despite encoding the ProM task in terms of the context in which it would be executed, average ProM performance for the longest delay level ranged between 0.56 – 0.67. It is possible that previous research using the standard delay-execute paradigm overestimates ProM performance.

In fact, some features about the design of ProM tasks in the standard delay-execute paradigm, as well as in the current dissertation, may encourage a higher rate of ProM detection than what may occur in operational environments. First, ProM tasks in these paradigms are framed as implementation intentions. Implementation intentions identify not only *when* a ProM task has to be executed, but also *what* action has to be done to execute the task (Gollwitzer, 1999). In operational environments, however, ProM tasks may not define the specific window of opportunity or the action (Holbrook & Dismukes, 2009). Because implementation intentions define the specific context of execution, detection of the window of opportunity, and consequently, ProM execution may be higher when ProM tasks are framed in the format of an implementation intention.

An additional design feature that may encourage higher ProM detection relative to operational environments has to do with the frequency with which participants performed ProM tasks. In the current dissertation participants performed 12 ProM trials and 6 non-ProM trials over the course of each experiment. Thus, the number of ProM trials was twice as many as the non-ProM trials. As with previous research on ProM, the higher number of ProM vs. non-ProM trials was done to maximize the number of ProM data points from each participant. However, an unintended consequence of this design feature was that participants may have developed a generalized goal of remembering to execute ProM tasks. Maintaining this generalized goal may have lead participants to defaulting towards making a ProM response on most trials.

This generalized goal of ProM responding may not develop in operational environments. This is because the frequency with which ProM tasks are performed in operational environments may be fewer than what occurs in previous studies using the standard delay-execute paradigm. Therefore, the rate of performing ProM tasks in operational environments may potentially be lower than that in previous research. Future studies could address the problem of the generalized ProM goal by increasing the number of non-ProM trials relative to ProM trials. This may also help simulate the lower frequency of ProM responding in operational environments.

An additional limitation of the current dissertation involved the nature of the sample. The current dissertation was conducted on a college sample. This sample was relatively naïve to the demands of the ongoing tasks. It is possible that relatively low familiarity with the ongoing tasks, as well as strategies to perform the ProM task, may have adversely impacted ProM performance.

Future studies could investigate delay-execute ProM with samples that are more familiar with the types of ongoing tasks used in the current dissertation, i.e., healthcare providers. A more experienced sample would also illuminate how ProM tasks are supported by strategies to perform ongoing tasks.

Despite these limitations, the current dissertation highlighted the effect of context on ProM in uncertain, dynamic environments. Specifically, when ProM tasks are framed as remembering to execute an action after a given number of ongoing tasks, performing tasks in a certain, predictable order helps ProM. This is because knowledge about the order of performing tasks can be used to define the specific context in which the ProM task has to be executed. However, knowledge about the order in which tasks have to be performed does not offer an additional boost to ProM when ProM tasks are framed in terms of the specific context in which the tasks have to be executed. Thus, defining the context of ProM execution may be resilient against performing tasks in uncertain operational environments.

APPENDIX

Table 1

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 2 (Task Type: ProM task vs. no ProM task) ANOVA for the Dependent Variable of Accuracy on Accuracy on Ongoing Task Measures for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.009	0.009	0.54	0.47	0.01
Task type	1	0.001	0.001	0.31	0.58	0.007
Task order x Task type	1	0.006	0.006	1.94	0.17	0.05

Table 2

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 2 (Task Type: ProM task vs. no ProM task) ANOVA for the Dependent Variable of Accuracy on Response Time for Questions of the Ongoing Task Measures for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	11.81	11.81	4.66	0.04	0.10
Task type	1	0.78	0.78	3.56	0.07	0.08
Task order x Task type	1	0.14	0.14	0.66	0.42	0.02

Table 3

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 2 (Task Type: ProM task vs. no ProM task) ANOVA for the Dependent Variable of Response Time for Advancing Through Information Slides on Ongoing Task Measures for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.27	0.27	0.19	0.67	0.005
Task type	1	0.50	0.50	5.98	0.02	0.13
Task order x Task type	1	0.21	0.21	2.54	0.12	0.06

Table 5

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1st vs. 2nd. vs. 3rd) ANOVA for the Dependent Variable of Whether Participants Remembered That they had to Execute the ProM Task for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.03	0.03	0.24	0.63	0.006
Delay	2	0.38	0.16	2.41	0.1	0.05
Block	2	0.14	0.07	1.32	0.27	0.03
Task order x Delay	2	0.14	0.07	1.04	0.37	0.02
Task order x Block	2	0.19	0.09	1.74	0.18	0.04
Delay x Block	4	0.25	0.06	1.54	0.19	0.04
Task order x Delay x Block	4	0.21	0.05	1.27	0.29	0.03

Note. Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity.

Table 7

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1st vs. 2nd. vs. 3rd) ANOVA for the Dependent Variable of Whether Participants Remembered to Execute the ProM task During the Correct Window of Opportunity for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	1.06	1.06	2.23	0.14	0.05
Delay	2	7.90	3.95	20.92	.001	0.33
Block	2	0.07	0.03	0.25	0.78	0.006
Task order x Delay	2	1.87	0.93	4.94	.009	0.11
Task order x Block	2	0.10	0.05	0.36	0.70	0.009
Delay x Block	4	0.71	0.18	1.24	0.30	0.03
Task order x Delay x Block	4	0.27	0.07	0.47	0.76	0.01

Table 9

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1st vs. 2nd. vs. 3rd) ANOVA for the Dependent Variable of Whether Participants Remembered to Execute the Correct ProM Response for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.04	0.04	0.17	0.68	0.004
Delay	2	0.25	0.12	1.13	0.33	0.03
Block	2	0.21	0.11	1.16	0.32	0.03
Task order x Delay	2	0.67	0.18	1.68	0.19	0.04
Task order x Block	2	0.58	0.29	3.14	0.05	0.07
Delay x Block	4	1.28	0.32	3.81	0.005	0.08
Task order x Delay x Block	4	0.07	0.02	0.21	0.93	0.005

Note. Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity.

Table 11

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1st vs. 2nd. vs. 3rd) ANOVA for the Dependent Variable of Whether Participants Remembered to Execute the Correct ProM Response During the Correct Window of Opportunity for Experiment 1

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.40	0.40	0.84	0.37	0.02
Delay	2	7.24	3.32	18.06	0.001	0.30
Block	2	0.12	0.06	0.42	0.66	0.01
Task order x Delay	2	1.18	0.74	3.39	0.03	0.08
Task order x Block	2	0.38	0.16	1.17	0.32	0.03
Delay x Block	4	1.29	0.32	2.12	0.08	0.05
Task order x Delay x Block	4	0.41	0.10	0.67	0.61	0.02

Table 12

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 2 (Task Type: ProM task vs. no ProM task) ANOVA for the Dependent Variable of Accuracy on Response Time for Questions of the Ongoing Task Measures for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	1.38	1.38	0.95	0.34	0.03
Task type	1	0.004	0.004	0.12	0.90	0.001
Task order x Task type	1	0.07	0.07	0.24	0.63	0.006

Table 13

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 2 (Task Type: ProM task vs. no ProM task) ANOVA for the Dependent Variable of Accuracy on Response Time for Questions of the Ongoing Task Measures for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	1.38	1.38	0.95	0.34	0.03
Task type	1	0.004	0.004	0.12	0.90	0.001
Task order x Task type	1	0.07	0.07	0.24	0.63	0.006

Table 14

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 2 (Task Type: ProM task vs. no ProM task) ANOVA for the Dependent Variable of Response Time for Advancing Through Information Slides on Ongoing Task Measures for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.10	0.10	0.08	0.78	0.002
Task type	1	0.31	0.31	2.81	0.10	0.07
Task order x Task type	1	0.04	0.04	0.34	0.56	0.009

Table 16

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1^{st} vs. 2^{nd}. vs. 3^{rd}) ANOVA for the Dependent Variable of Whether Participants Remembered That they had to Execute the ProM task for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.21	0.21	1.14	0.29	0.03
Delay	2	0.19	0.09	2.0	0.14	0.05
Block	2	0.12	0.06	1.14	0.33	0.03
Task order x Delay	2	0.04	0.19	0.39	0.68	0.01
Task order x Block	2	0.19	0.10	1.83	0.17	0.04
Delay x Block	2.65	0.16	0.04	1.12	0.35	0.03
Task order x Delay x Block	4	0.18	0.04	1.21	0.31	0.03

Note: Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity.

Table 18

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1^{st} vs. 2^{nd}. vs. 3^{rd}) ANOVA for the Dependent Variable of Whether Participants Remembered to Execute the ProM Task During the Correct Window of Opportunity for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.07	0.07	0.23	0.63	0.006
Delay	2	0.41	0.20	1.47	0.23	0.04
Block	2	0.35	0.18	0.95	0.39	0.02
Task order x Delay	2	0.14	0.07	0.50	0.61	0.01
Task order x Block	2	0.42	0.21	1.12	0.33	0.03
Delay x Block	4	1.50	0.38	2.75	0.03	0.06
Task order x Delay x Block	4	0.50	0.13	0.92	0.46	0.02

Table 20

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1st vs. 2nd. vs. 3rd) ANOVA for the Dependent Variable of Whether Participants Remembered to Execute the Correct ProM Response for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	0.001	0.001	0.002	0.97	0.001
Delay	2	0.78	0.39	4.60	0.01	0.10
Block	2	0.04	0.02	0.19	0.83	0.005
Task order x Delay	2	0.13	0.07	0.77	0.46	0.02
Task order x Block	2	0.03	0.02	0.15	0.86	0.004
Delay x Block	4	0.60	0.15	1.73	0.15	0.04
Task order x Delay x Block	4	0.08	0.02	0.23	0.92	0.006

Note: Responses were counted as correct even if participants pressed a non-ongoing task key outside the window of opportunity.

Table 22

F-table Depicting Values of the 2 (Task Order: Certain vs. Uncertain) X 3(Delay: 0 vs. 1 vs. 2) X 3(Block: 1st vs. 2nd. vs. 3rd) ANOVA for the Dependent Variable of Whether Participants Remembered to Execute the Correct ProM Response During the Appropriate Window of Opportunity for Experiment 2

Source	df	Sum of Squares (SS)	Mean Square (MS)	F	p	partial η^2
Task order	1	.006	.006	0.02	0.90	0.001
Delay	2	0.49	0.24	1.73	0.18	0.04
Block	2	0.20	0.10	0.51	0.60	0.01
Task order x Delay	2	0.36	0.18	1.29	0.28	0.03
Task order x Block	2	0.40	0.20	1.04	0.36	0.03
Delay x Block	4	2.11	0.53	3.53	0.003	0.08
Task order x Delay x Block	4	0.71	0.18	1.78	0.32	0.03

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