EFFECTS OF UNEMBEDDED TIME- AND EVENT-BASED PROSPECTIVE MEMORY TASKS ON AN ONGOING WORKING MEMORY TASK

by

ANNA OBRAZTSOVA

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June 17, 2008	Sarit Golub, Ph.D.
Date	Chair of Examining Committee
June 17, 2008	Joseph Glick, Ph.D.
Date	Executive Officer

Susan Croll, Ph.D.

Ray Johnson, Jr., Ph.D.

Jeffrey Parsons, Ph.D.

Laura Rabin, Ph.D.

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract

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by

Anna Obraztsova

Advisor: Sarit Golub, PhD

The present investigation focused on the relationship between prospective memory (PM) and working memory (WM). The multinomial theory (Smith, 2003) proposes that all PM tasks exert a cost on an ongoing task. The multiprocess theory (Einstein et al., 2005) suggests that the extent of PM cost to the ongoing task depends on the complexity of the PM task, with the provision that some PM tasks can be completed automatically. In an effort to evaluate predictions made by these two theories within a unified experimental setting, the present study investigated the impact of engagement in three types of PM tasks, and assessed the contribution of individual WM capacity in this process.

Participants performed an ongoing WM task under three PM conditions: time-based (TB), event-based (EB), and time-based with reminder (TBR); a

control group completed the ongoing task without the PM. Ongoing task performance measures included accuracy and reaction time (RT).

Our results did not provide unequivocal support for either the multiprocess or the multinomial theory. There were no significant difference between the control and the experimental groups, a finding that was complicated by unexpected performance pattern by the control group. However, results indicated that participants in the most demanding condition (TB) were significantly least likely to improve their RT relative to baseline, compared to participants in the least demanding condition (EB), while the TBR group performed in the middle (ns). When aided with a reminder, the TB group performed slower than the EB group but faster than the TB group, suggesting that the reminder effectively alleviated some of the processing cost of he pure time-based PM task. Finally, rate of responding was proportional to individual WM capacity: there was a main effect of WM, with High WM participants performing more accurately and faster on the ongoing task compared to the low WM participants. Notably, WM capacity did not moderate the effect of PM task on the ongoing task performance, with comparable performance patterns observed across the WM capacity spectrum.

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Introduction

Prospective memory is commonly defined as remembering to do something in the future, or the act of having remembered to do something that was planned in the past. A particular hallmark of the prospective memory concept is a delay between the formation of the plan and its execution, called *delayed intention* (for example, "'I must remember to call my dentist on Friday,' said Elsa on Tuesday.").

Within the construct of prospective memory, researchers have identified different types of tasks. Meacham and Leiman (1982) distinguished between habitual prospective remembering (e.g., remembering to take medication every day with breakfast) and episodic prospective remembering (e.g., remembering to order opera tickets for June 7th). In *event-based* prospective memory, the intended action is triggered by an external event (e.g., water the plant when you get home). In *time-based* prospective memory, the intended action must occur at a specified time (e.g., call dentist at 10 am) or in specified intervals of time (e.g., take one aspirin every four hours). Remembering to execute this action at the specified time must occur in the absence of overt external cues, but by the internally-generated "time cue" (Einstein and McDaniel, 1990).

The processes supporting prospective memory are often further subdivided into prospective and retrospective components (Einstein & McDaniel, 1996). A successful execution of a prospective memory task involves remembering *that* you must call your dentist on Friday (a prospective component,

memory for intention), as well as remembering *what* you have to do when Friday comes (a retrospective component, memory for content of the intention). In other words, success in prospective remembering depends both on cue identification (*that*) and retention retrieval (*what*).

As an everyday task, prospective memory is most commonly encountered by individuals adhering to a regular regiment of treatment. For these individuals, *adherence* to treatment – or prospective memory success – is paramount to wellness, while *non*adherence may carry adverse consequences. Because *non*adherence to treatment is a common and vital concern, understanding the processing costs and potential methods to alleviate them of prospective memory tasks is of paramount imporantce. The present investigation evaluated the impact of three different types of prospective memory task on an ongoing working memory task, and offered insights into effective strategies for prospective memory success that are applicable to treatment adherence and everyday prospective remembering.

We begin with a review of common methods utilized to study prospective memory, as well as the neuropsychological correlates of prospective memory processes, in order to provide background for a discussion of contemporary theories of relationship between prospective memory and working memory. Next, we will review key studies on treatment adherence, which link prospective memory performance to individual working memory capacity. Finally, we will introduce an apparent contradiction between the two most current theories of

prospective memory / working memory interaction which provided the impetus for the present investigation.

Prospective Memory: Methods of Study

Because prospective memory is a task of high ecological significance, both laboratory-controlled and naturalistic investigations are commonly conducted. Maylor (1996a) and Rich, Svoboda and Brown (2006) reviewed some of the experimental manipulations typically employed in the laboratory and in the field. Discussion of these methods is relevant here to contextualize the reported results, as there can often be notable discrepancies in evaluation of the seemingly similar constructs.

Einstein and McDaniel (1990, 1996) developed an experimental technique for investigating prospective memory in controlled laboratory conditions. In the "Einstein – McDaniel paradigm," participants perform two concurrent tasks: an "ongoing task" that the participant performs for the duration of the session, and an embedded "background task" – the prospective memory task – that requires a particular response to a specified "target." A target is defined as any signal that has been associated with a prospective intention, like a word or a shape, or an event. An example of a prospective memory task is responding whenever a displayed word belongs to a particular category (e.g., animals, clothing). Commonly, the ongoing task is a working memory task and is performed on the computer. Occurrence of the prospective cue is manipulated by the experimenter, and constitutes an "event" to which the participant must respond

by executing the prospective intention. The instructions for the prospective memory task are given before the instructions for the ongoing task, thus insuring the lapse of time between intention formation and intention execution. Some experimenters use a stimulus cue that is categorically the same as the stimuli in the ongoing task (e.g., in a word learning task, the prospective cue would be a specified word), whereas others opt for an unrelated cue (e.g., in a word learning ongoing task, the prospective cue would be a sound or a geometrical pattern). In a time-based prospective memory task, the cue must be internally generated by the participant, and the response must be made in the absence of any external cues. Thus, the Einstein-McDaniel paradigm allows flexibility in the choice of tasks and prospective cues, and is used in the majority of experimental studies of prospective memory.

Naturalistic studies of prospective memory attempt to simulate everyday situations. Participants are typically required to phone in or mail a postcard to a specified address, following either a time-based or an event-based assignment. Walbaum (1997) requested her college-student participants to call the laboratory between 10 am and 2 pm (a time-based task), either during the week or during the weekend. After controlling for the use of external reminders, the results indicated that students assigned to this time-based prospective memory task during the week were more compliant than students assigned to call during the weekend. By using their class and activity schedule as anchor events, the weekday group students essentially adapted the prospective memory task from a

time-based (call between 10am and 2pm) to an event-based (call after class). In contrast, this "anchoring" was less tenable for the weekend group participants, since students' weekends tend to be less structured (Walbaum, 1997).

The challenge of using time as a memory cue is also demonstrated in studies of retrospective, autobiographical memories (i.e., memory for past personal events). In their review of organization and retrieval of autobiographical memories, Reiser, Black and Abelson (1985) argued that individuals encode and "tag" information by embedding the details of a particular event into a cognitive context of *activity* – a set of actions that form a goal-oriented sequence – that can subsequently be used as a memory retrieval aid and refine the search for particular information. On the other hand, a time reference, although potentially relevant to the event, is less valuable as a retrieval cue because it is less likely to be part of the organizing *activity* scenario (Reiser, Black & Abelson, 1985). For example, the event of going hiking is likely to be recalled much faster in response to the activity-based query, where the context provides a "spotlight" for memory search (e.g., "What did you do while visiting friends in the country?"), compared to a time-based query which leaves fewer relevant tags (e.g., "What did you do at 2pm on April 22?"). Therefore, the challenge presented by time cues is evident both in retrospective and prospective memory studies, attesting to the greater attentional involvement required for operating with, and incorporating temporal dimensions of cognitive events.

Although naturalistic studies can inform of general patterns of prospective memory performance, they suffer from the confound of the participants' use of memory aids, which may or may not be accounted for by the experimenters. For example, although significant age differences in prospective memory task performance are reported in laboratory studies (see below), in naturalistic studies of prospective memory older adults consistently outperform younger adults. Older adults' superior performance has been attributed to their efficient use of external memory aids such as calendars and to-do lists (reviewed in Maylor, 1996b).

In summary, while laboratory studies provide a more structured environment in which to assess the variables affecting prospective memory, their weakness is in the confined duration of the task, which may be too limited. Naturalistic studies, on the other hand, exert less experimental control and may in fact document differences in strategy use, rather than true prospective memory ability.

Neuropsychological Correlates of Prospective Memory

Despite the ecological relevance of prospective remembering, and a body of literature that describes various types and processes that support it, there have been relatively few investigations of neuropsychological correlates of prospective memory. According to Kliegel, Martin, McDaniel and Einstein (2002), prospective memory relies, in part, on working memory resources, the "executive functions" of planning and strategic attention allocation. Given the evidence that the frontal lobes of the brain mediate neural functions that control WM and

executive functions, the frontal lobes emerge as the most fitting candidates for prospective memory support. In her review, Glisky (1996) pointed out that the purported relationship between prospective memory performance and frontal lobe function has been derived from indirect association and theoretical synthesis, rather than from direct, experimentally controlled studies. For example, it is known that older adults do less well than younger adults on “frontal” tasks that require planning, strategic flexibility and monitoring. Furthermore, older adults do not perform as well on prospective memory tasks as younger adults (but see the mixed findings on the age effect in prospective memory below). Thus, intact frontal function is hypothesized to be involved in successful prospective remembering, especially on prospective tasks that place greater demand on frontal faculties, such as executive attentional resources (Glisky, 1996).

Bisiacchi (1996) emphasized that performance on prospective memory tasks can be related to both executive frontal functions as well as the retrospective, hippocampally-dependent, memory processes. This observation fits well with the notion that successful prospective remembering is a multifaceted process, that relies on successful encoding, successful storage, attentional monitoring, inhibition of ongoing tasks and strategic retrieval of the planned intention. This view is further supported by Shallice (1996) who stressed that in prospective memory tasks, the hippocampus-dependent process of intention retrieval is subservient to, rather than independent of, the intact function of the

prefrontal areas that supervise the strategic allocation of attentional resources to the subprocesses of prospective remembering.

Recently, evidence for neurophysiological correlates of prospective memory has been gathered using both non-invasive empirical methods, and focused investigation of some pharmacologically-altered states. West and Krompinger (2005) used the event-related potential (ERP) technique to study patterns of neural activation in retrospective and prospective memory tasks. West and Krompinger (2005) sought to test the hypothesis that prospective remembering is a dynamic conglomerate that relies both on working memory processes and retrospective memory, and is distinct from retrospective memory task of recognition. They designed an experiment requiring participants to study a target word for prospective recall and a target word for a test of recognition. After the study interval, participants engaged in a task requiring them to make semantic-relatedness judgments about pairs of words. Embedded in this task, a target for the prospective memory task appeared, and participants were told to respond with a specified key press. Following this task, an old/new recognition trial was administered, requiring participants to discriminate between studied and novel items. Results indicated that that ERP activations followed expected patterns for recognition (frontal P2 component FN 400) and prospective memory tasks (N300 and prospective parietal positivity), with some overlap. Notably, when participants successfully responded to a prospective memory target, there was a unique activation of right frontal areas. Thus, results suggested that the

prospective memory task is distinct in requiring additional modulation by frontal activity that is not related to retrieval of the intention or cue recognition alone West and Krompinger (2005).

Neural substrates of prospective memory were examined further in a functional magnetic resonance imaging (fMRI) study conducted by Simons, Scholvinck, Gilbert, Frith and Burgess (2006). The experimenters' goal was to examine whether neural activation patterns during an event-based prospective memory task supported the functional distinction between cue identification and retention retrieval processes of prospective remembering made by McDaniel and Einstein (1996). Two versions of the event-based prospective memory task were developed, making either cue identification or intention retrieval more challenging. It was hypothesized that if cue identification and retention retrieval relied on similar neural mechanisms and were supported by the anterior prefrontal cortex, neural activation in the two different prospective memory task versions would show much overlap. Behavioral data revealed that participants were more accurate on the ongoing task compared to the prospective memory tasks, and that they were less accurate on high-load intention retrieval trials compared to high-load cue identification trials.

The neuroimaging data revealed much overlap in activation between the cue identification and intention retrieval conditions; both tasks activated anterior prefrontal cortex, as well as lateral prefrontal and the parietal cortical region, which was consistent with neuroimaging studies of prospective memory by West

and Krompinger (2005). However, some distinct patterns of activation were detected as well. In the intention-retrieval prospective memory task, there was greater activation in posterior cingulate and precuneus areas, which have been linked to episodic retrieval (e.g., Habib, Nyberg & Tulving, 2003). In the cue identification condition, there was greater activation in anterior cingulate, lateral prefrontal and parietal areas that have been linked with vigilance and attention in visual search tasks. This finding is echoed in a recent report by Lungu, Liu, Waechter, Willingham and Ashe (2007), who showed that anterior cingular cortex was activated more on non-typical trials requiring more directed attention (similar to cue identification in prospective memory), while the medial prefrontal cortex was engaged in monitoring, strategic planning, and maintaining overall task demands across trials (similar to intention formation and retention in prospective memory). Thus, several studies have demonstrated that although many of the same prefrontal areas are active during both cue-identification and intention-retrieval conditions of prospective memory tasks, differential activations in the prefrontal cortex suggested a functional distinctiveness for event-based prospective remembering.

Recently, West, Bowry and Krompinger (2006) used ERPs to demonstrate mutual modulation of working memory and prospective memory. Their results indicated that frontal lobe activation increased in response to load in either working memory or prospective memory tasks. The overlap of activated areas supported the hypothesis that prospective memory depends, at least in part, on

working memory resources, and that the frontally-mediated limited attentional resources are tapped by both working memory and prospective memory tasks. In a subsequent study, West (2007) used ERPs to demonstrate that prospective memory success is supported by strategic monitoring processes that are distinct from processes that support cue recognition.

Drug Effects on Prospective Memory

Further examination of neurophysiological correlates of prospective memory is supplied by studies that document effects of psychoactive drugs on prospective memory performance. Rich, Svoboda and Brown (2006) showed that diazepam, a common anxiolytic that has a sedative effect on cortical and subcortical regions, interferes with neural processing required for successful prospective remembering, but not with processes that service sustained attention, supporting the multifaceted complexity of successful prospective remembering.

Ecstasy (MDMA) is a psychoactive street drug that has been associated with permanent neurological damage, resulting in retrospective memory deficits (reviewed in Heffernan, Jarvis, Rodgers, Scholey & Ling, 2001). Heffernan et al. (2001) administered a self-report prospective memory questionnaire to regular ecstasy users to investigate the effects of ecstasy on prospective memory. Survey results indicated that, compared to non-users of drugs, ecstasy users reported significantly more prospective memory failures in their everyday lives. Furthermore, reported deficits in prospective memory correlated with declines on

a verbal fluency task typically used to assess executive functioning. Although Heffernan et al. (2001) acknowledged that self-report data lacked experimental robustness, it was proposed that, in light of detected correlations with executive function measures, prospective memory deficits in ecstasy users may stem from ecstasy-related neurological damage to frontal lobe networks necessary for execution of planned intentions.

Finally, recent reports indicate that nicotine may act as a “spotlight” and improve performance in an event-based prospective memory task. However, the bolstering effect of nicotine on the prospective memory task may be conditional on the cognitive load of other ongoing activities. Rusted and Trawley (2005) investigated the effects of 1mg nicotine and ongoing working memory load on an event-based prospective memory task that was embedded in a lexical decision task. Smokers and non-smokers received either nicotine or placebo nasal spray prior to testing. The lexical decision task required participants to view letter strings presented on the computer screen and press a “Yes” button when the string formed a legitimate English word, or press a “No” button when the string did not form a legitimate English word. The prospective memory task required participants to press the space bar whenever either the letter P or Q appeared in the letter stings shown. Additionally, working memory load was manipulated between subjects. That is, half of the participants listened to auditorily presented digits (1-9) and pressed another button whenever the digit nine was presented

while performing the lexical decision and prospective memory tasks. The other half of the participants did not perform the digit task.

The results indicated a main effect of working memory load: prospective memory performance was adversely affected by the ongoing working memory task, supporting the view that prospective memory depends on the availability of adequate attentional resources. Additionally, a significant antagonistic Working Memory Load by Drug interaction revealed that nicotine bolstered prospective memory performance for the no-load participants, but hindered prospective memory performance when the working memory task was performed concurrently. Rusted and Trawley (2005) hypothesized that the benefit offered by nicotine in the no-load condition could be attributed to the induced physiological arousal that facilitated performance on the prospective memory task. However, in the concurrent working memory load condition, the nicotine-induced physiological arousal was compounded by the stress of the added task, thereby surpassing the optimal level of arousal and impairing performance on the prospective memory task.

In a subsequent investigation, Rusted, Trawley, Heath, Kettle and Walker (2005) assessed whether the nicotine-induced advantage was uniform across prospective memory tasks of varying difficulty. The prospective memory task was embedded in the lexical decision task, as described above, and was either “automatic” (response to two target words) or “strategic” (response to two target letters embedded within words). Results indicated that nicotine improved

prospective memory performance when the targets required strategic, but not automatic processing. Rusted et al. (2005) interpreted these results to indicate that nicotine facilitates the deliberate allocation of the attentional resources in situations when the task requires sustained strategic focus on incoming information. Therefore, the effects of nicotine are observed on complex prospective memory tasks that depend on strategic allocation of attentional resources.

In summary, based on theoretical predictions, as well as direct empirical observations, successful prospective memory performance appears to rely on intact executive function resources, which are associated with healthy frontal lobe functioning. Decriments in prospective memory performance have been suggested to result from frontal dysfunction. Neuropsychologically, this lends strong support to the notion that prospective memory relies on complex higher cortical functions such as attention, planning, attending and decision-making, and that it is distinct from neuroanatomical and neuropsychological correlates of retrospective memory.

Interactions between Prospective Memory and Working Memory

Although dependent on intact working memory resources, prospective memory is distinguished from just another working memory task in that a planned action is necessarily *out* of immediate awareness for some time. In their *process model*, Kliegel, Martin, McDaniel and Einstein (2002) propose that prospective memory arises from successful execution of four consecutive phases, each with

distinct neuropsychological correlates and purported underlying cognitive processes. The first stage is *intention formation*, during which the plan to execute some action in the future is formed. This stage is thought to rely heavily on planning skill and the ability to identify and focus on relevant goals. In the second phase, *intention retention*, this plan must be remembered during some delay during which execution of this plan is either inappropriate or impossible. The retention phase is a key component of retrospective memory (i.e., keeping some information in memory while not using it), and does not rely on working memory resources. It is also a part of prospective memory that is most helped be external aids like to-do lists, alarm clocks, and other reminders.

For example, contrary to commonly observed memory decline observed in older adults, early investigations of effects of age on prospective memory did not demonstrate expected deficits (see Moscovitch, 1982). In fact, older adults, in naturalistic settings, were actually more successful than their younger counterparts at various prospective memory tasks. Subsequent review of these results demonstrated that, compared to younger adults, older adults were more likely to adapt to the challenging demands of prospective tasks and support their performance with external aids (such as to-do lists or calendars) (cf. Maylor, 1996b). Thus, external memory aids specifically support the retention of intention of a prospective memory task. However, retaining an intention over time does not guarantee prospective memory success.

In order to lead to apposite completion of a prospective memory task, the planned action must be retrieved and initiated in the third stage of Kliegel et al. model, the *intention initiation* phase, when the relevant cue is encountered. Intention initiation is a complex activity, which is responsible for many failures on prospective memory tasks. Its success depends on (1) attentional resources that allow the identification of the relevant cue, (2) highly selective and strategic focus that allows one to discriminate between relevant and irrelevant cues, and (3) cognitive flexibility that facilitates the switch from (and inhibition of) the ongoing task and promotes initiation of the planned activity.

In many instances, the properties of the cue determine whether the prospective intention will be initiated: the easier it is to detect the cue, and the more salient the cue is perceived to be, the easier it is for participants to complete the prospective memory task by strategically allocating attentional and processing resources to monitor for, and detect the prospective memory cue (Kliegel, Martin, McDaniel & Einstein, 2001; McDaniel & Einstein, 2000). This advantage of distinctive targets applies to older adults as well. In a study of age effects in prospective memory performance, Cherry et al. (2001) demonstrated that when the target that was meant to evoke the planned response was clearly identifiable and distinct from background items, older adults performed as well as younger adults on event-based prospective memory tasks. The more distinctive the cue, the better was the prospective memory performance, and the more similar the performance between older and younger adults.

Finally, in the fourth phase of *intention execution*, the original plan must be carried out, facilitated by inhibition and cognitive flexibility resources that mediate efficient switching between the ongoing and the planned activities, in spite of (or concurrent with) whatever demands the ongoing task imposes. Thus, while intention formation, intention initiation, and intention execution all rely heavily on executive processes of planning, monitoring and active attending, as well as cognitive flexibility and response inhibition, the retention of intention is primarily supported by episodic retrospective memory. When someone makes a mental note (plans an intention) to wish a friend a happy birthday next Wednesday, this intention is encoded into LTM and is presumably not revisited until the appropriate context (Wednesday) presents the opportunity to proceed with attention-demanding processes, intention initiation, and intention execution.

To empirically test the process model, Kliegel et al. (2002) conducted a neuropsychological evaluation of executive functions and, one week later, administered a prospective memory task involving all four stages outlined above. Preliminary neuropsychological measures included tests of verbal and non-verbal fluency (S-words and design generation), a problem-solving task (Tower of London), and a test of cognitive flexibility, planning, and inhibition (Wisconsin Card Sorting Task (WCST). During the second session, participants were given a set of guidelines for completing several laboratory tasks. The five-point instructions concerned the goals, the allowed order, and the timing instructions. Participants were asked to verbalize their plan for completing the tasks (intention

formation), and then a Stroop Task was administered (requiring cognitive flexibility and inhibition). Following the Stroop task, participants were required to recall their intention (intention retention), and other filler tasks (another planning task and a questionnaire) were administered. The prospective component required participants to initiate their planned actions as soon as the filler tasks were complete (intention initiation), and finally, they were scored on their accuracy of following previously memorized instructions (intention execution).

Data from the study conducted by Kliegel et al. (2002) revealed significant correlations that highlighted the following relationships: (a) *Intention formation* was significantly correlated with planning task and non-verbal cognitive fluency; (b) *Intention retention* was not significantly correlated with *any* executive function measures; (c) *Intention initiation* was significantly correlated with high performance on measures of planning, cognitive flexibility and response inhibition (WCST and Tower of London); and (d) *Intention execution* was significantly correlated with a measure of cognitive flexibility (WCST) and non-verbal cognitive fluency (Design generation task). The process model predicted all obtained significant correlations (Kliegel et al., 2002).

In light of robust findings of attentional resources and working memory capacity declines in older adults (cf., Salthouse, 1991), research on prospective memory performance in this population grants an opportunity to examine the contribution of working memory and attentional resources to different aspects of prospective memory. Although several experiments found no age differences in

performance on simple prospective memory task (e.g., Kliegel, McDaniel & Einstein, 2000, Einstein & McDaniel, 1990; Cherry & LeCompte, 1999), effects of age on complex prospective memory tasks were more nuanced. Older adults remembered the details of the plan they formulated as well as younger adults, but they were less likely to form elaborate plans, initiate planned actions at an appropriate time, or comply with the demands of the planned activity (Kliegel et al., 2000). Older participants remembered what they had to do, but failed to carry out the task in the right context. Thus, older adults demonstrated deficits in intention formation and strategic planning, intention initiation and intention execution, but not in the intention retention over time. These deficits have been hypothesized to depend primarily on working memory and attentional and executive resources, which are vulnerable to age effects. Thus, the observed pattern of prospective memory failure in older adults is consistent with the process model and highlights the diversity of cognitive processes required for prospective memory success.

The process model is generally accepted as a theoretical framework for investigating prospective memory processes, although researchers disagree on the contribution of working memory resources to the *intention initiation* stage of prospective memory.

"An Easter Egg is Dear for Easter": Models of the Role of Working Memory in Intention Initiation

Timely and apt initiation of intention emerges as the crux of prospective memory success. As the Russian proverb quoted above warns, a prospective memory task is completed successfully only if it is initiated at the right time and in the right context. In the current literature, there are four theoretical models regarding the intention initiation process. Some researchers maintain that intention initiation can occur automatically, such that whenever the target is encountered, the planned action "springs to mind" (Einstein and McDaniel, 1996; Otani, Landau, Libkuman, St. Louis, Kazen & Throne, 1997). Others contend that whether the intention is initiated depends on the attentional demands of competing ongoing tasks (Marsh & Hicks, 1998; Stone, Dismukes & Remington, 2001).

Another team proposes that prospective memory in general, and the intention initiation phase in particular, necessitates continuous, working memory-dependent monitoring, and cannot be automatic (Smith, 2003; Smith & Bayen, 2004, 2005). Finally, a recent theory suggests that intention initiation depends on the interaction between the demands of a particular prospective task and the demands of the ongoing situation (McDaneil & Einstein, 2000; Einstein et al., 2005), such that intention initiation can be automatic when the prospective memory task is easy, but relies on limited attentional resources when the

demands of the prospective memory task increase. Each of these theoretical proposals is reviewed below.

Intention initiation occurs automatically: the case for event-based prospective memory

Einstein and McDaniel (1996) proposed that time-based prospective memory tasks are fundamentally different from event-based prospective memory tasks, in that the former rely heavily on continuous monitoring, while the latter can be accomplished successfully via spontaneous retrieval of intention upon an encounter with the relevant cue. Time-based prospective memory tasks require strategic and frequent monitoring by limited attentional resources, which are known to decline with age (cf. Salthouse, 1991). Not surprisingly, older adults perform significantly less well on time-based prospective memory tasks as compared to younger adults (Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; Einstein & McDaniel, 1990, 1996).

In contrast, Einstein and McDaniel (1996) proposed that event-based prospective memory occurs in the absence of working memory involvement. They argue that two non-working memory processes are necessary for event-based prospective remembering: (1) a strong association between the relevant cue and the planned action during the intention formation stage (the strong cue-planned action association ensures that when the relevant cue is encountered in the near future, it would necessarily evoke the planned action) and (2) maintaining the “heightened state of activation” of the relevant cue, which, similar

to priming, would make its detection a largely effortless task. Einstein and McDaniel's (1996) theory of automatic intention initiation fits well with the minimal age differences found on event-based prospective memory tasks, because age-susceptible cognitive resources are not those required for event-based tasks (e.g. Einstein & McDaniel, 1990).

The heightened state of activation of the planned intention, which is presumed to facilitate the evocation of the planned intention in response to the relevant cue, has been termed the "intention superiority effect" (Marsh, Hicks & Bryan, 1999). This means that, following successful intention formation, whenever the relevant cue is encountered, it will automatically set off the (time-consuming) process of intention retrieval. Marsh, Hicks, and Watson (2002) instructed participants to engage in a lexical decision task, within which an event-based prospective component was embedded. As part of the lexical decision task, participants pressed a particular button when the string of letters shown on the screen formed a correct word in English. Additionally, for the event-based prospective memory task, participants were instructed to press a different button whenever they encountered a word that belonged to a specified category (animals or clothing). A typically expected finding in lexical decision tasks is that identification of true words is faster than rejection of non-words; participants were instructed that the lexical decision task was of prime importance to the study, and that the prospective component was of secondary interest.

Marsh, Hicks, and Watson (2002) sought to test the proposed properties of the intention superiority effect, namely that an encounter with a relevant cue automatically leads to a time-consuming retrieval of the planned intention. They hypothesized that when relevant cues are presented, participants' word/nonword lexical decisions will be slower for items that actually lead to the appropriate prospective response, but would be comparatively faster if the prospective response fails. Results from three experiments supported this hypothesis; an encounter with an animal or clothing word that set off intention initiation and lead to the planned response took longer to identify as a word, presumably because of the time-consuming process of noticing the cue, retrieving the intention, and coordinating the appropriate response. Prospective task cues that were successfully noticed by participants and led to the appropriate response resulted in longer prospective memory times, compared to missed relevant cues. Thus, Marsh, Hicks and Watson (2002) supported Einstein and McDaniel's (1996) proposal that intention initiation in event-based prospective memory tasks can be accomplished automatically, following successful association between relevant cue and planned action during the intention formation phase.

Intention initiation in a simple event-based prospective memory task appeared to occur automatically and independently of the demands of the ongoing task in a study conducted by Otani et al. (1997). The researchers hypothesized that if intention initiation can be achieved without significant working memory involvement (i.e., that it is largely automatic), increasing working

memory demands in concurrent tasks would not affect event-based prospective memory performance. Participants engaged in a word-learning task (ongoing) and were required to respond to a particular target word for the prospective memory task. Experimenters manipulated the difficulty of the ongoing task by making rehearsal of the words more difficult by several levels of articulatory suppression. Although the participants' performance on the ongoing tasks decreased with increased working memory demands, their performance on the event-based prospective memory task was unaffected. The authors concluded that on *simple* event-based prospective memory tasks, processing demands on the ongoing activity do not influence performance on the event-based prospective memory task, and thus retrieval of the intention was deemed automatic and independent of working memory involvement in concurrent activity.

Graf and Uttl (2001) further argued that the prime factor that distinguishes prospective memory from vigilance is the disengagement of working memory and attentional resources at the time of intention initiation. According to their view, the amount of working memory resources allocated to thinking about a particular intention versus other ongoing tasks dictates the status of these intentions. During a vigilance task, a short-term intention (I need to press a red button when the blue square appears) dominates awareness for the duration of the task. In contrast, a true prospective memory task occurs when the intention for some future action is made (I need to buy stamps after work), but is realized following a period during which the attentional resources were focused not on the intention,

but on unrelated ongoing activities. Thus, vigilance and prospective memory form a conceptual continuum rather than distinct categories (Graf & Uttl, 2001).

This view is further supported by the findings of Brandimonte, Ferrante, Feresin, & Delbello (2001), who conducted a study that differentiated between cognitive processes underlying event-based prospective memory and vigilance. They proposed that while vigilance and event-based prospective memory are similar in that each requires a response to a target stimulus, response in a vigilance task requires constant attentional monitoring, while intention initiation in a prospective memory task does not. In a prospective memory task the intention is formed (i.e., encoded into memory) at the onset of the task and is only retrieved from retrospective memory once the relevant cue appears, and does not require monitoring. Thus, the retrieval component is necessarily present in a prospective memory task, but is absent in a vigilance task that is performed "online".

Brandimonte et al. (2001) further hypothesized that the difference in underlying processes in vigilance and prospective memory tasks will be reflected in response time (RT) to the ongoing task. In a vigilance task, RT will be longer than in a prospective memory task, because of the cost of maintaining the intention to respond to the cue in consciousness. In contrast, the RT will be shorter for participants who are engaged in a prospective memory task, because the cue would elicit the response automatically, without imposing additional processing demands.

Two experiments were performed using the Einstein-McDaniel paradigm discussed above. The ongoing task was a lexical decision task, which included both word vs. non-word and living beings vs. non-living being discrimination trials. The background, or prospective task, was a “stopping” task, where the participants were instructed *not to respond* when a target cue appeared. Three groups of participants received different background task-framing instructions. In the vigilance condition, the importance of not responding to target cues was emphasized during instructions and target cues were included in the practice trial to ensure that the participants understood the importance of remaining vigilant and not responding to target cues. In the prospective memory condition, the participants were instructed not to respond when target cues appeared, but did not receive any of the target cues during the practice trial, thus ensuring that the planned intention was not revisited. In the control condition, participants just performed the ongoing lexical decision task.

The results supported the authors’ hypotheses, demonstrating longer RTs in the ongoing lexical decision task for the vigilance group, and shorter RTs in the ongoing task for the prospective memory and control groups. Furthermore, there was a significant benefit of decreased error rate on the stopping task in the vigilance group, compared to the prospective group, presumably afforded by the sustained focus on the stopping task that was emphasized for this group. Finally, the authors observed repetition priming in the prospective memory group but not in the vigilance group, showing that participants in the prospective memory group

made fewer errors on the fourth occurrence of the target cue compared to the first occurrence of the target cue, while the number of errors in the vigilance group remained unchanged across target cue presentations.

Brandimonte et al. (2001) concluded by emphasizing that the degree of conscious, “online” monitoring for cues that is required is the fundamental difference in underlying cognitive processes that enable vigilance and event-based prospective memory: while a vigilance task requires one to persistently scan the environment for relevant targets, the retrieval of the planned action in response to a target cue in a prospective memory task occurs with at least some degree of automaticity. Consequently, while vigilance is an all-consuming and attention-exhaustive task, in a prospective memory task, working memory resources are available during the intention retention phase.

However, as detailed below, interactions between event-based prospective memory tasks and cognitive processes required for ongoing activities appear to be more complex under closer investigation.

Intention Initiation is Dependent on the Attentional Demands of the Ongoing Task

Marsh and Hicks (1998) examined event-based prospective memory performance under varied working memory and executive function demands of the ongoing tasks. Furthermore, ongoing tasks were chosen to isolate particular subprocesses of Baddeley’s (1983, 2000) working memory system. The system consists of a *central executive*, which allocates attentional resources to, and coordinates the information to be processed by, three subsidiary systems: *the*

phonological loop (auditory stimuli), the *visuo-spatial sketchpad* (visuo-spatial stimuli), and the *episodic buffer* (information from all modalities that correspond to the same event, to be integrated into the long term storage). The central executive acts as a "supervisory" element and is implicated in manipulating complex multi-modal information, sequencing of the ongoing tasks, dedicating limited attentional resources to tasks that are deemed relevant (at the expense of other tasks), and in general coordinating all processing that is carried out by the subsidiary systems (Baddeley, 1983, 2000).

Marsh and Hicks (1998) found that prospective memory performance did not suffer when the ongoing tasks involved phonological loop suppression, or non-monitoring tasks involving the visuospatial sketchpad, but declined dramatically when the ongoing tasks required high-load monitoring and planning, in both the verbal and visuospatial domains. These central executive-dependent tasks that required planning and monitoring appeared to significantly and preferentially impair performance on the prospective memory task. Thus, Marsh and Hicks (1998) demonstrated that event-based prospective memory performance is impaired when the central executive resources of planning and monitoring are divided, but not when the ongoing tasks rely on working memory faculties that do not require high involvement of the central executive.

Similarly, Stone, Dismukes and Remington (2001) used as ongoing activity a visuo-spatial task that required monitoring and decision making, and examined the effect of ongoing task load and articulatory suppression on event-based

prospective memory. They found that prospective memory performance decreased when encoding of prospective instructions was interfered by a shadowing task, and that increasing the complexity of the visuo-spatial task also impaired prospective memory performance. These results concur with Marsh and Hicks's (1998) conclusion that prospective memory performance is dependent on the available central executive working memory resources that manage planning and monitoring.

The Multinomial Model: All Prospective Memory Tasks Rely on Working Memory

In a series of experiments, Smith and colleagues (Smith, 2003; Smith & Bayen 2004, 2005, 2006; Smith, Hunt, McVay & McConnell, 2007) argued that not only do *all* prospective memory tasks demand limited attentional resources, but also that, as a consequence, prospective memory execution taxes performance on the ongoing tasks if they rely on the limited attentional resources.

For example, Smith (2003) compared participants' performance on an ongoing lexical decision task as a function of an embedded versus the delayed prospective memory task. The lexical decision task measured participants' correct identification of a presented string of letters as either a word or a non-word. The prospective memory task required participants to press the F1 key when a specified target word appeared. For half of the participants, the prospective memory response had to be carried out during the lexical decision task (embedded condition), whereas for the other participants, the prospective memory response had to be carried out after the lexical decision task was

completed (delayed condition). The experimenter measured the RTs of responses to lexical decision trials that were 20 trials away from the target words, to limit the confound of motor response delays.

Results indicated that RTs on the lexical decision task were longer for participants in the embedded prospective memory task condition, compared to participants who were not required to respond to the prospective cue during the ongoing lexical decision task. This supported Smith's proposal that event-based prospective memory is an effortful, attention consuming process that continuously requires and competes for limited available attentional resources with other attention-dependent tasks, even in the absence of relevant cues (2003).

Furthermore, Smith (2003) demonstrated that individual working memory capacity predicted the speed of intention initiation. High working memory capacity individuals responded faster to prospective cues that were more challenging to process compared to their low capacity counterparts, while working memory capacity did not differentiate between the groups when the prospective memory cue was less challenging. This finding concurs with Smith's hypothesis that availability of attentional resources is critical for strategic monitoring of relevant cues and intention initiation phases of prospective remembering.

The main idea proposed by Smith (2003) is that event-based prospective memory is an attention-demanding process that taxes limited attentional

resources even in the absence of prospective memory cues, thus imposing cost on any ongoing processes that also require attentional resources. In particular, the intention retrieval phase necessarily requires limited attentional resources because of strategic monitoring of the environment that must occur to identify a target and initiate a planned action (Smith, 2003). This view was further expanded, resulting in Smith and Bayen's formal multinomial model (2004, 2005) of event-based prospective memory.

The multinomial model (Smith & Bayen, 2004, 2005) maintains that (1) event-based prospective memory depends on the capacity of *non-automatic* Preparatory Attentional and Memory processes *(PAM),* which are highly related to working memory capacity; (2) available attentional resources are necessarily shared by all ongoing tasks (some prospective, others not); and (3) the better the performance on an attention-dependent prospective memory task, the worse the performance on other ongoing attention-dependent tasks, and vice versa.

The experimenters manipulated cognitive load of the working memory-dependent ongoing task and / or the event-based prospective memory task, as well as the stated importance of either of the tasks. The results indicated that (a) working memory capacity, measured by span tasks, predicted prospective remembering; (b) the higher the cognitive load of the ongoing task, the worse the performance on the prospective memory task (corroborating with Marsh & Hicks, 1998); (c) there was an accuracy benefit in the prospective memory task when it

was deemed important, and there was an associated cost on the ongoing working memory-dependent task (Smith & Bayen 2004).

A key contribution of Smith and Bayen's (2004) multinomial model of prospective memory is its emphasis on the working memory contribution to prospective remembering, particularly the non-automatic nature of the intention initiation and intention retrieval phases, and the reciprocal connections between prospective and working memory-dependent ongoing tasks. According to the model, if both the prospective and the ongoing tasks require limited working memory resources, there will be a cost imposed on one of the tasks whenever the other is (a) more demanding and (b) more important.

The Multiprocess Model: Interaction Between Processing Demands of Prospective Memory Tasks and Ongoing Working Memory Tasks

Finally, the revised multiprocess framework (McDaniel & Einstein, 2000) updated by Einstein et al. (2005) maintains that, in contrast to Smith and Bayen's (2004) theory, whether the limited attentional resources are involved depends on the type of event-based prospective memory task. According to this model, it is inefficient to always dedicate limited cognitive resources for prospective memory tasks that are easy (and can be accomplished 'automatically', such as event-based tasks), but for more complex prospective memory tasks, such as time-based tasks, monitoring is indeed required and indeed imposes cost on ongoing activities. Thus, intention initiation occurs automatically for easy, well-associated,

single tasks with an easily identifiable cue, without imposing a cost on working memory.

Einstein et al. (2005) designed a procedure to observe the effect of automatic intention initiation. Participants were engaged in a lexical decision task, with prior introduction of a single, distinct (red letters) prospective cue. However, participants were instructed to *ignore and disregard* the prospective cue, and focus on rapid responding to the lexical decision task. The main dependent variable was the reaction time on lexical decision trials. Since participants were instructed to *not* focus on the prospective cue, Smith and Bayen's (2004) theory would predict no costs on the lexical decision task. However, Einstein et al. (2005) observed longer reactions times on lexical decision trials that contained the prospective task cue. Einstein et al. (2005) interpreted this effect to indicate that the prospective intention was activated *automatically*, and thus resulted in slowed response to the lexical decision item. This spontaneous retrieval of intention can be likened to a Stroop–like interference of an automatic process (prospective intention initiation) with the controlled process (lexical decision task).

Conversely, intention initiation is resource-consuming and begins to resemble vigilance, in terms of strategic, attentional, planning and monitoring resources it requires for demanding prospective tasks. For example, prospective memory tasks that are time-based, incorporate several cues, and are deemed important, would necessitate continuous and strategic monitoring of the

environment. In this case, the high-load prospective memory task would significantly tax working memory resources, thus sabotaging working memory-dependent performance on the ongoing tasks.

Concurrent with the model proposed by Smith and Bayen (Smith 2003; Smith & Bayen, 2004, 2005), Einstein et al. (2005) demonstrated that a complex prospective memory task imposes cost on ongoing working memory-dependent processes. Response times to the ongoing lexical decision task were slower when the prospective memory task was deemed important, contained several different cues, or when the prospective cue required strategic monitoring.

Logie, Maylor, Della Sala and Smith (2004) focused on the interaction between age, type of prospective memory task (event-based or time-based), and amount of concurrent working memory demand. Younger and older participants viewed a one-minute-long film while engaged in a task of arithmetic verification, which either imposed a high or low load on working memory resources. Concurrently, one half of the participants was instructed to carry out a simple event-based prospective memory task, while the other half was instructed to carry out a time-based prospective memory task (these participants were also given access to a clock, but the arrangement prevented them from monitoring the clock and the film simultaneously).

The main finding of interest was that older adults in the high working memory load condition were significantly more likely to fail on the prospective memory task, regardless of the type of prospective memory task. Therefore,

although no age differences in prospective memory task performance were found when participants had presumably adequate cognitive recourses to dedicate to the prospective task, when the working memory load on the concurrent task increased, prospective remembering by older adults was significantly more adversely affected.

Notably, and in contrast to some prior studies (e.g. Park et al., 1997), there were no age differences in performance on the time-based prospective memory task. However, older adults checked the clock significantly more often than their younger counterparts. The authors suggested that this finding may indicate that older adults were more aware of the prospective task and the need to monitor the environment strategically; in effect, older adults may have compensated for the high cognitive demands of the time-based task by remaining extra vigilant throughout the session and constantly keeping their prospective intention in awareness. This pattern of behavior is more consistent with the view that prospective memory can be considered a special case of a vigilance task; however, as pointed out by Graf and Uttl (2001), in this case the task loses the key characteristic of a prospective memory task, namely, the temporary withdrawal of immediate attention from the maintenance of the prospective intention.

It appears that older adults in the Logie et al. (2004) study were able to adapt to the demands of the task, and adopted a successful, albeit more costly to the attentional resources, strategy for completing the challenging time-based

prospective memory task for the short duration of the study. This study demonstrates that allocation of attentional resources to prospective memory tasks depends not only on the type of prospective memory task, but also on its perceived difficulty and importance, as well as the demands of the ongoing background activity. Therefore, it appears that due to the *limited* nature of attentional resources, in multiple-task situations, success on a given task depends on strategic task prioritization and consequent resource allocation that imposes processing cost on non-attended tasks (cf. Strayer & Johnston, 2001; West, 2007).

Given the diversity of findings regarding the effect of prospective memory tasks on ongoing activities, the multiprocess framework (Einstein et al., 2005) suggests that prospective memory operates in an adaptive dual nature: working memory does not need to be taxed on easy tasks, but when the task is difficult, working memory resources are strategically employed.

Implications of the Prospective Memory / Working Memory Relationship to Treatment Adherence

While the relationship between prospective memory and working memory is an interesting area of study from a basic science perspective, the interaction between these two processes also has important implications for everyday life. For example, individuals living with a chronic illness must engage in a complex ongoing prospective memory task: treatment adherence. Depending on the illness and regimen, treatment adherence may be an event-based prospective

memory task (e.g., taking a pill every day with lunch), a time-based prospective memory task (e.g., taking a pill every 6 hours), or both (e.g., taking a pill every 6 hours with at least 12 ounces of water). In case of illnesses or conditions that require consistent adherence to a medication regimen, intact prospective memory can make a lifesaving difference.

As a prospective memory task, medication adherence represents a *habitual* task, one that occurs with regularity and lacks novelty. On the one hand, this property allows the integration of the prospective task into the daily routine, thereby forming well-established memory associations (breakfast – green pill), but on the other hand, the relevant cue may be more easily missed precisely for the lack of specificity (breakfast – wash dishes; breakfast – have coffee; breakfast – green pill). When the more challenging, time-based tasks are concerned, the complexity of medication regimen appears to play a crucial role: although patients typically do not have trouble with “one-a-day” or “twice-a-day” dosage, anything more frequent potentially threatens adherence by increasing the working memory load. Perhaps once- or twice-a-day medications are strategically and efficiently “converted” from time-based tasks into easier, event-based tasks by association with stable life events such as meals. Furthermore, research indicates (Einstein & McDaniel, 1996; Marsh & Hicks, 1998) that performance on prospective memory tasks suffers when the limited attentional resources are required by the highly demanding ongoing tasks. When applied to medication adherence, this implies that adherence will suffer among individuals

who are cognitively engaged during the day, and may fail to detect the appropriate cues and initiate the intention at the appropriate time, or fail to execute the intention even when the appropriate cue is detected.

Of course, there are several non-cognitive factors to consider in treatment adherence. For example, a patient's physiological response to the medication may serve as a relevant cue for the next appropriate time for a drug, thus improving adherence. The opposite can occur as well: a medication may make the patient feel unwell, and this would decrease the likelihood of adherence (Park & Kidder, 1996). Additionally, medication adherence is complicated by the neuropathology of the disease for which medication is taken (reviewed in Hinkin et al., 2002).

Perhaps there is a confounding between the results of the disorder and prospective remembering as it applies to taking medication. Alternatively, it is possible that individuals who are not adhering to medication may be non-responders to medications that are intended to improve their state. Finally, the patient's experience, expectations, beliefs, values and motivations regarding the medication treatment can all influence adherence (see S*elf-regulatory model of medication adherence*, Leventhal & Cameron, 1987, cited in Park & Kidder, 1996). For example, it has been shown that the subjective importance of treatment (or, in general, prospective memory tasks, see below) can dramatically improve adherence to this treatment (cf. Park & Kidder, 1996; Kliegel, Martin, McDaniel & Einstein, 2004).

Adherence to a complex and demanding treatment regimen – i.e. an ongoing continuous prospective memory task—may impose costs on other essential activities that rely on working memory. Greater understanding of these costs is critical to effective treatment of individuals with chronic illness. Concurrent with the models of prospective memory – working memory relationships described above, prospective memory requires working memory resources in at least some phases. Thus, based on the conceptual theories of relationship between prospective and working memory systems, the following predictions can be made regarding the relationship between working memory and the prospective task of treatment adherence.

First, if performance on the prospective memory task of treatment adherence depends on the amount of available cognitive resources, as described by Marsh and Hicks (1998), then overall cognitive ability will predict treatment adherence. Furthermore, the complexity of treatment regimen can be predicted to interact with overall cognitive ability, such that individuals with fewer attentional resources would better adhere to simple but not to complex prospective memory regimens. Second, if the multinomial model proposed by Smith and Bayen (2003, 2005) is true, the reverse will also be true, such that a salient prospective memory task will tax the limited working memory resources, and thus impose a cost on any other (unrelated) working memory-dependent activities.

The first prediction is supported by research of treatment adherence in HIV+ adults, for whom non-adherence can have grave consequences. For

example, Hinkin et al. (2002) documented an interaction effect between overall cognitive functioning and the complexity of medication regimen in HIV+ adults. Cognitive function assessment included measures of information processing, verbal memory, working memory, executive function and motor dexterity. Adherence to medication regimen was tracked for four weeks using specially equipped medication dispenser caps (Medication Event Monitoring System – MEMS), which allowed for a precise record of when the containers were opened. The obtained results indicated that while the cognitively intact patients were able to comply with either the simple (once- or twice-a-day) or complex (three times a day) medication regimen with 80-85% accuracy, the cognitively impaired patients evidenced a 30% drop in adherence to a complex medication regimen, compared to a simple one. These results lend support to the recent update of the multiprocess framework proposed by Einstein et al. (2005, reviewed above), in that simple prospective memory tasks may require little effortful attention compared to tasks that require more strategic monitoring and thus require greater contribution of the limited attentional resources.

In a follow-up study, Hinkin et al. (2004) examined the effects of age and cognitive performance on treatment adherence in HIV+ adults. Interestingly, the significant main effect of age demonstrated that *older* patients (over 50 years older) were more likely to adhere to their treatment regimen, perhaps due to better strategy employment. However, there was also a significant interaction between age and overall cognitive performance. Cognitively impaired older

patients were much less likely to adhere to treatment regimen, compared to cognitively impaired younger patients. Both studies attest to the importance of adequate cognitive (including working memory) functioning for optimal treatment adherence and concur with Marsh and Hick's (1998) proposal that prospective memory success depends on the availability of attentional resources. However, it is important to keep in mind that the course of HIV disease process, which is hypothesized to disrupt frontal lobe functioning, may be particularly relevant to prospective memory deficits (Carey, Woods, Rippeth, Heaton & Grant, 2005).

The second prediction is supported by evidence for prospective task-imposed costs on working memory-dependent ongoing activities (Smith, 2003; Smith & Bayen, 2004, 2005), as well as importance effects that are observed in the dual-task Einstein-McDaniel paradigm. Specifically, Kliegel, Martin, McDaniel and Einstein (2004) found that heightened importance of a prospective memory task improved prospective performance, and impaired performance on an ongoing task. The authors concluded that the cost of the prospective memory task occurred due to participants' more strategic allocation of cognitive resources. It appears that to do well on a task that matters means doing less well on tasks that matter less.

Limitations of Past Research on Prospective Memory

Both the multinomial model (Smith and Bayen, 2004, 2005; Smith 2003) and the multiprocess framework (Einstein et al., 2005) argue that prospective memory success can, at least in some circumstances, impose a cost on

unrelated working memory-dependent processes. However, these two models disagree about the degree to which different types of prospective memory tasks affect ongoing attention-demanding activities. Since treatment adherence and its success are paramount for a patient's health, with potentially serious consequences of inconsistent adherence, further investigation of the cost of prospective memory tasks on working memory in ecologically valid experiments can unveil clinically relevant information that could be used to optimize adherence, adjustment, and well-being.

The main difference between the multiprocess and multinomial theories concerns the presumed difficulty (i.e. attentional demands) of the prospective memory task. The Einstein et al. (2005) multiprocess framework proposes that the extent to which prospective memory tasks tap into limited attentional resources – and thus complicate or disrupt ongoing working memory activities – depends on the difficulty of the prospective memory task in question. As discussed above, time-based prospective memory tasks are typically considered to be more difficult than event-based prospective memory tasks, and thus require more attentional resources.

According to the multiprocess framework, most event-based prospective memory tasks are easy and do not tax the attentional resources. An "easy" prospective memory task is defined as a task in which (a) the prospective memory cue is distinctive, (b) there is a strong association between cue and intended action, (c) the intended action is easy to execute, and (d) the

background task allows for the processing of the prospective memory cue (Kliegel et al, 2001; McDaniel & Einstein, 2000). If these conditions are met, event-based prospective memory tasks are considered *"automatic"* and do not tax the attentional resources: the planned action simply "pops into mind" when the cue is encountered.

However, the multiprocess model does acknowledge that the need to recruit attentional resources increases as the complexity of the prospective memory task increases. In contrast, the Smith and Bayen (2005) multinomial model proposes that ***all*** types of prospective memory tasks demand limited attentional resources, thereby affecting performance on ongoing tasks that rely on these resources, although increasingly demanding types of prospective memory tasks may require greater involvement of working memory resources (Smith, 2003; Smith & Bayen, 2004, 2005; Smith, Hunt, McVay & McConnell, 2007).

At present, both models (Einstein et al., 2005; Smith & Bayen, 2004) leave important questions unanswered, particularly in regard to extending findings from laboratory experiments to the real-life prospective memory task of treatment adherence. First, in the experiments cited above, almost all prospective memory tasks were event-based. In contrast, the majority of treatment adherence tasks are time-based (e.g., "take every six hours," "take four times a day"). Exclusion of time-based prospective memory tasks from experimental investigations contributes to an incomplete conceptualization of the prospective memory

phenomenon and hinders our understanding of the cognitive processes that underlie it. Second, in all experiments, the cues for the prospective memory task were *embedded* in the ongoing working memory task; that is, the word that was meant to signal intention initiation was part of the stimulus used in the ongoing task. For example, in a sentence verification task, a cue to perform a prospective memory task is a word in a stimulus sentence. This type of design may confound signal detection performance with actual working memory performance on the ongoing task. Third, experiments examining the effect of prospective memory tasks typically manipulated complexity by making the target (i.e., the prospective memory cue) more difficult to distinguish, either perceptually or semantically, from the filler items of the ongoing task.

However, in real-life tasks of prospective memory, (1) individuals encounter both event-based as well as time-based tasks; (2) the cues for the prospective memory tasks, whether time- or event-based, are seldom "embedded" into ongoing activities, and in fact are often disruptive in that the person must do something *other* than the ongoing activity (taking a pill is not similar to writing a report; calling for an appointment is not similar to cooking); and (3) prospective memory cues are typically ***not*** difficult to distinguish (either you eat a meal or not; either it is morning or not; either four hours have passed or not). A prospective memory cue and task that are not related to the stimuli in the ongoing task may be a better analogy for the prospective memory task of treatment adherence.

The Present Study

The current study was designed to provide an ecologically valid and experimentally controlled investigation of the relationship between prospective memory and ongoing working memory-dependent activities. Specifically, this investigation aimed to address three limitations of past research. First, the study was designed to clarify the relationship between prospective memory tasks and the ongoing working memory task by preserving the concurrence in time but not in activity (i.e., the prospective memory cue and task are not embedded in the working memory task). In previous studies, the cue for the prospective memory task was also part of a stimulus used in an ongoing task (e.g., a word that was used as a prospective memory cue was part of a sentence used for a sentence verification task). In our study, the cue for the prospective memory task is entirely divorced from the ongoing task, both in source (alarm device vs. computer screen) and in nature (auditory vs. visual). This design was intended to be more naturalistic, and attempts to preserve the disruptive nature of the prospective memory task to the working memory task.

Second, the study compared the impact of three *types* of prospective memory tasks – time-based, event-based, and time-based with an auditory reminder – on the ongoing working memory task. The first two conditions allowed us to compare the impact of event-based and time-based tasks (versus control) on performance in a working memory task. Inclusion of the time-based prospective memory task with reminder group allowed us to evaluate the

contribution of *subjective* perception of the prospective memory task on working memory performance, and allowed us to assess the effect of a common mnemonic strategy (an auditory reminder, a frequently used “alarm” function on a cell phone) on the cost the prospective memory task imposes on the ongoing task. To our knowledge, other investigators have not compared the effects of these types of prospective memory tasks on the same ongoing task.

Third, this study aimed to examine the contribution of individual differences in working memory capacity to the demands of the dual task, in light of findings from the treatment adherence literature that stipulate that prospective memory success depends in part on the patients’ extant working memory function (Hinkin et al., 2002, 2004).

Design Overview

To address these aims, we used a dual-task experimental design in which participants engaged in a working memory task (the *N*-back task) under four prospective memory task conditions: (a) a time-based prospective memory task; (b) a time-based prospective memory task with an auditory signal provided as a reminder; (c) an event-based prospective memory task with an unembedded auditory cue; and (d) a control condition, in which the prospective memory component is absent. The dependent measures in this study were accuracy and response time on the ongoing working memory task.

It is important to note that the variant of the *n*-back task used in our study was self-paced. Participants were presented with a stimulus digit and it remained

on the screen until a response was entered. Immediately after a response was entered, a new stimulus digit appeared on the screen. In this experimental setup, the response-stimulus onset interval was zero, and participants had unlimited time to respond to a given stimulus before the next stimulus appeared. The main consequence of using this experimental design decision was that obtained RTs were, on average, in the order of 4 – 6 seconds, which was incomparably higher than RTs reported in typical studies that utilized fixed inter-trial intervals of several seconds on the *n*-back task (for examples, see Callicott, Mattay, Bertolino, Finn, Coppola et al., 1999; Owen, McMillan, Laird & Bullmore, 2005; Parmenter, Shucard, Benedict & Shucard, 2006). Unlike studies that employ fixed inter-trial intervals for the *n*-back task to assess working memory, the self-paced rate of presentation of *n*-back trials used in our study allowed us to focus on the effect of prospective memory processes on the speed of responding to an ongoing task. Our variant of the *n*-back successfully reflected within- and between-groups variability in response speed, although readers should consider the unconventional variation of the *n*-back task used in the present study.

Specific Aims

Aim 1: To examine the impact of an unembedded prospective memory task on working memory performance. Two models (Einstein et al., 2005 and Smith & Bayen, 2004) make different predictions about the cost imposed by a prospective memory task on the ongoing task. According to the multiprocess model (McDaniel & Einstein, 2000; Einstein et al., 2005), event-based

prospective memory tasks that can be classified as “automatic” – with easy to distinguish cues, simple action, and a strong association between the cue and the action – do not require extensive attentional processing. If this reasoning is correct, we expect comparable performance on the ongoing task in the control, event-based prospective memory task, and time-based prospective memory task with reminder groups. We also expect that participants in the time-based prospective memory task group would show a cost on the working memory task (decreased accuracy and/or increased RTs). According to the multinomial model (Smith & Bayen, 2004), all prospective memory tasks consume limited attentional resources. If this reasoning is accurate, we would expect participants in the control group to perform significantly better (higher accuracy, faster response time) than all prospective memory task groups.

Aim 2: *To determine whether performance on the ongoing working memory task differs according to the type of the prospective memory task before the prospective memory task.* The primary study hypothesis is that the impact of the prospective memory task on working memory depends on the *type* of the prospective memory task (i.e., the amount of attentional resources it requires). This hypothesis is based on pervious research studies that show varied cost depending on the type of prospective memory task target in event-based memory tasks (Kliegel et al., 2001; McDaniel & Einstein, 2000). To our knowledge, time-based and event-based prospective memory tasks have not been investigated within the same experimental paradigm.

It was hypothesized that the more demanding a prospective memory task is, the greater the adverse impact on the ongoing task before the prospective memory task occurs. Specifically, it is predicted that the adverse impact on the ongoing task will range from least in the Control group to most in the Time-based group. Time-based with reminder group is expected to perform better than the Time-based group and similar to the Event-based group. The Event-based group is expected to perform worse than the Control group.

This hypothesis can be subdivided further into two parts. First, it is predicted that, in the presence of a physical reminder cue for the prospective memory task (as in the time-based with reminder group), the attentional burden of monitoring will be lifted, and thus the cost on the ongoing working memory task will be reduced compared to the time-based group (without reminder). Reduced performance on the ongoing task in the time-based prospective memory task group (reflecting monitoring and resource allocation to the prospective memory task), compared to unimpaired performance in the time-based with reminder group (reflecting strategic *non*-monitoring for the time cue due to the preset reminder that acts as “outsourced” attention) would be consistent with the multiprocess view (Einstein et al., 2005). The multiprocess view suggests that an auditory reminder serves as an easily detected stimulus that has a clear association with the prospective memory act, and thus consumes comparatively fewer attentional resources than a task without such a cue like a time-based prospective memory task. Alternatively, comparable scores in the time-based

and time-based with reminder groups would lend support to the multinomial model (Smith & Bayen, 2004), and highlight the attention-demanding nature of prospective memory tasks regardless of external aids.

Second, we predicted that participants' performance immediately before the prospective memory task is dictated by their subjective expectation of the task. Therefore, we expect that performance on the ongoing task would decline more for participants who expect a (more difficult) time-based task (although a reminder is provided) than for participants who expect an (easier) event-based task. Note that practically, participants in the time-based with reminder group and in the event-based group experience the same situation, with the only difference being time-based with reminder group participants' awareness of the time cue related to the prospective memory task.

Better performance on the ongoing task by participants in the time-based with reminder group compared to the time-based without reminder group would support the multiprocess view (Einstein et al., 2005) that prospective memory tasks for which the cue is externalized and obvious do not require attentional resources. However, if participants in both time-based groups (with reminder and without) perform similarly – either showing a practice effect or a decline in performance immediately before the prospective memory task – then we will obtain support for Smith and Bayen's (2004) theory, which states that all prospective memory tasks depend on limited attentional resources and impose a cost on ongoing activity.

Better performance by participants in the event-based group, compared to the time-based with reminder group, would suggest that the subjective challenge of the time-based task leads participants in the time-based with reminder group to allot attentional resources to time monitoring (similar to vigilance), even though a physical reminder is provided and thus the task does not actually require time monitoring. Conversely, comparable performance by participants in the time-based reminder and event-based would indicate that the physical cue for the prospective memory task is an effective reminder that does not take away from participants' attentional resources dedicated to the ongoing task.

Aim 3: To determine whether working memory capacity contributes to the relationship between performance on the prospective memory task and the ongoing working memory-dependent task. Recent studies from the treatment adherence and aging literature indicate that individual differences in working memory function are related to prospective memory success (e.g., Hinkin et al., 2002; Hinkin et al., 2004; Kliegel, McDaniel & Einstein, 2000; Smith, 2003). It is predicted that (1) high working memory capacity participants will perform faster and more accurately than low working memory capacity participants in all groups, and (2) on trials preceding the prospective memory task, high working memory capacity participants will evince strategic allocation of attentional resources by performing faster in conditions where monitoring for time is not necessary (time-based task with reminder group, event-based task group, and control group), and

slower in the condition where time monitoring is paramount to task success (time-based task group).

Although high-working-memory-capacity participants are expected to generally outperform their low-working-memory-capacity counterparts on our working-memory-dependent tasks, it is possible that the observed slowing of high-working-memory-capacity participants before the prospective memory task in the time-based group will reflect a variant of a “speed-accuracy tradeoff”, insuring optimally accurate performance on both the prospective memory task (on-time execution) as well as the ongoing task. On the other hand, uniform superiority of high-working-memory-capacity participants across groups and time segments would argue for an overall, rather than strategic advantage.

Method

Participants

Participants were recruited from the Queens College Psychology Department subject pool (n = 117) and the Queens College student body at large. Inclusion criteria were: 18 year or older, fluency in English and normal or corrected-to-normal vision. Participants recruited from the Psychology department subject pool (n = 106) received two research participation credits towards their coursework; those recruited from the community (n = 11) received $20 for their time. All participants signed a consent form approved by the Queens College IRB prior to participating.

Materials

The experimenter used pen and paper to record participants' responses to the Letter Number Sequencing subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III). Computer-based tasks (counting span and *n*-back tasks) were delivered on a Dell personal computer workstation, containing a processing unit, a 15-inch flat screen monitor, an ergonomic wireless keyboard and an ergonomic wireless computer mouse. The counting span task, as well as pretest and main sessions of the *n*-back task, were programmed using MediaLab software produced by Empirisoft. To control for individual differences in touch-typing speed, participants were instructed to use the computer mouse *only* for all *n*-back tasks, and computer mouse and keyboard for the counting span task. The "cue" in the event-based prospective memory task condition, and the "auditory

stimulus" in the time-based prospective memory task with reminder condition was an auditory alarm produced by a battery-operated digital kitchen timer (operated by the experimenter). The same device was used as a clock to provide time information in the time-based prospective memory task condition.

Research Design

To test the hypothesis that prospective memory processes compete with other tasks for limited attentional processes, participants were assigned a prospective memory task and were asked to engage in an ongoing working memory task. The prospective memory task was designed so that it would occur *during* the working memory task, allowing us to measure working memory performance before and after completion of the prospective memory task. A mixed-factorial research design was used to capture changes in performance on the working memory-dependent task among four experimental conditions. The between-subjects independent variable, *Group*, consisted of four levels/conditions: (a) time-based prospective memory task, (b) time-based prospective memory task with reminder, (c) event-based prospective memory task, and (d) control condition, which did not include any prospective memory task component. Participants were assigned to groups randomly. The within-subjects independent variable, *Time*, captured the participants' performance at different stages of the working memory task. The levels of this independent variable were: (a) *Baseline*, capturing average performance over the first 20 trials; (b) *Before prospective memory task*, capturing average performance over

the 20 trials immediately preceding the prospective memory task trial; (c) *After prospective memory task*, capturing average performance over the 20 trials, three trials after the prospective memory task trial; and (d) *End Baseline*, capturing average performance over the last 20 trials of the set. The dependent variables in the working memory task were accuracy (percent correct), response time (RT) (in seconds), and transformed RT (percent of baseline RT, see below).

Procedure

The experiment was conducted in two sessions. Session 1 consisted of a baseline working memory assessment and a practice trial for the working memory task used in the second session. The practice trial served to familiarize participants with the demands of the working memory task and to derive an individualized target time for the prospective memory task using a regression equation obtained from the first 15 participants. The regression equation used was the following: *Target minute for PM task = 7.28 + (1.28 * time to complete working memory practice trial (in minutes))*. Session 2 occurred between four and nine days after the first session, and consisted of a dual task session, in which participants were randomized to one of the four prospective memory task conditions and completed the working memory task.

Session 1 Measures. Each participant completed a baseline working memory assessment in order to statistically control for baseline variability in individual performance speed among participants. The working memory assessment included the Letter Number Sequencing subtest of the WAIS-III, a

counting span test, and a pretest / practice set of the working memory task: the *n*-back.

The *Letter Number Sequencing task* is a subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III) (The Psychological Corporation, 1997), that assesses working memory. Participants were presented, verbally, with several numbers and letters in "scrambled" order (e.g., D-7-V-3) and were asked to re-arrange the sequence such that all the numbers were presented first, in numerical order, and all the letters were presented last, in alphabetical order (e.g., 3-7-D-V). The length of the given sequence increased every three trials, and the task was discontinued if all three trials in a set were completed incorrectly. The sum of all correct items (raw score) was converted to a scaled score based on the participant's age, using the standard WAIS-III administration and scoring manual.

The *Counting Span task* taps into attentional resources by requiring participants to count geometrical shapes while remembering numbers, and has been shown to reliably assess working memory in healthy young adults in several key studies concerned with working memory - prospective memory interactions (e.g., Smith, 2003; Smith & Bayen, 2005; Case, Kurland & Goldberg, 1982). In the computerized version of this task, delivered via MediaLab software, participants were presented with arrays of geometrical figures (dark blue circles, light blue circles and dark blue rectangles, on a light grey background) and were required to count the number of dark blue circles. After several such arrays were

presented in a set, participants were asked to recall all totals of dark blue circles in that set, in the order in which the arrays were shown. Participants completed 21 sets. Within each set, arrays were randomized to create a standardized assessment to be administered in the same order to all participants. Participants' performance was scored as the number of fully correct trials (0 – 21), correct arrays (0 – 108), and, in a method developed by Smith (2003), the number of correct arrays in fully correct trials (0-108).

Working Memory task pretest: the N-*back*. After the counting span task, a pretest version of the *n*-back task was presented. The *n*-back test is a sensitive measure of working memory for healthy young adults. In the *n*-back task, a series of numbers were shown in the center of the computer screen, one at a time. On each screen the participant also saw a row of "buttons," labeled one through nine. The participants' task was to click on the number that occurred *n* positions before the currently displayed number (see Courtney, Petit, Haxby, & Ungerleider, 1998). During the first session, participants performed a "2-back" version of the *n*-back task: that is, participants were asked to click on the number that was presented two screens before the currently presented number. Once the participant clicked on the number deemed to be the correct answer, the next number appeared, resulting in a participant-paced presentation rate. The goal of this set was to acquaint participants with the *n*-back task and to estimate the participants' rate of *n*-back performance to be used in predicting the target prospective memory task time for each participant in the dual task session (see

below). All instructions to the *n*-back task were delivered via computer display, with several examples and an opportunity for participants to ask the experimenter to clarify the task demands.

In order to capture working memory task performance data before and after the prospective memory task during session 2, it was necessary to account for each individual's overall *n*-back speed. To meet this goal, the experimenter recorded the time it took each participant to complete the 50 trials of the *n*-back pretest. Pretest speed was then used in a regression equation to estimate participant's performance during session 2 and to derive a target time for the prospective memory task. The target time for the prospective memory task was intended to fall within the 2-back portion of the *n*-back session and to provide sufficient performance data before and after the prospective memory task, as well as a baseline measure. Overall pretest accuracy, expressed as percentage of correct *n*-back trials, was also computed.

Session 2: Dual task session. In this session, participants engaged in the identical ongoing working memory task under the four experimental conditions.

Working Memory task: the N-*Back*. Participants performed a session of *n*-back tasks of increasing difficulty. The easier tasks were included in order to minimize the vigilance attributes of the prospective memory task by providing a time lapse between prospective memory task instructions and relevant execution time frame. Additionally, we aimed to limit participants' fatigue from the continuous *n*-back task while still allowing for the target time to occur within the

more demanding, 2-back, portion of the task. The first 60 trials formed a 0-back part: participants were asked to press a number that was shown on the screen for one second. The next 60 trials formed a 1-back part: participants were asked to press a number that appeared right before the currently shown number.

The last 150 – 250 trials formed a 2-back part: participants were asked to press a number that appeared two screens before the currently presented number; this 2-back section was identical to the one practiced by all participants during the first experimental session. The length of the 2-back portion depended on each participant's performance speed on the pretest; that is, to insure that the prospective memory target fell within the 2-back part of the *n*-back session, more trials were presented to faster performers.

All parts of the *n*-back session were prefaced by specific instructions and examples, as well as an opportunity for participants to ask questions of the experimenter. Accuracy of the *n*-back tasks was emphasized over speed for all participants to insure that participants performed the task according to instructions. *N*-back task performance normally improves with practice, so we were particularly interested in patterns that diverge from the expected improvement over time.

Prospective Memory Task: Conditions. The prospective memory task entailed taking a glass pebble from a container hidden in the desk drawer. This task was completed under one of four experimental conditions:

(1) *Time-Based (TB) group* participants were provided with a digital clock displaying the current time and were asked to complete the prospective memory task minutes after the beginning of the working memory session. The exact number of minutes was tailored to each participant to insure that the prospective memory task time occurred during his or her 2-back portion of the working memory task.

(2) *Time-Based with Reminder (TBR) group* participants were asked to complete the prospective memory task minutes after the beginning of the *n*-back session, but were provided with a digital clock set to sound an alarm at the specified time. The exact number of minutes was tailored to each participant to insure that the prospective memory task time occurred during his or her 2-back portion of the working memory task.

(3) *Event-Based (EB) group* participants were asked to perform the prospective memory task when they heard an auditory alarm, but were not told when the alarm would sound. It was explicitly stated that the alarm would sound only once during the session; no time cues were provided for this group.

(4) *Control group* participants did not engage in any prospective memory task but completed the entire *n*-back session.

It is important to note that although the TBR and the EB groups experienced the same situation – an auditory alarm sounded during the session

to indicate that a planned task is to be carried out – their *subjective* experience, and expectation, of the session were different. In the case of the TBR group, the auditory alarm *served a useful purpose* by minimizing the need to attend to the clock, thus making the time-based prospective memory task easier. Participants in the EB group, on the other hand, were neither aware of the time the alarm would sound, nor did they perceive any additional benefit from having an alarm, aside from signaling to carry out a planned task. In fact, it is conceivable that some participants in this group experienced anxiety without any cues that could help predict the occurrence of the alarm. The experiential contrast between the TBR and the EB groups may provide insight into the role of expectation in prospective remembering.

During the dual task session, the experimenter recorded the trial at which participants completed the prospective memory task, in order to compile standardized performance timeline relative to the prospective memory task trial. For participants in the control group, the target trial was derived by taking an average of prospective memory task trials of participants in the experimental groups.

Data Processing

N-*Back Task*. Working memory task data was reviewed for outliers on RT data, defined as equal to or greater than two standard deviations from the mean. Data from participants whose mean RT values met the outlier criterion were removed from the dataset. For each participant, *before task* and *after task* mean

accuracy scores and mean RT scores were calculated, spanning 20 trials for each segment. The relevant trials were selected based on the trial at which a participant completed the prospective memory task.

This method of standardization is presented in Figure 1, which shows the trials included into the *before task* and the *after task* segments, and their position relative to the trial at which the prospective memory task occurred. For example, if participant A completed the prospective memory task at trial 89, her *before task* time frame, spanning 20 trials, would be calculated as a mean of trials 69 to 88. If participant B completed the prospective memory task at trial 42, his *before task* time frame, spanning 20 trials, would be calculated as a mean of trials 22 to 41.

For the *after task* segments, we calculated a mean of 20 trials after the prospective memory task, excluding the three trials immediately following the prospective memory task to control for the post-task disruption and re-engagement with the task demands (see Figure 1). This standardization procedure allowed for control of individual variability in performance speed across the entire sample. Calculation of baseline segments (baseline, and end baseline) was independent of the prospective memory task trial, and was calculated as a mean of respective 20 trials.

Additionally, to control for within-subjects variability in speed of responding, and to standardize each participant's performance to his or her *baseline* RT, we derived transformed RT scores for each participant. *Transformed RT* scores were calculated by dividing each participant's *before*

task, after task, and end baseline RT scores by his or her *baseline* RT score, and multiplying the results by 100 to obtain percentage scores. Thus, a transformed RT score of 120 indicated a 20 percent increase in raw RT, relative to baseline RT. Similarly, a transformed RT score of 90 indicated a 10 percent decline in raw RT, relative to baseline RT. This transformation resulted in *before task, after task,* and *end baseline* scores that reflected net change from *baseline* scores for all participants.

Working Memory Capacity. In order to assess the contribution of individual working memory capacity to the relationship between prospective memory and working memory, participants were categorized based on their performance on the counting span task. Participants who correctly completed more than 50 percent of counting span trials formed the “high working memory capacity” group and participants who correctly completed less than 50 percent of counting span trials formed the “low working memory capacity” group. Counting span scores were tested with an independent-samples t-test to ensure that resultant groups were, in fact, distinct samples with respect to working memory capacity.

Statistical Procedures Overview

All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS), version 16.0.

Preliminary analyses. To evaluate differences in demographic factors among the groups, as well as between retained and excluded participants, we

compared groups on demographic variables of age, gender, and race using ANOVAs for continuous variables and Chi Squares for dichotomous variables. Planned comparisons were performed using t-tests and ANOVAs targeting specific groups. Differences at $p < 0.05$ were considered significant.

Aim-specific analyses. Statistical analyses targeting each specific aim of the study are reported below. Primary dependent variables (accuracy, raw and transformed RT) were tested for kurtosis and skewness and met criteria for normality, permitting the use of parametric statistics throughout the study.

To examine Aim 1 (the impact of an unembedded prospective memory task on working memory performance on the ongoing working memory task), experimental groups were compared on the three dependent variables measuring performance on the ongoing working memory task: accuracy, raw RT and transformed RT. This analysis consisted of a one-way ANOVA with the independent variable (Group: Time-based prospective memory task, Time-based with reminder prospective memory task, Event-based prospective memory task, Control).

To examine Aim 2 (the effect of different types of prospective memory task on the ongoing working memory task *around* the time of the prospective memory task), we conducted several planned analyses to follow up on the main analysis described above. Planned comparisons were carried out for all Group pairs and for two sets of Time segments: *baseline* vs. *before PM task*, and *before PM task* vs. *after PM task*.

First, we compared each experimental prospective memory task group to the control group. This was achieved by three 2 (Group) by 2 (Time) mixed-factorial ANOVAs with the between-subjects factor Group were (1) Time-based prospective memory task, Control; (2) Time-based with reminder prospective memory task, Control; and (3) Event-based prospective memory task, Control. Second, we compared experimental prospective memory task groups to each other. This was achieved by three 2 (Group) by 2 (Time) mixed factorial ANOVAs. The levels of the between-subjects factor Group were (1) Time-based prospective memory task, Event-based prospective memory task; (2) Time-based prospective memory task group, Time-based prospective memory task with reminder; and (3) Time-based prospective memory task group; Event-based prospective memory task group. Analyses were carried out twice to capture two distinct segments of the dual task session; thus, we included the within-subjects factor Time with two sets of levels: *baseline* vs *before prospective memory task*, and *before prospective memory task* vs. *after the prospective memory task*. All analyses were repeated for dependent variables of accuracy, raw RT, and transformed RT.

To examine Aim 3 (working memory capacity contribution to the relationship between performance on the prospective memory task and the ongoing working memory task), we integrated Working Memory Capacity as a separate factor into the primary analyses. As described above, participants were split into High WM and Low WM subgroups based on their counting span score.

To investigate the overall contribution of WM capacity to participants' performance in the dual task, we first conducted a 4 (Group: Time-based prospective memory task, Time-based prospective memory task with reminder, Event-based prospective memory task, Control) by 2 (WM: high, low) factorial ANOVA on the dependent variables of accuracy, raw RT and transformed RT.

Subsequently, to focus on performance pattern differences before the prospective memory task, we added the additional variable of Time. High and Low WM participants in all experimental groups were compared on their ongoing task performance before the prospective memory task occurred, controlling for individual variability at baseline. This analysis consisted of a 4 (Group: Time-based prospective memory task, Time-based prospective memory task with reminder, Event-based prospective memory task, Control) by 2 (WM: high, low) by 2 (Time: baseline, before prospective memory task) mixed factorial ANOVA. All analyses were conducted on three dependent variables: accuracy, raw RT and transformed RT. Planned comparisons were performed to assess interaction effects between Group and WM Capacity.

Results

Data Overview

Participants

A total of 117 members of the Queens College community were recruited for the present experiment. Forty-nine participants were excluded from analyses due to failure to complete part(s) of the experiment (N = 5), accuracy below 70% on *n*-back tasks (N = 10), failure to complete the prospective memory task (N = 2), performance of the prospective memory task outside of the experimentally-relevant time frame (N = 26), or outlier RT data on the *n*-back task (N = 6). Excluded participants did not differ significantly from included participants on demographic variables of age ($p = 0.251$), gender ($p = 0.694$) or race ($p = 0.957$), or performance on the counting span task ($p = 0.112$).

The final sample consisted of 68 participants. Distribution to experimental conditions was the following: Time-based group (N = 19), Time-based with reminder group (N = 16), Event-based group (N = 18), and Control group (N = 17). There were no statistically significant differences between groups on any demographic variables. Demographic information for the experimental groups is summarized in Table 1.

Working Memory Assessment

Working memory assessment included the Letter Number Sequencing task and the Counting Span Task.

Letter Number Sequencing. Due to the limited range of scaled Letter Number Sequencing scores, they were not used in evaluation of participants' working memory capacity. Counting span scores were used instead, as indicated below.

Counting Span Task. Performance on the counting span task was evaluated using Smith's (2003) method, resulting in a *span score*, or the number of correct arrays in fully correct trials (range 0-108). This score was the basis of assignment to High or Low working memory subgroups. Participants whose performance was correct on more than 50 percent of the trials were considered "High WM" (N = 36), and those who correctly completed less than 50 percent of the trials were considered "Low WM" (N = 32). An independent-samples t-test supported this division by indicating that High WM and Low WM groups were significantly different on the measure of counting span (t (66) = 9.847, p = 0.0001). There were no statistically significant differences on the counting span scores between experimental conditions (F (3, 64) = 0.631, p = 0.598). Distribution of High and Low WM participants among experimental groups is displayed in Table 2.

N-Back pretest. One-way ANOVA revealed no significant differences between groups on pretest measures of *n*-back accuracy (F (3, 64) = 1.547, p = 0.211) or *n*-back pretest average RT (F (3, 64) = 0.553, p = 0.648). This uniformity in performance measures allowed us to conclude that prior to the dual task session, participants in all groups mastered the *n*-back task to similar levels.

The regression equation used to determine prospective memory target times for participants in the experimental groups (see above) successfully predicted times in the relevant timeframe in 70% of possible cases.

Specific Results

Aim 1: To examine the impact of an unembedded prospective memory (PM) task on working memory performance on the n-back task during the dual task session.

The four experimental groups were compared in a one-way ANOVA on the dependent measures of *n*-back accuracy, RT and transformed RT. Group performance on the ongoing task is represented in Figure 2 (Accuracy), Figure 3 (RT) and Figure 4 (transformed RT).

Overall, there was a significant effect of Group for accuracy (F (3, 268) = 3.132, $p = 0.026$), with the Event-Based (EB) group performing significantly better compared to all other groups (all $p < 0.05$) (See Figure 2). There were no significant differences in accuracy between Time-Based (TB), Time-Based with Reminder (TBR), or Control groups. Although there was no significant main effect of Group on raw RT, Figure 3 shows that the order of groups from fastest to slowest was (1) TB group; (2) TBR group; (3) EB group; and (4) Control group. These data show *averaged* raw RT performance over the entire session of the working memory task. Contrary to our predictions, a post-hoc comparison revealed that the Control group was slower than the TB group at levels approaching significance ($p = 0.054$). Assessment of accuracy and RT data together did not suggest significant speed-accuracy trade-off across groups.

When transformed RT data were assessed, the main effect of Group approached significance (F (2, 268) = 2.41, p = 0.067), with the EB group demonstrating significantly lower transformed RTs compared to the TB group (p = 0.01), and lower scores compared to the TBR (p = 0.057) and Control (p =0.073) groups at trend levels (Figure 4). Thus, transformed RT data show that although the TB, TBR and Control groups performed, on average, with RTs comparable to baseline performance, the EB group demonstrated a significant reduction in RTs relative to baseline levels. In particular, the significant contrast between the two time-based tasks (TB and TBR groups) and the event-based task (EB group) is notable for discriminating between different *types* of prospective memory.

The contrasting findings in raw vs. transformed RT data point to the conceptual discrepancy between overall rate of responding and *rate of change* of responding. To wit, the TB group showed fastest averaged raw RT overall (Figure 3), but highest transformed RT (Figure 4). These data reflect an important behavioral pattern in the TB group: although these participants were faster in rate of responding to the ongoing task than participants in other groups, they were also less likely to *improve* their RT scores throughout the task.

In summary, our data revealed significant group differences in performance on the working memory task. Although the difference in accuracy or speed between Control and Experimental groups was not significant, among the experimental groups significant differences were observed. The EB group

showed greater accuracy, as well as a significant reduction in transformed RT scores than the TB and TBR groups, suggesting an overall advantage in working memory task performance compared to the two time-based groups.

Furthermore, once the raw RT data were transformed to normalize each participant's score to his or her baseline rate of responding, trends in the predicted direction were observed. Transformed RT data reflected the processing demands of the three experimental groups by demonstrating that participants in the most demanding condition (TB) were on average least likely to improve their performance speed relative to baseline, compared to participants in the least demanding condition (EB), while the reminder-assisted TB group (TBR) performed in the middle.

Aim 2: *To determine whether performance on the ongoing working memory task around the time of the prospective memory task differs by the type of the prospective memory task.*

First, we conducted a 4 (Group) by 2 (Time) mixed factorial ANOVA to investigate the effect of PM task condition on participants' accuracy and RT between *baseline* and *before PM task* segments of the *n*-back dual task session. For measures of groups' performance across all segments of the ongoing task, refer to Figure 5 (Accuracy), Figure 6 (raw RT) and Figure 7 (transformed RT).

Although there were no significant differences in accuracy between groups, post-hoc tests revealed that the EB group was overall more accurate than that TBR group ($p = 0.076$). However, on the time interval from *baseline* to

before the PM task, the TBR group gained in accuracy while the TB group declined in accuracy ($p = 0.078$) (Figure 5). The difference in accuracy before the PM task between the TB and the TBR groups suggests that PM-related attending in the TB group pulled attentional resources away from the ongoing task, but once the attending was made unnecessary by the external cue, as in the TBR group, participants were able to attend to the ongoing task without (self-initiated) distraction.

There were no significant differences on RT (Figure 6), although raw RT data revealed that, compared to the EB group, which got faster between *baseline* and *before PM task* segments, the TB group got slower ($p = 0.098$). This difference approached significance when transformed RT data were assessed ($p = 0.057$). Thus, TB and EB groups show different patterns of responding immediately prior to the prospective memory task, perhaps reflecting the higher processing cost of the time-based PM task, compared to the event-based task. Assessment of accuracy and RT data together did not reveal a significant speed–accuracy trade-off across groups, indicating that participants accommodated the processing demands of prospective memory tasks without sacrificing accuracy of performance on the ongoing task.

In order to further examine the performance patterns before the PM task, planned pairwise group comparisons were carried out using 2 (Group) by 2 (Time) mixed factorial ANOVAs. See Figures 8 and 9 for raw RT and

transformed RT difference scores plotted along with accuracy *before the task* for reference.

When the three experimental groups were compared to the Control group, no significant differences on accuracy, raw, or transformed RT scores were discovered. This unexpected finding may lead to the conclusion that the presence of the prospective memory task does not have a quantitative or a qualitative impact on performance on the ongoing task. However, extreme variability on all measures of performance within the Control group merits caution in assessment (see Discussion below).

Experimental groups comparisons on raw RT difference scores (Figure 8) revealed that TBR and EB groups were most similar on all performance measures, following a pattern of declining response time between *baseline* and *before PM task* segments, while maintaining accuracy at high levels, suggesting that the presence of a prospective memory task did not interrupt the participants' improvement on the ongoing task. Notably, lack of significant differences between the TBR and EB groups highlights the fact that performance on the ongoing task followed the same pattern despite different subjective expectations of the task.

Although no significant differences in raw RT were found between the TB and the TBR groups, the pattern of performance in these two groups is noteworthy for showcasing the effect of the external cue addition to the time-based task. With accuracy levels immediately preceding the prospective memory

task *equivalent* – and high, at over 92% – for the two groups, raw RT data displayed markedly different patterns immediately before the PM task: While the TB groups slowed down, the TBR group sped up, relative to baseline RT (Figure 8). The transformed RT data (Figure 9) slows a slightly attenuated pattern of the same relationship: in the TB group, 58% of participants slowed down before the PM task, while in the TBR group, the distribution was equal between participants who sped up and those who slowed down. Although these differences did not reach statistical significance, the pattern of performance was in the hypothesized direction, suggesting that the attentional burden of a time-based task can be alleviated by externalizing the prospective memory cue as in the time-based with reminder condition.

Finally, a comparison of the TB group to the EB group showed no significant differences in accuracy or raw RTs (Figure 8), but a trend for the main effect of Group and a Group by Time interaction when transformed RT data were assessed (Figure 9). Participants in the TB group were slower to respond, on average, than the EB group ($p = 0.076$). When these groups were compared on their change pattern on the interval between *baseline* and *before PM task* segments, participants in the TB group gradually increased response time, while the EB group gradually decreased response times before the PM task, relative to baseline ($p = 0.076$).

Second, we conducted a 4 (Group) by 2 (Time) mixed factorial ANOVA to investigate the effect of PM task condition on participants' accuracy and

response time between *before PM task* and *after PM task* segments of the *n*-back dual task session. There were no significant main effects on accuracy, although a post-hoc test analysis revealed that the EB was on average more accurate than the Control ($p = 0.045$) and the TB ($p = 0.09$) groups (Figure 5). On average, groups were more accurate after the PM task compared to before the PM task, although statistical significance was not attained.

Data from raw (Figure 6) and transformed RT (Figure 7) demonstrated a significant main effect of Time ($F(1, 64) = 19.752$, $p = 0.000$ and $F(1, 64) = 21.309$, $p = 0.000$, for raw and transformed RT respectively), with all groups performing significantly faster after the prospective memory task, compared to before the prospective memory task. This exemplifies a practice effect that is commonly observed on *n*-back tasks. Post-hoc group comparisons also revealed that the TB group evidenced a significantly greater decline in both raw ($p = 0.071$) and transformed RT ($p = 0.052$) scores compared to the TBR group: although TB group was slower than the TBR group before the PM task, groups responded at similar rates after the task. This pattern of performance suggests that, although the processing demands associated with a time-based task have a slowing effect on ongoing task RT before the target time is reached and the PM task executed, this processing constraint is lifted once the prospective memory task is complete, and participants reach response speeds equivalent to the reminder-aided time-based group of lesser attentional load.

In summary, our data indicated some compelling differences in groups' performance before and after the prospective memory task. Although there were no significant differences between groups, observed patterns of data suggest a Group by Time interaction effect, with TB and TBR groups showing contrasting patterns of responding rate before the prospective memory task while maintaining accuracy performance at same and high levels. In particular, RT data revealed that the TBR group increased speed of responding before the prospective memory task, while the TB group decreased the speed of responding before the prospective memory task. Notably, although the TB group experienced a slowing in RT before the PM task, these participants recovered to levels comparable with other groups immediately *after* completing the prospective memory task, suggesting that the processing cost of a demanding time-based prospective memory task may be transient.

Aim 3: To determine whether working memory capacity contributes to the relationship between performance on the prospective memory task and the ongoing working memory-dependent task.

In order to determine the contribution of working memory (WM) capacity to the prospective memory / working memory relationship we conducted an analysis in two parts. First, we focused on overall effect of WM capacity on performance across groups, by conducting a 4 (Group) by 2 (WM Capacity) factorial ANOVA on accuracy, raw RT and transformed RT measures. Next, to explore the contribution of WM capacity to groups' performance on the key time segment –

before the prospective memory task – we conducted a 4 (Group) by 2 (Working Memory Capacity) by 4 (Time) mixed factorial ANOVA. Finally, we conducted planned group and time segment comparisons to elucidate potential interaction effects between independent factors. Since *Aim 3* is concerned specifically with WM main effects and interactions with other independent variables, this section reports only WM-related patterns in data; for discussion of Group and Time differences, refer to the section on *Aim 2* above.

Overall, groups performed at similar levels of accuracy throughout the task and across WM subgroups, although on average, High WM participants were more accurate (96.1%) than their Low WM counterparts (94.25%). Figure 10 shows that on average, High WM participants were significantly faster than Low WM participants (raw RT, $F(1, 264) = 5.097$, $p = 0.025$). Figure 11 displays a similar pattern of performance observed on transformed RT data at levels approaching significance ($F(1, 264) = 3.184$, $p = 0.076$): High WM participants did not exhibit an overall decline in RT throughout the ongoing task, as did their Low WM counterparts. A compelling WM by Group interaction effect was revealed on raw RT ($F(3, 264) = 13.44$, $p = 0.0001$), showing that High WM participants in the TB and EB groups were significantly slower than Low WM participants, but the opposite pattern was observed in the TBR and Control groups. In the TBR and Control groups, High WM participants were faster than Low WM participants (See Figures 12 and 13). The significant Group by WM interaction was not preserved in the transformed RT data, which showed

comparable patterns of performance between High and Low WM participants (See Figure 14).

The difference between raw and transformed RT outcomes highlights the importance of taking individual variability into consideration. Transformed RT scores focus on each individual's change score relative to his or her baseline rate of performance, and are thus particularly suitable to capture differences in performance patterns that are linked specifically to experimental conditions (i.e., type of prospective memory task), not to the overall cognitive processing reserves of participants in the two WM subgroups.

Planned comparisons between High and Low WM participants were carried out for all Group pairs on Time segments *baseline* vs. *before PM task.* Although there were no significant differences in accuracy or transformed RT, raw RT data analyses confirmed the significant Group by WM interaction on TB to Control (F (1, 32) = 7.508, p =0.01) and EB to Control comparisons (F (1, 29) = 5.307, p = 0.029) (Figure 13). High WM participants in the TB and the EB groups were significantly slower to respond compared to Low WM participants, while in the Control and the TBR groups High WM participants were faster to respond compared to Low WM participants (F (1, 29) = 12.226, p = 0.002). Finally, raw RT data revealed a significant Group by WM interaction when TB and TBR groups were compared: High WM participants in the TB group were on average significantly slower compared to High WM participants in the TBR group (F (1, 31) = 4.31, p = 0.046).

In conclusion, our data indicated a complicated relationship between working memory and prospective memory. On average, High WM participants performed significantly faster than Low WM participants on the ongoing task, but they were also less likely than Low WM participants to substantially increase their response speed throughout the ongoing task relative to baseline performance. Furthermore, raw RT data revealed an unexpected dissociation between WM capacity and type of prospective memory task, suggesting an underlying difference in approach to the dual task dictated by particular prospective memory task constraints. However, High and Low WM participants exhibited comparable patterns of performance in transformed RT scores in all experimental conditions. The discrepancy between raw and transformed RT findings may suggest that the demands of different prospective memory tasks pose common challenges across the WM capacity continuum, although individual processing capacity may contribute to the overall performance level.

Discussion

The present study was designed to investigate the impact of engagement in a prospective memory task on performance in an ongoing working memory task, and to assess the contribution of individual working memory capacity in this process. The design of our study allowed for comparison of the attentional demands of three different types of prospective memory tasks – time-based, event-based, and time-based with reminder – within the same working memory task, and to insert our findings into the current discourse between two prominent theories of the prospective memory / working memory relationship: the multinomial theory (Smith, 2003; Smith & Bayen, 2004) and the multiprocess theory (Einstein et al., 2005). By revealing the differential processing demands of the three prospective memory tasks, as well as similarities in performance patterns among individuals of varying working memory capacity, our results lend themselves to practical applications for medical treatment adherence and everyday prospective memory. The following sections address specific aims of the study and discuss our findings in greater detail.

Do Prospective Memory Tasks Affect Ongoing Task Performance?

The question driving the current investigation focused on the overall effect of prospective memory task(s) on an ongoing working memory task. Of the four processes involved in successful prospective remembering, *intention initiation* has been shown to rely on limited working memory processes (Kliegel et al., 2002). Therefore, in a situation where another task consumes working memory

processes, prospective memory processes associated with intention initiation may compete for limited working memory resources. However, there is an ongoing debate in the literature on the *extent* of working memory demand exerted by different types of prospective memory tasks.

According to the multiprocess view (Einstein et al., 2005; McDaniel & Einstein, 2000), the extent of working memory taxation depends on the difficulty – in terms of attentional, monitoring and perceptual demands – of a prospective memory task. The multiprocess theory thus asserts that *easy* event-based prospective memory tasks, which do not require complex perceptual identification of the prospective memory cue, lead to intention initiation *automatically*, without involvement of, or impact on, working memory resources.

In contrast, the multinomial theory of prospective memory (Smith, 2003; Smith & Bayen, 2004) argues that *all* prospective memory tasks consume limited attentional resources and thus negatively impact performance on ongoing working memory tasks. By including a control group in our experiment, we aimed to assess the impact of an event-based and two types of time-based prospective memory tasks on an ongoing working memory, in order to test the assumptions of the multiprocess and multinomial theories. We expected that addition of any prospective memory task to the ongoing task would tap into limited attentional processes and lead to compromised performance on the ongoing task compared to the control group.

The results of our study did not provide unequivocal support for either the multiprocess or the multinomial theory. There was no significant difference between the control and the experimental groups. This finding was unexpected. If performance on the ongoing task was statistically unchanged by the presence of different types of prospective memory tasks, then the argument that prospective memory processes rely on, and consume limited working memory resources is not upheld. This finding is diametrically opposite to the proposal advanced by Smith's multinomial view of prospective memory (Smith, 2003; Smith & Bayen, 2004). Even the multiprocess view, which proposes that some *easy* types of prospective memory tasks do not affect working memory performance would have predicted that our time-based task, which involved monitoring for time cues, would adversely affect performance on the ongoing task (Einstein et al., 2005).

However, when the three prospective memory groups were compared, our results supported our hypothesis, and indicated that performance on the ongoing task was disrupted in direct relation to the attentional demands of the assigned prospective memory task. The group that required only intact auditory perception to detect the prospective memory task cue – the Event-Based group— was significantly more accurate, and more likely to increase speed of responding throughout the task, compared to other prospective memory groups. The group that required the most monitoring of the provided clock for time cues – the Time-Based group – was least likely to increase speed of responding throughout the

task. And the group that possessed both the time (potentially distracting) and the auditory (potentially advantageous) cues – the Time-Based with Reminder group – performed in the middle. These patterns of overall ongoing task performance appear to support the multiprocess view (Einstein et al., 2005) in that the easier prospective memory tasks appear to be less taxing in terms of their impact on the ongoing working memory task than the more demanding prospective memory tasks. However, because comparison with the control group was inconclusive, Smith's multinomial theory (2003) cannot be ruled out. Importantly, our study provided a unique experimental setting to quantify the differential effects of *both* time-based and event-based tasks on the *same* ongoing task.

How can we explain the unexpected performance of the Control group?

Our data indicated that the Control group – faced only with the task of completing the ongoing task alone – performed less accurately and slower, on average, than groups with prospective memory tasks. Since our randomization procedures were successful in eliminating differences between groups on all subject variables assessed (age, gender, race, working memory capacity), the fact that this group was outperformed on the ongoing task by all experimental groups seems surprising.

One potential explanation of this finding is that the Control group was not motivated to perform at optimal levels because the task at hand lacked challenge. For the Control group, the second session consisted of two short

sections of easy versions of the *n*-back task, followed by a longer section of the more demanding *n*-back version. All participants were recruited for the "Multitasking Study," and may have formed certain expectations of the task based on the description. Since participants in the Control group already practiced the more demanding *n*-back during pretest, they may have become unmotivated to perform the same task they already performed, and for a longer period of time, without the addition of a new task.

Another potential explanation for the performance of the Control group may be provided by the Distraction - Conflict theory of social facilitation (Baron, Moore & Sanders, 1978). According to this theory, performance on a simple task can be enhanced in the presence of optimal level of distraction, which prevents participants from *additional* distraction that would hinder performance on the task at hand. In our study, participants in all experimental groups but the control group received prospective memory task instructions. The necessity to process the demands of a prospective memory task may have allowed participants in the experimental groups to perform the ongoing working memory task more effectively, compared to participants in the control group who may have been more likely to get distracted from the ongoing task by task-irrelevant thoughts.

Alternatively, participants in the control group may have been conditioned to expect that all sections of the ongoing task would consume about the same time. Since the final and more difficult section of the *n*-back task was longer than the two preceding sections, participants in the Control group could have found

themselves frustrated with the task and waver in applied effort and performance. With no novelty or challenge of an additional prospective memory task, participants in the Control group may not reflect an adequate *control* for prospective memory groups, whose experience of the dual task session was marked not only by the added complication of the prospective memory task, but also by a novel challenge to master.

It is possible that high variability among participants in the Control group may have masked real differences between absence and presence of a prospective memory task. Some possibilities to limit these design shortcomings in the future would be to make all sections of the second session the same length, to eliminate filler tasks, to add a non-prospective memory task for the control group to accommodate participants' expectations, or to alter task instructions with emphasis on both accuracy and consistent rate of performance.

How Do Different Types of Prospective Memory Task Affect Ongoing Performance?

By comparing prospective memory groups to each on the ongoing task immediately prior to the prospective memory task, we sought to answer three questions: (1) Does performance on the ongoing task reflect the presumed attentional demand of a prospective memory task? (2) Can time monitoring and associated out-of-task attending be "outsourced" to an external auditory cue? And (3) How do subjective expectations about the demands of a prospective

memory task affect performance on the ongoing task? These questions are discussed below.

Does performance on the ongoing task reflect the presumed attentional demand of a prospective memory task?

We expected that attentional demands of our experimental tasks ranged from highest in the time-based condition to lowest in the event-based condition, with the time-based with reminder condition falling in the middle. This assumption was driven by the practical constraints of the three different prospective memory tasks, and predicted by both the multinomial (Smith, 2003; Smith & Bayen, 2004) and the multiprocess (Einstein et al., 2005) models.

In the time-based condition, successful prospective remembering requires that participants dedicate some attentional resources away from the ongoing task to track the clock for the target time. In the event-based condition, successful prospective remembering requires that participants recognize the provided auditory stimulus as a signal to carry out the planned task; this task does not require any disengagement from the ongoing task nor does it entail any time-specific cues about the occurrence of the auditory signal.

In the time-based with reminder condition, attending to the clock is not necessary for successful prospective task execution on time, but the time cue is provided. With the combination of both event-based and time-based features, this condition provides the benefit of the externalized reminder as well as the

potentially distracting information about the exact time remaining before the auditory alarm is to occur.

The results supported our hypothesis, showing that participants in the more demanding prospective memory task group (time-based) were less likely to speed up than participants in the less demanding prospective memory task group (time-based with reminder), who, in turn, were less likely to speed up than participants in the least demanding prospective memory task group (event-based). Practice effects (gradual reduction of RT scores) are commonly observed on n-back tasks, and in our experiment were demonstrated by participants in the event-based prospective memory task group. Deviation from the practice effect pattern in the time-based task and time-based task with reminder groups are particularly noteworthy, and possibly suggestive of the disruptive nature of the more resource-consuming prospective memory tasks.

As discussed above, it is difficult to ascribe our results to either the multiprocess or the multinomial theory exclusively, due to lack of a reliable control group. However, the fact that the observed performance patterns matched the hypotheses generated by the multiprocess model suggests that prospective memory complexity – and associated attentional demand – exists on a continuum that is reflected in a continuum of cost to the ongoing working memory task.

Can time monitoring and associated out-of-task attending be "outsourced" to an external auditory cue?

Comparison of the two time-based task groups is at the crux of the practical application of this investigation. The popularity of alarm clocks, birthday reminder services and wake-up calls stems from the assumption that the difficult part of prospective memory – *intention initiation* – can be delegated to a mechanical (or electronic) device that is *not* our working memory. We hypothesized that the processing cost on the ongoing task in the time-based task group could be reduced by the introduction of an external auditory reminder. The results of the present experiment support our faith in gadgets. Immediately prior to the prospective memory task, participants in the time-based task group exhibited predictable slowing of response speed, but participants in the time-based task with reminder group exhibited increasing response speed, without sacrificing accuracy of responding.

This pattern is consistent with the multiprocess view (Einstein et al., 2005) in that an easily-perceived auditory reminder serves as an unequivocal signal to execute the planned action, and thus consumes comparatively fewer attentional resources than a task without such a cue. Of note, the two groups showed matching patterns of speed performance on all other segments of the ongoing task, suggesting that the processing cost of a prospective memory task is experienced only immediately before the planned intention is to be carried out. The multinomial theory (Smith, 2003; Smith & Bayen, 2004) upholds this pattern by accentuating that prospective memory success depends on *preparatory* attentional processes. Our results sustain aspects of both the multiprocess and

the multinomial theories of prospective memory, as well the common practice of technological "crutches" to prospective remembering.

How do subjective expectations about the demands of a prospective memory task affect performance on the ongoing task?

What is the difference between an event-based prospective memory task and a time-based prospective memory task with a pre-set reminder? Both groups engage in an ongoing task, and both groups hear an auditory alarm that signals the proper moment to execute the planned action. The subtle difference between these two conditions is the subjective expectation of the task difficulty. Participants in the event-based task group *expect* a simple task that rests entirely on an external stimulus – response association: hear alarm → execute planned action. On the other hand, participants in the time-based task with reminder experience a more nuanced situation. For these participants, the prospective memory task is defined by the time-based component, and since the demands of a time-based task are higher than the demands of an event-based task, the subjective preparation for the dual task session may be expected to be involved with planning for proper time-monitoring.

When a reminder is provided to participants in the time-based task condition, it acts to *relieve* the attentional burden of attending the time cues immediately before the prospective memory task (see above). However, the presence of a reminder does not entirely eliminate the processing cost on the ongoing task. This "intermediate" performance in the time-based with reminder

group before the prospective memory task suggests that participants in this condition are pulled away from the ongoing task *in spite of* knowledge that time-monitoring is not essential for prospective memory success. Smith's multinomial theory (2003; Smith & Bayen, 2004) provides a better fit for this result than the multiprocess view, by highlighting that prospective memory tasks are inherently taxing, and always require attentional processing for successful performance.

There are several explanations for observed "intermediate" pattern of performance in the time-based with reminder group. First, participants may actively seek time cues throughout the ongoing task to engage with the prospective memory task demands and to remain aware of elapsed time. Having access to the clock, and thus the ability to gauge the exact time of ongoing task interruption, takes attentional resources away from the ongoing task. The ensuing processing costs to an ongoing task, in the order of seconds, may hinder performance on a task like the *n*-back. However, in everyday situations when a time-based prospective memory task is supplemented by a reminder, occasional diversion of attentional resources to *check the time* may be an effective strategy for resource allocation, optimized work flow, and overall management of a multitasking situation with relatively innocuous costs to the ongoing activity.

Second, reliance on a technological aid to alert one to an important task perhaps comes with an implicit distrust of said technology. A tendency to *double-check* the time, even in the presence of a preset alarm, may serve as a backup strategy to ensure that the prospective memory task is carried out on time. Thus,

in a time-based with reminder task group, the reminder appears to lift some of the processing load compared to an unassisted time-based task, but it may not necessarily eradicate attentional pull it to the same levels as seen in the event-based task group.

How Does Individual Working Memory Capacity Affect Performance in a Dual Task?

Contribution of individual working memory resources to prospective memory success has been well documented (see Kliegel, McDaniel & Einstein, 2000; McDaniel et al., 1999; Park et al., 1999; Smith & Bayen, 2005). Declining working memory capacity associated with clinical conditions like HIV+ has particularly grave consequences for adherence to treatment, a process that exemplifies a salient prospective memory task (see Hinkin et al., 2002, 2004). In assessing the impact of working memory capacity to the relationship between prospective and working memory processes, we aimed to investigate the extent to which working memory capacity plays a role in dual task performance and to assess the effect of working memory capacity on performance in different experimental groups for potential interaction effects.

Our results confirmed our hypothesis, and corroborated previous studies, by demonstrating that High working memory capacity participants were overall faster in their performance on the ongoing task than their Low working memory capacity counterparts. However, High working memory participants were also less likely than Low working memory participants to substantially increase their

response speed throughout the ongoing task. One possibility is that High working memory participants performed at ceiling levels for RT from the onset of the task, and thus did not demonstrate “improvement”. The Low working memory participants, on the other hand, benefited from continued practice of the *n*-back task and gradually reduced their RTs. In other words, Low working memory participants may require more practice to attain *n*-back mastery than High working memory participants. Another possibility is that High working memory participants developed and engaged successful strategies for the ongoing task *sooner* than Low working memory capacity participants.

Significantly, overall performance differences between High and Low working memory capacity participants were eliminated when scores were standardized to individual baseline performance. It appears that although individual processing capacity contributes to overall performance level, the demands of different prospective memory tasks pose common challenges across the working memory capacity continuum.

Of particular interest to this discussion is the lack of observed association between working memory capacity and type of experimental tasks. We hypothesized that immediately prior to planned action execution, High working memory capacity participants would dedicate more attentional resources to time-monitoring (and away from the ongoing task) in the time-based prospective memory group, but not in other conditions that required less out-of-task monitoring. This prediction stemmed from Smith and Bayen’s (2005) assertion

that high working memory capacity participants were more likely to engage in preparatory attentional processes that are thought to underlie successful prospective performance. Our results partially supported this hypothesis. Compared to Low working memory participants, High working memory participants in our sample were slower in the time-based and event-based task groups, but faster in the control and time-based with reminder task groups.

Conceptually, the dual task session can be divided into two phases: in the first phase, participants are expecting the prospective memory task cue; in the second phase, participants finish the ongoing task after the prospective memory task is complete. Could the difference between High and Low working memory capacity participants in performance strategy on the dual task be attributed to particular prospective memory task strategies employed in the first phase of the dual task? In order to answer this question, we must first analyze the similarities between the Time-based and Event-based prospective memory tasks conditions and the Time-Based task with Reminder and Control conditions.

Participants in the time-based and event-based prospective memory task groups share the experience of *waiting for* a cue to signal that a planned action is to be executed. The cue must be generated *internally* in the former group and *externally* in the latter, but both groups may share an *anticipatory* experience that consumes some of the limited attentional resources. In contrast, participants in the time-based task with reminder group may experience the first phase of the ongoing task as a *simplified* (by the preset auditory cue) version of the pure time-

based task, and thus perceive the anticipation of the auditory cue as less intrusive (however, as discussed above, these participants may still be distracted by the available time cues that foretell the disruption of the ongoing task). The control group, in the absence of a prospective memory task, is expected to simply work until the end of the task without the intrusive thoughts of expected disruption.

If High working memory participants are expected to strategically allocate attentional resources in situations that require *more* attentional resources, then it is not surprising that they exhibit slower rates of responding in time-based and event-based prospective memory task conditions. As described above, the structure of dual task sessions involving these prospective memory conditions add a potentially resource-consuming expectation factor. When active expectation is reduced, High working memory participants dedicate attentional resources to the ongoing task and achieve higher performance speed. Low working memory capacity participants, on the other hand, are perhaps less strategic in the allocation of attentional resources that are available. Paradoxically, such “non-attending” may serve as an advantage in prospective memory tasks that entail anticipation. The fact that low working memory capacity participants took longer to respond in the time-based with reminder and control conditions may point to their distractibility and failure to focus on a task at hand.

As noted above, working memory capacity effects were not preserved when data were normalized to individuals’ baseline rates of responding. One

interpretation of this finding is that working memory capacity determines *overall* level of performance on the ongoing task, and does not impose strategic advantage (or disadvantage) on managing different prospective memory tasks of varying attentional demand. On the other hand, transformed scores may mask the real difference between high and low working memory capacity participants, and their approaches to different prospective memory tasks. Perhaps the difference in task demands processing and associated resource allocation planning occurs not during, but *before* the dual task session begins. In order to gain a full appreciation for the role of working memory capacity in prospective memory processing, both raw response speed and transformed RT data should be considered in evaluation of our results.

Applications to Treatment Adherence and Everyday Multitasking

Results of our study can be extended to practical applications in the area of treatment adherence. First, we demonstrated that, compared to other prospective memory tasks, event-based prospective memory tasks are least disruptive to performance on the ongoing task, particularly for individuals of low working memory capacity. Second, our data indicated that the attentional burden of time-based prospective memory tasks can be somewhat alleviated by the introduction of an externalized, easily identifiable, auditory reminder.

These findings suggest that regimens of treatment, should, whenever possible, be linked to discrete events or, in the case of time-based routines, be supplemented with explicit, easily-identifiable reminders. It is important to

recognize that even in light of working memory deficits, prospective memory tasks can be made more accessible by simplifying attentional demands related to monitoring for appropriate prospective cues. Of course, many treatment regimens far exceed in complexity the type of laboratory tasks we employed in our experiment. Future investigations into the nature of prospective memory processing should incorporate variables of task complexity and task frequency in order to better approximate the challenges faced by many patients on a regular basis.

Data Patterns of Interest

There were several noteworthy null findings in experiment. First, all but two participants in prospective memory task groups successfully performed the planned action. This high adherence rate is a departure from many laboratory-based studies of prospective memory that utilize embedded prospective memory cues. Embedded cues require participants to engage in stimulus discrimination processes that are rarely required in prospective memory tasks in ordinary circumstances. We specifically used unembedded prospective memory task cues to increase externally validity of our study. Our findings suggest that the chosen prospective memory task was ecologically relevant and comparable to everyday scenarios of prospective memory.

Second, all participants attained comparable levels of competency in the ongoing task and demonstrated a reliable practice effect throughout the dual task session. Furthermore, experimental conditions demonstrated the greatest

disparity during the segment of the ongoing task immediately preceding the prospective memory task. These patterns of performance suggest that the ongoing task was an apt setting in which to examine the disruptive effects of prospective memory processes.

Third, contrary to our expectation, there was very little variability in accuracy of responding in the ongoing task while great variability was observed in RT. This outcome is possibly due the instructions participants received prior to beginning the dual task session: to focus on accuracy of the ongoing task. We delivered these instructions to ensure that the working memory load of the demanding 2-back task was not counteracted by poor task compliance. The resultant variability in RT afforded greater quantitative insight into the effects of the prospective memory tasks without the detrimental confounds of a speed-accuracy trade-off.

Limitations and Directions for Future Research

Our study was exploratory in nature and results should be interpreted with caution. Importantly, even where our findings did not reach significance, patterns of performance were in expected, or compellingly unexpected, directions. Practical and clinical applications of understanding prospective memory processes may inspire further research, which could achieve greater experimental control if caveats noted below are avoided.

The greatest hindrance to our experiment was individual variability in response times on the ongoing task. It is possible that our chosen structure of the

n-back task (self-paced) encouraged non-compliance with task demands and resulted in unfocused performance and artificially inflated RT scores. In order to gain more uniform RT data, future studies may consider designing the *n*-back task which might employ predetermined inter-trial and response-trial intervals. An additional benefit of such task constraints may be emergent variability in accuracy data, which may help elucidate the disruptive nature of prospective memory processes. Additionally, future studies may consider other types of working memory tasks to serve as *ongoing* tasks. For example, an arithmetic verification task may serve as a flexible working memory canvas on which to explore the impact of different prospective memory processes. Reducing variability in experimental, as well as control groups, would allow for a better examination of the multinomial and multiprocess theories.

Several caveats were identified in the delivery of the prospective memory task cues. First, participants performed only one prospective memory task per session. Although this setup allowed us to collect data from one “prospective memory episode”, there is a possibility that participants in all conditions perceived this prospective memory task more as a vigilance task (see discussion above on the role of expectations of prospective memory task). Approaching a prospective memory task as a vigilance task would defeat one of the main defining characteristics of prospective memory: time between intention formation and intention initiation, during which the planned intention is out of immediate awareness (see Brandimonte et al., 2001; Graf & Uttl, 2001).

Additionally, a single isolated prospective memory episode is hardly analogous to the habitual prospective memory task of treatment adherence we hoped to capture. In order to preserve and to examine the unique nature of prospective memory, future studies should aim to avoid situations that risk experiential confusion between prospective and vigilance tasks by increasing the interval between intention formation and intention initiation and exploring the effects of repeated prospective memory cues during a session.

Second, the experimenter, not the participants, selected the auditory stimulus used as a reminder for our study. Although experimenters routinely select materials to be used in research studies, our study aimed specifically to use an auditory stimulus that would be perceived as a positive aid to a complex task. People choose mnemonic devices that work for them based on extremely personal reasons; ultimately, personal relevance is what often determines functional success of a mnemonic device. Some participants in our study may have disliked the auditory stimulus used, or may have been startled rather than gently alerted by its onset. Future experimenters should assess any stimuli used as reminders for neutrality, without sacrificing distinctiveness. Perhaps participants should be pre-exposed to reminder stimuli to minimize anxiety associated with an unknown and upcoming stimulus.

The third issue concerns the personal nature of mnemonic devices. In our experiment, the target times for the prospective memory tasks, as well as reminders, were preset by the experimenter and carried no personal significance

to the participants. In everyday prospective memory situations, the planned action, as well as the selected reminder, often carry semantic information. Could it be that the more meaningful prospective memory tasks are more disruptive, overall? Alternatively, is it possible that personally-selected and personally-set reminders are more effective in alleviating the attentional demands of time-based prospective memory tasks than experimentally-manipulated reminders? The answers to these questions could be obtained from carefully controlled experiments that engage participants in all phases of prospective remembering: from independent, not assigned, intention formation to reminder selection, to intention initiation and execution.

Conclusions: The Big Picture

The design of the present experiment provided a unique opportunity to quantify processing costs of both event-based and time-based prospective memory tasks on the same ongoing working memory task. In many everyday situations of multitasking (including, but not limited to treatment adherence), prospective memory failure may lead to adverse – and frustrating – consequences. The results of our study confirmed the hypothesized: higher cost of time-based tasks and lower cost of event-based tasks. Furthermore, we observed that addition of a reminder to the time-based task alleviates some of the processing cost and is effective as a prospective memory aid.

Although it remains to be explored whether a reminder allows one to “just set it and forget it,” our findings on working memory capacity effects suggest that

the challenge of prospective memory tasks is experienced similarly along the processing prowess continuum. The questions raised by the results of the present investigation open productive avenues for future research, and may lead to better understanding of common challenges of – and remedies for – complicated cognitive experiences – be it remembering to take medication on time or avoiding trips to the ‘belated birthday wishes’ aisle.

Table 1

Demographic Information for Experimental Groups

		Group			
		Time-based	Time-based with reminder	Event-based	Control
Demographic Variable	N	19	16	16	17
Age	Mean	21.47	22.69	20.31	22.18
	Range	18 - 31	18 - 38	18 - 26	18 - 44
	SD	3.642	6.437	2.414	7.618
Gender	Male	6	5	6	5
	Female	13	11	10	12
Race	Caucasian	8	9	10	9
	African American	1	1	1	3
	Asian American	2	2	2	0
	Hispanic	5	2	1	2
	Pacific Islander	0	0	1	0
	Other	3	2	1	3

Table 2

Distribution of High and Low Working Memory (WM) Participants among Experimental Groups

		Group				
		Time-Based	Time-Based with Reminder	Event-Based	Control	Total
WM	High	9	8	9	10	36
	Low	10	8	7	7	32
	Total	19	16	16	17	68

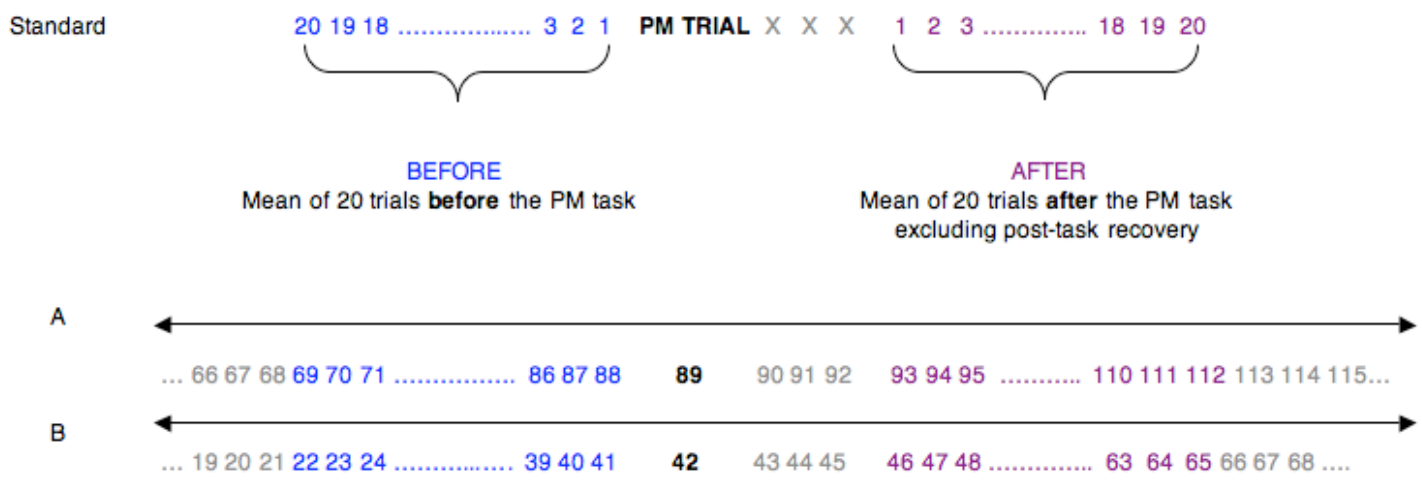

Figure 1. Derivation of standardized *before-task* and *after-task* mean RT score and accuracy score for each participant on the 2-back portion of the n-back task. The relevant trials will be selected based on the trial at which a participant completed the prospective memory (PM) task.

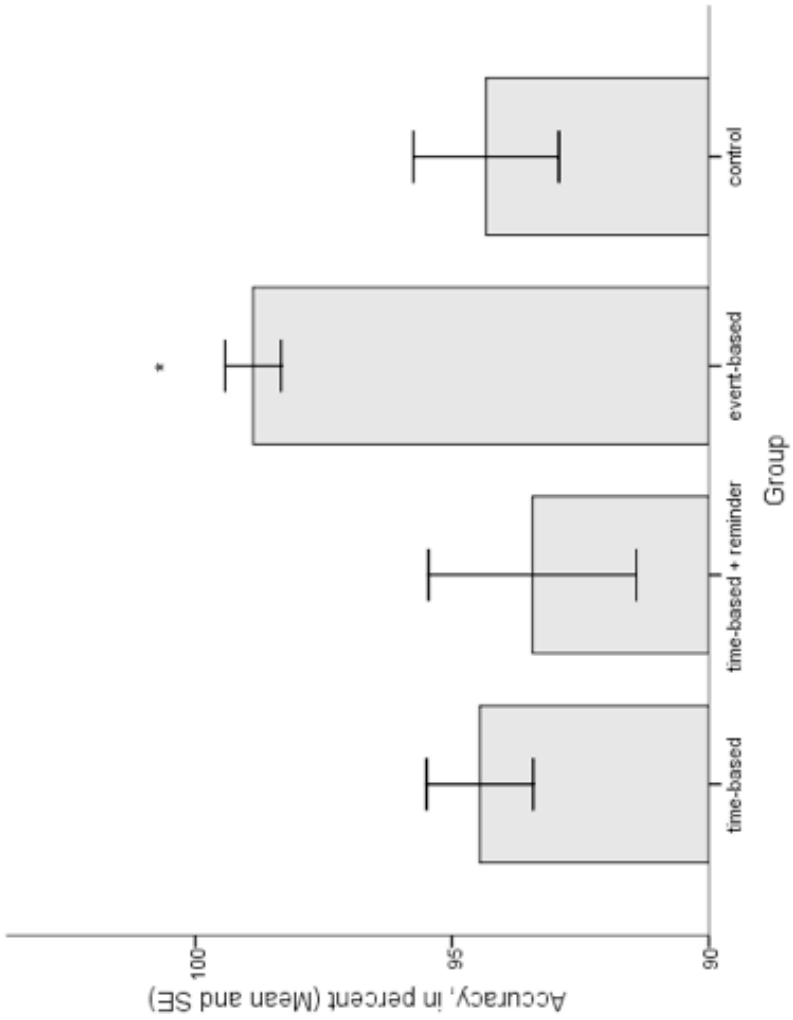

Figure 2. Mean accuracy (+/- 1 SE) for all experimental groups across four time segments of the working memory task. Accuracy was calculated as a percentage of correctly completed trials of the working memory task. Asterisk indicates a statistically significant difference between EB and other groups. Mean accuracy in the EB group was significantly higher than mean accuracy in the TB group ($p = 0.020$), the TBR group ($p = 0.006$), and the Control group ($p = 0.020$).

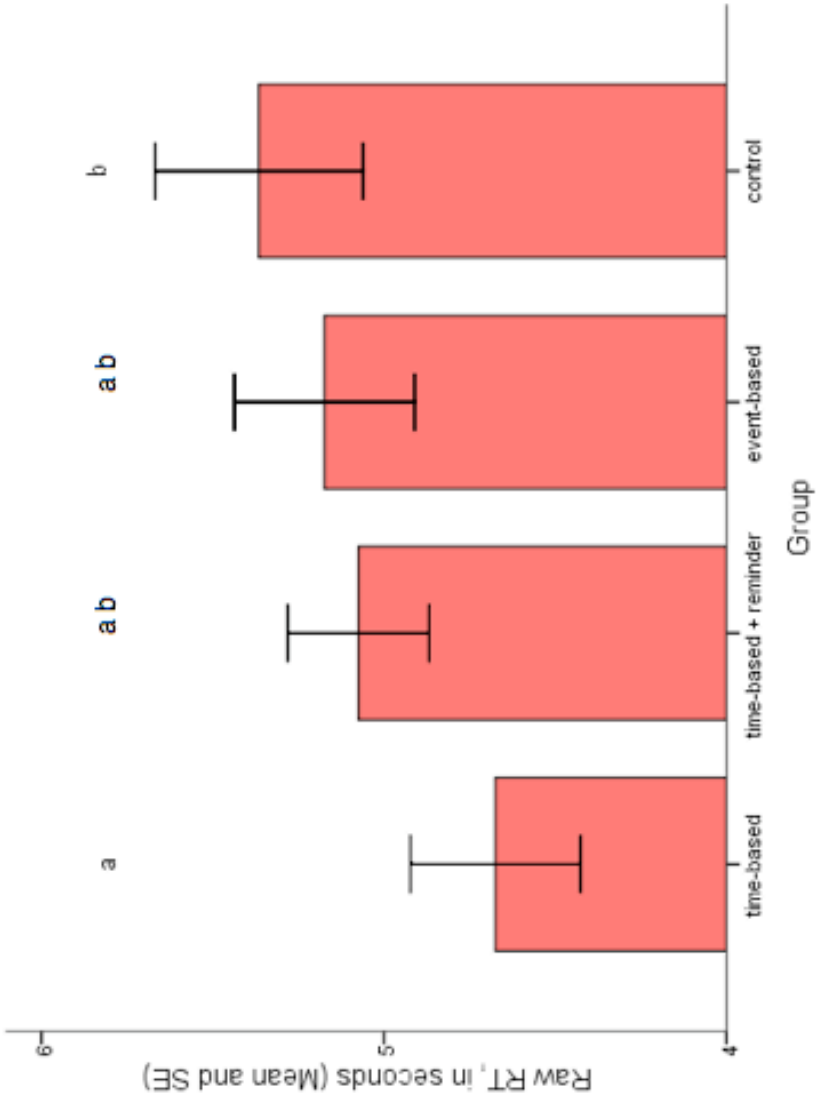

Figure 3. Mean raw RT (+/- 1 SE), in seconds, for all experimental groups. Mean RT in the TB group (a) was lower than mean RT in the Control group (b) at $p = 0.054$.

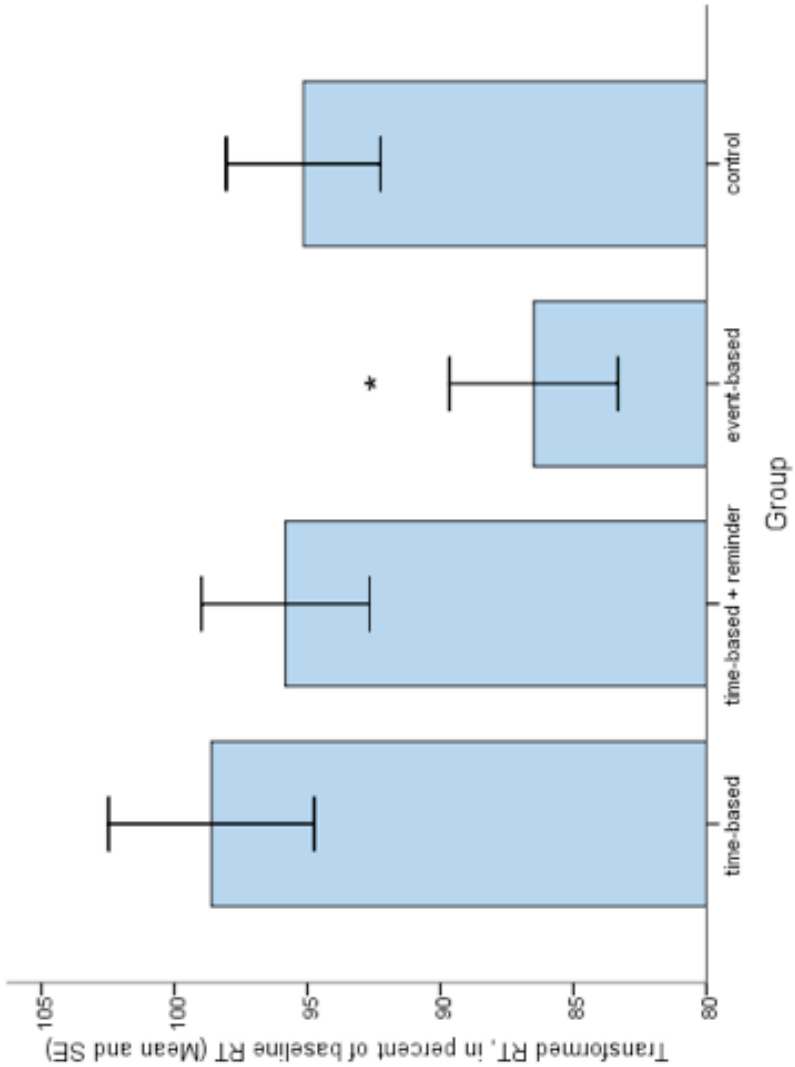

Figure 4. Mean transformed RT (+/- 1 SE), expressed as percent of baseline RT, for all experimental groups. Transformed RT scores were calculated by dividing each time segment score by the referent baseline score, and multiplying by 100. An asterisk indicates that the EB group was significantly lower on transformed RT than the TB group ($p = 0.01$), and approached significance on comparisons with the TBR ($p = 0.057$) and the Control ($p = 0.073$) groups.

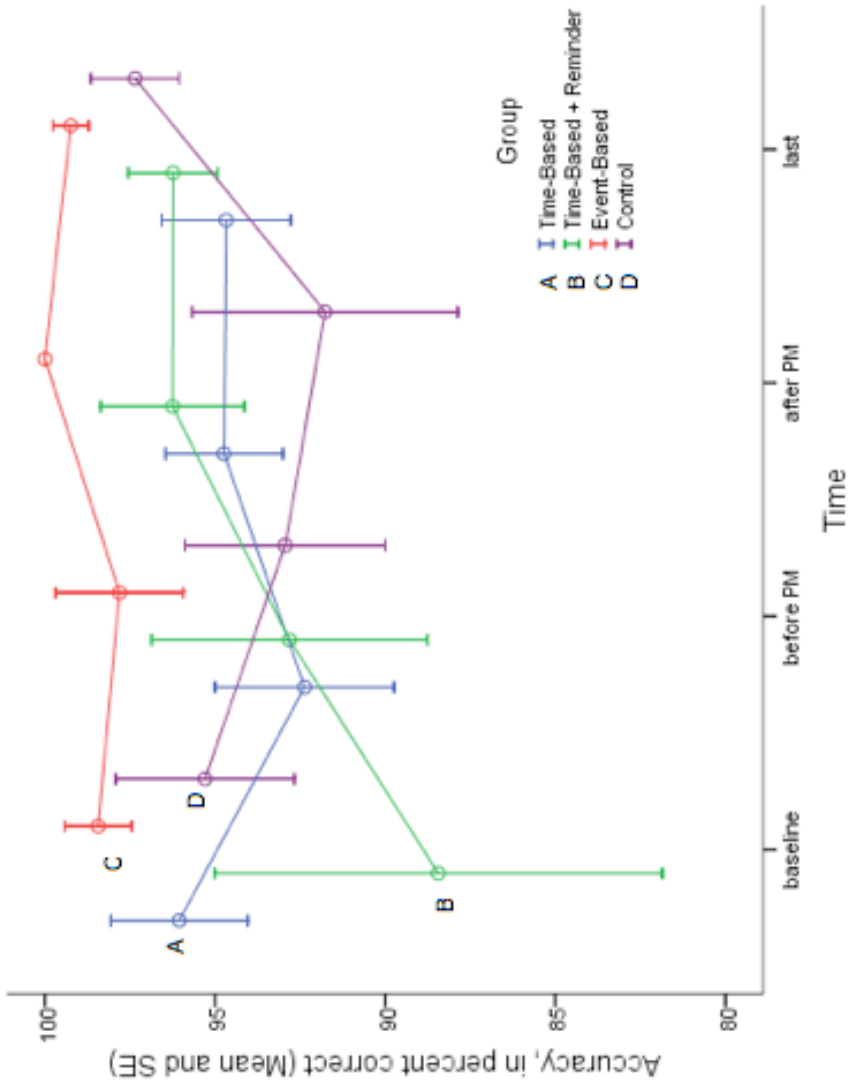

Figure 5. Mean accuracy (+/- 1 SE) for all experimental groups across four time segments of the working memory task. Accuracy was calculated as a percentage of correctly completed trials of the working memory task.

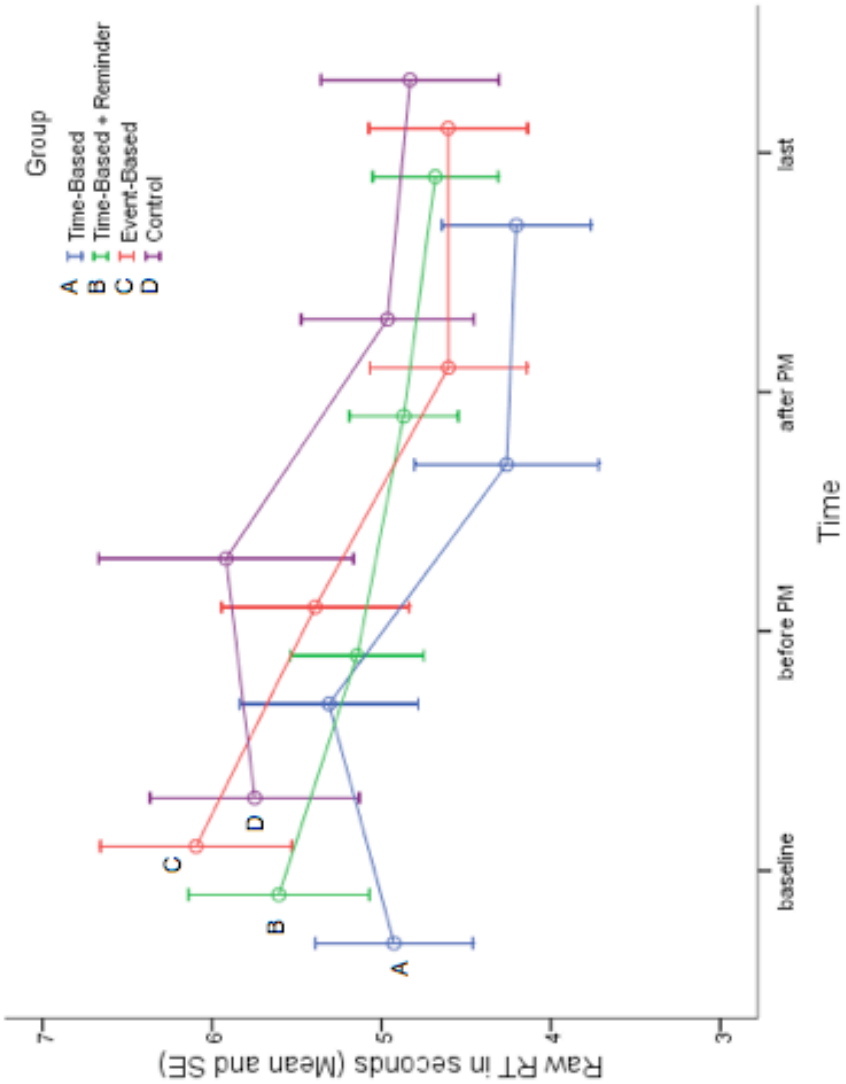

Figure 6. Mean raw RT (+/- 1 SE), in seconds, for all experimental groups across four time segments of the working memory task.

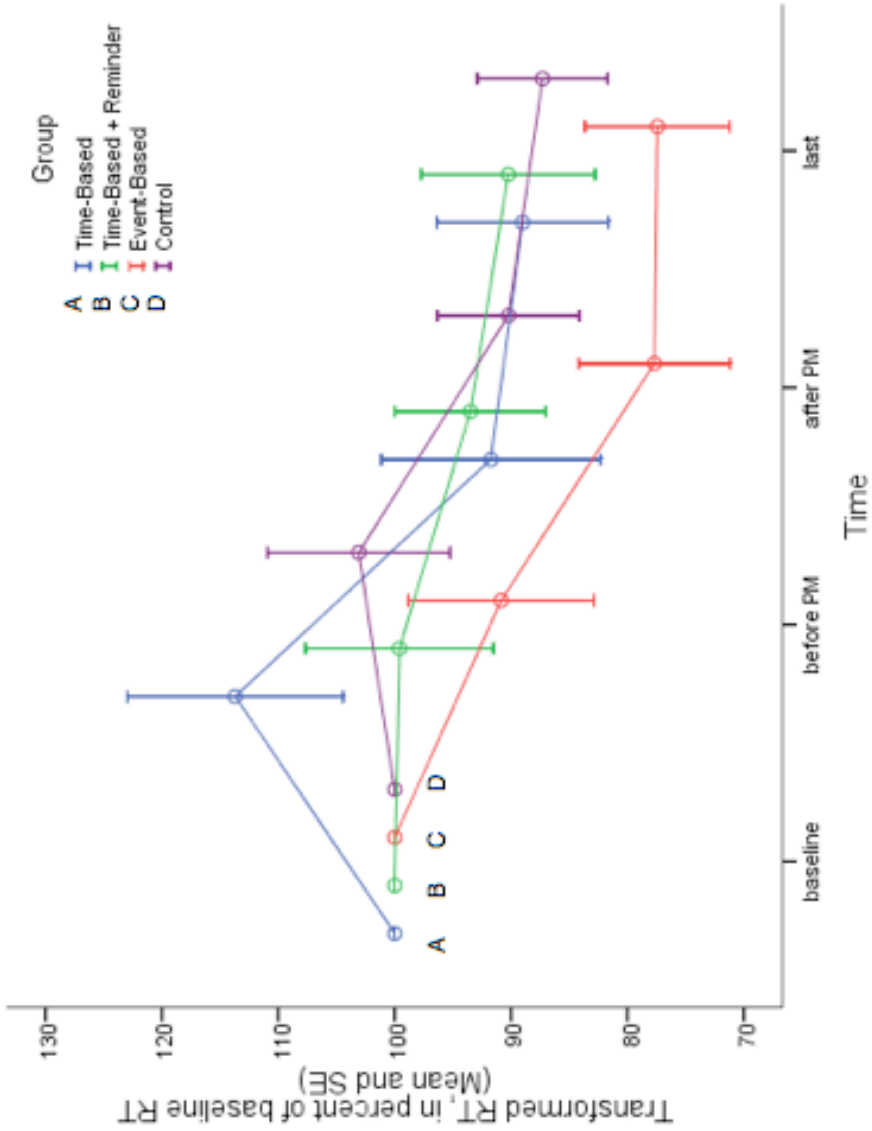

Figure 7. Mean transformed RT (+/- 1 SE), expressed as percent of baseline RT, for all experimental groups across four time segments of the working memory task. Transformed RT scores were calculated by dividing each time segment score by the referent baseline score, and multiplying by 100.

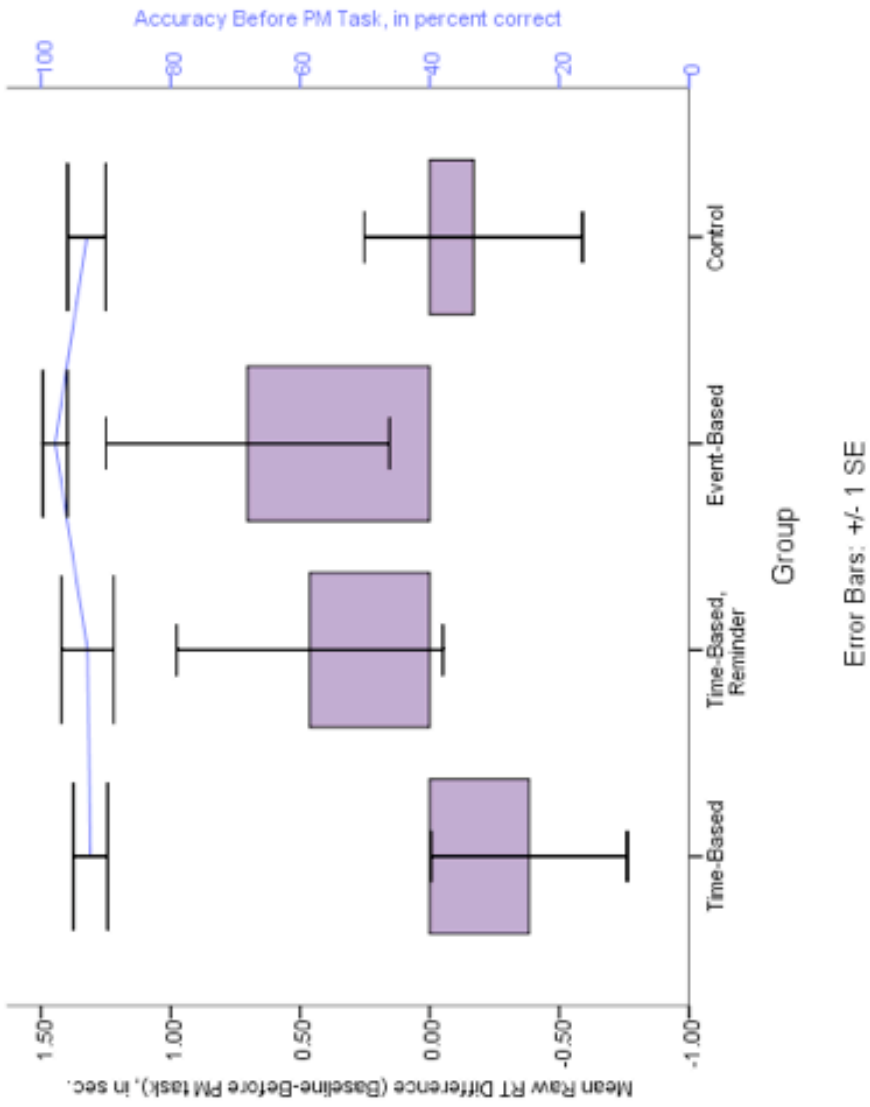

Figure 8. Mean raw RT difference scores (bars, +/- 1 SE), in seconds, for all experimental groups, plotted together with accuracy (line, +/- 1 SE) scores for the *before PM task* segment of the working memory task. Difference scores were obtained by subtracting *before PM task* raw RT from the *baseline* raw RT.

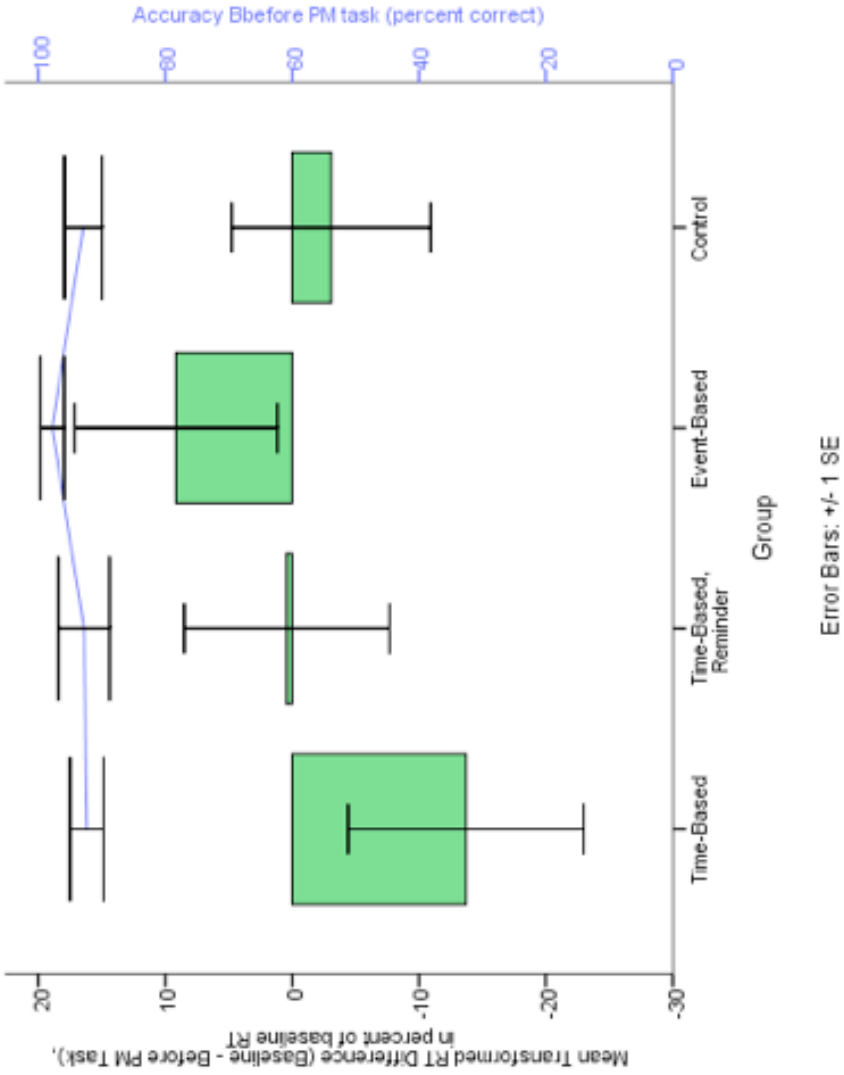

Figure 9. Mean transformed RT difference score (bars, +/- 1 SE), in percent of baseline RT, for all experimental groups, plotted together with accuracy (line, +/- 1 SE) scores for the *before PM task* segment of the working memory task. Difference scores were obtained by subtracting *before PM task* transformed RT from the *baseline* transformed RT.

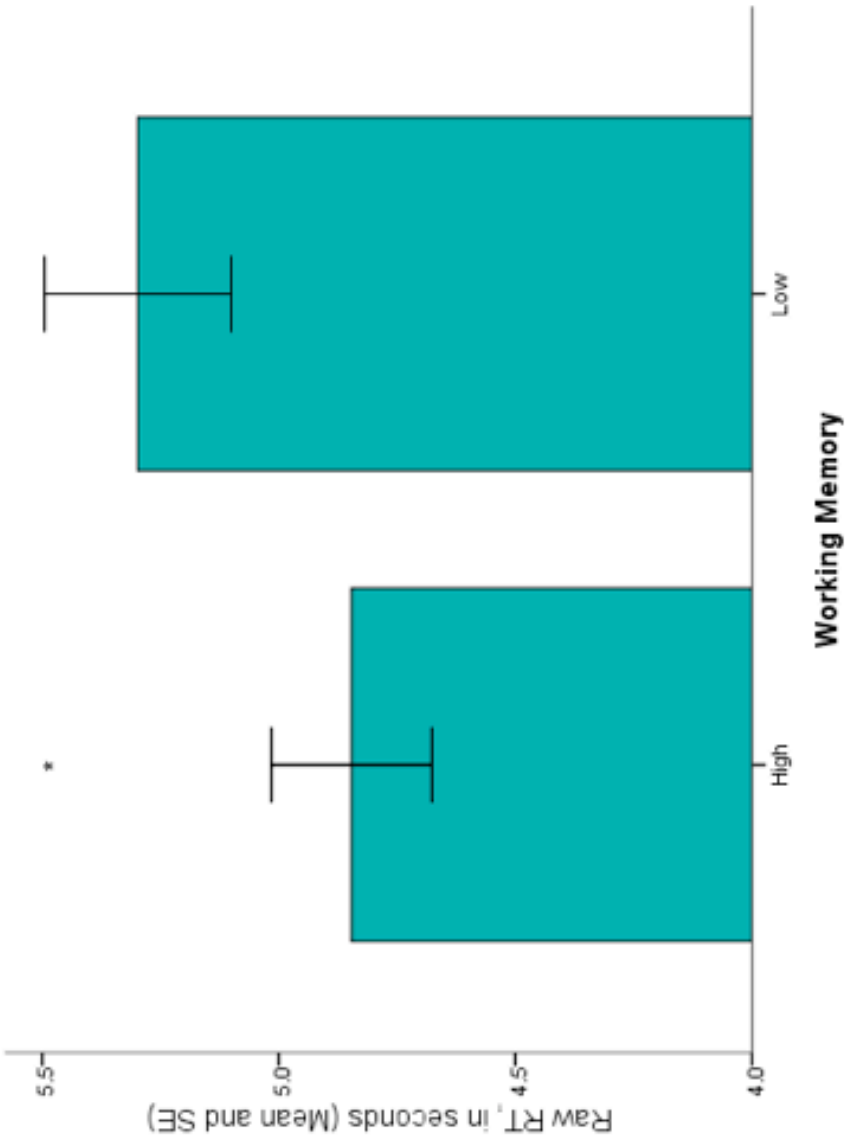

Figure 10. Mean raw RT scores (+ / - 1 SE), in seconds, for High and Low WM participants. An asterisk indicates that the High WM participants were significantly faster than Low WM participants ($p = 0.025$).

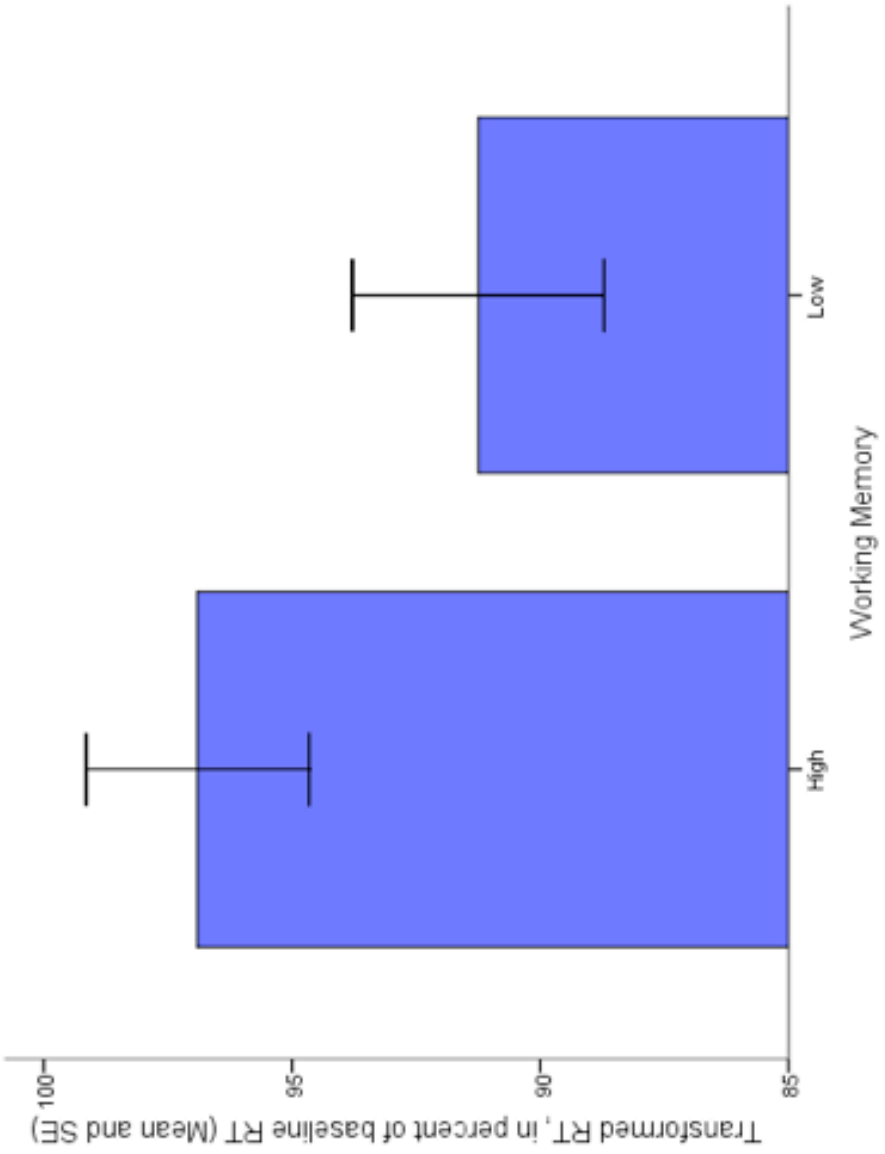

Figure 11. Mean transformed RT scores (+ / - 1 SE), in percent of baseline RT, for High and Low WM participants.

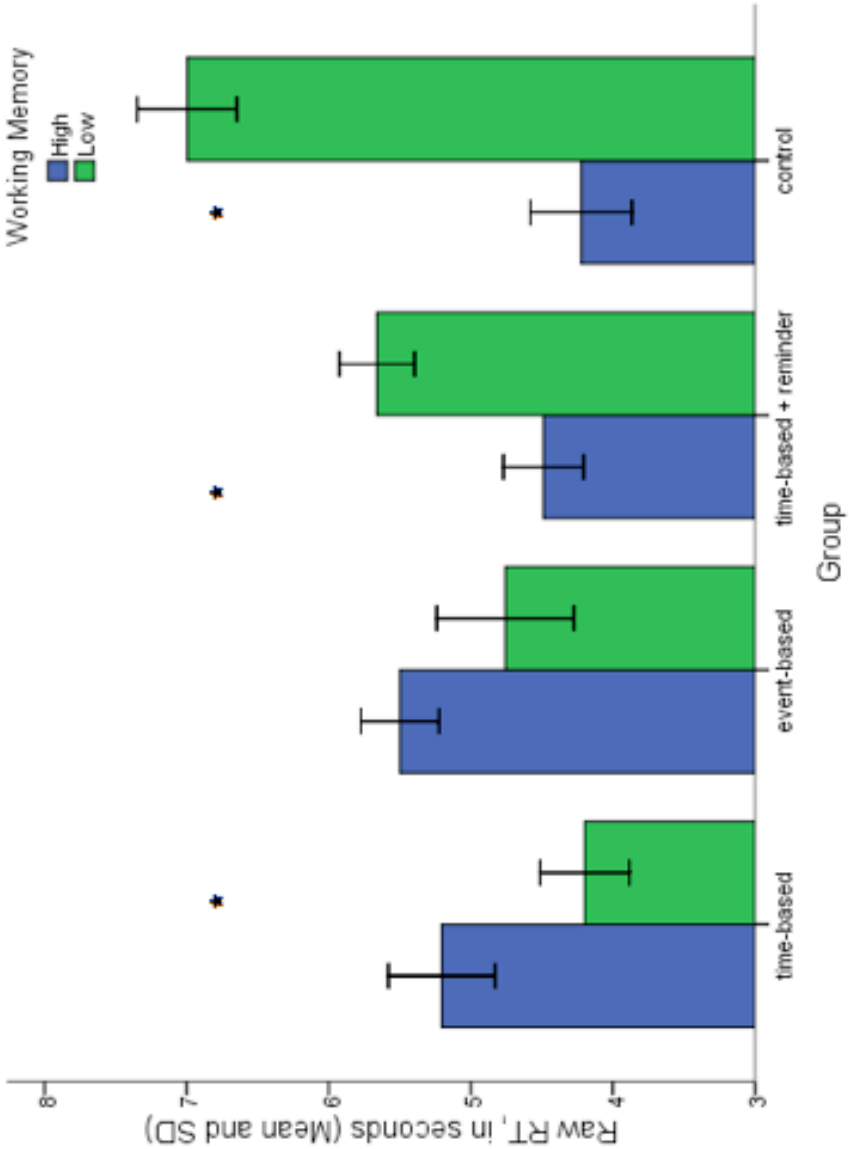

Figure 12. Mean raw RT scores (+ / - 1 SE), in seconds, for High and Low WM participants in all experimental groups. Asterisks indicate significant differences at $p < 0.05$.

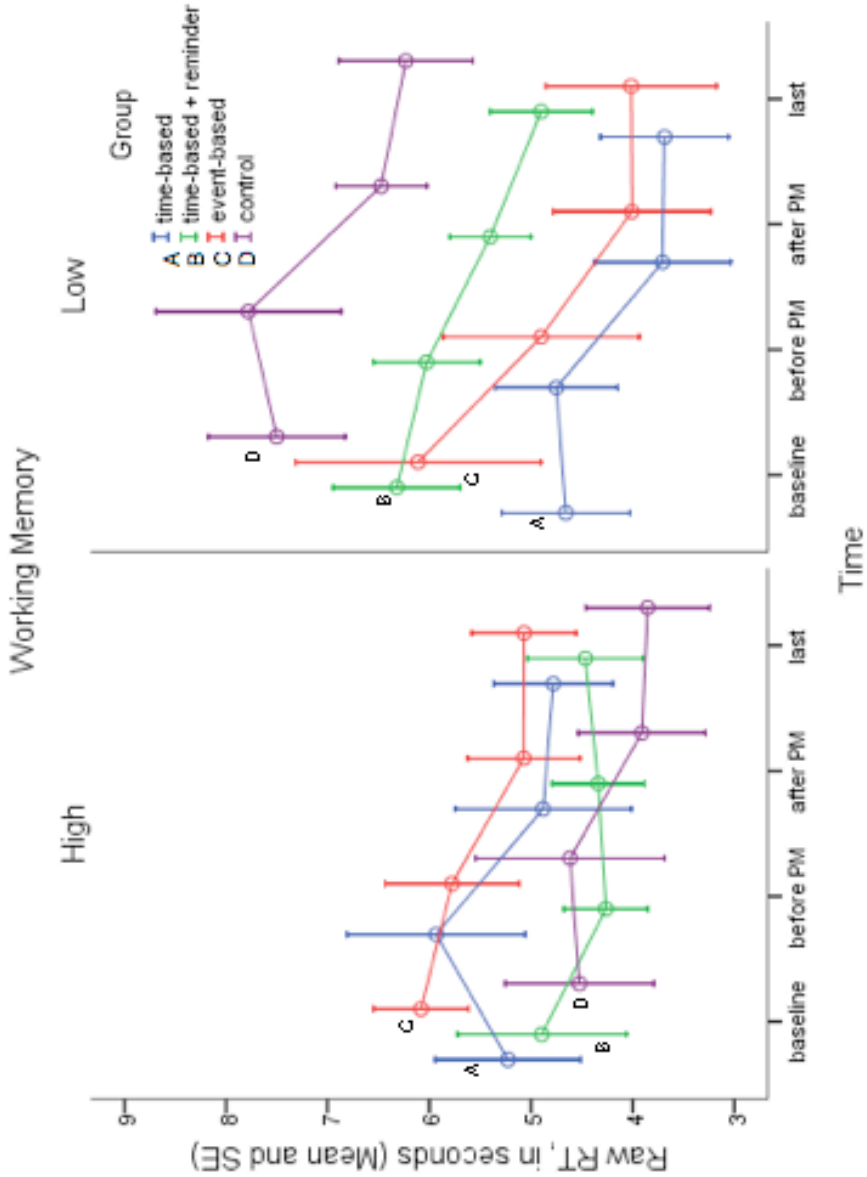

Figure 13. Mean raw RT (+/- 1 SE), in seconds, for all experimental groups across four time segments of the working memory task, paneled by two levels of Working Memory Capacity (High and Low).

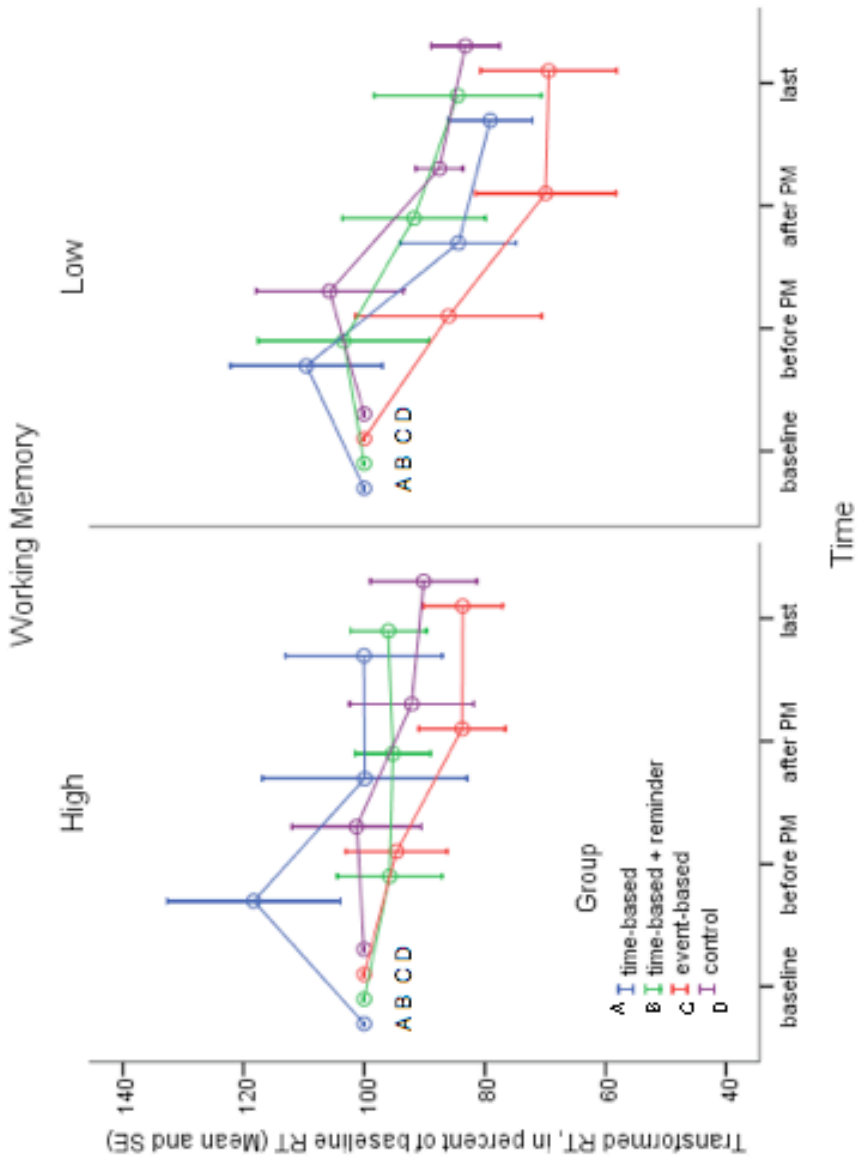

Figure 14. Mean transformed RT (+/- 1 SE), expressed as percent of baseline RT, for all experimental groups across four time segments of the working memory task, paneled by two levels of Working Memory Capacity (High and Low).

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