Cognitive Control Processes Underlying Continuous and Transient Monitoring Processes in Event-Based Prospective Memory

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved April 2015 by the
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May 2015

ABSTRACT

A converging operations approach using response time distribution modeling was adopted to better characterize the cognitive control dynamics underlying ongoing task cost and cue detection in event based prospective memory (PM). In Experiment 1, individual differences analyses revealed that working memory capacity uniquely predicted nonfocal cue detection, while proactive control and inhibition predicted variation in ongoing task cost of the ex-Gaussian parameter associated with continuous monitoring strategies (mu). In Experiments 2A and 2B, quasi-experimental techniques aimed at identifying the role of proactive control abilities in PM monitoring and cue detection suggested that low ability participants may have PM deficits during demanding tasks due to inefficient monitoring strategies, but that emphasizing importance of the intention can increase reliance on more efficacious monitoring strategies that boosts performance (Experiment 2A). Furthermore, high proactive control ability participants are able to efficiently regulate their monitoring strategies under scenarios that do not require costly monitoring for successful cue detection (Experiment 2B). In Experiments 3A and 3B, it was found that proactive control benefited cue detection in interference-rich environments, but the neural correlates of cue detection or intention execution did not differ when engaged in proactive versus reactive control. The results from the current set of studies highlight the importance of response time distribution modeling in understanding PM cost. Additionally, these results have important implications for extant theories of PM and have considerable applied ramifications concerning the cognitive control processes that should be targeted to improve PM abilities.

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Chapter 1

INTRODUCTION

Event-based prospective memory (PM) refers to relying on environmental cues to trigger retrieval of a deferred action plan from long-term memory. Consequently, PM requires an intimate balance between attention and memory processes that are necessary for monitoring the environment for the occurrence of cues and remembering the contents of the previously established intention. Perhaps one of the most widely demonstrated PM findings is that *cost* to ongoing task processing (e.g., slower responding) often occurs as a result of possessing an intention for future action relative to when the same task is performed with no intention (Smith, Hunt, McVay, & McConnell, 2007). Observed costs suggest that some capacity-consuming cognitive control process has been enacted to support PM cue detection and action retrieval, thereby reducing the executive resources available to support ongoing task processing (Marsh, Cook, Hansen, & Pallos, 2003). Despite the abundance of research investigating the conditions under which PM control processes are active (e.g., McDaniel & Einstein, 2000), relatively little is known about the *nature* of these control processes or the *regularity* in which they are enacted. Thus, the purpose of the current set of studies was to use a converging operations approach in conjunction with response time (RT) distribution modeling to better characterize the role of various control processes in ongoing task processing and cue detection.

Prospective Memory Monitoring Processes

In a typical event-based PM task, following the completion of practice with a particular ongoing task (control block) participants form an intention to perform a specific action upon encountering specific cues during the subsequent ongoing task (experimental block). For example, upon completing practice of a lexical decision task (LDT), participants are additionally given the PM instruction to press the "/" key after making their lexical decision any time an animal word (e.g., *dog*) occurs during a subsequent LDT. Cost analyses are generally derived from ongoing lexical decision latencies by comparing mean RTs between control and experimental blocks. Cost to ongoing task processing occurs when mean response latencies (on non-cue trials) are slower in the experimental than the control block. It is generally assumed that cost arises because ongoing and PM task demands draw on the same pool of limited executive resources, so as more resources are devoted to noticing cues, response latencies increase due to fewer resources being available for ongoing task processing (Marsh et al., 2003).

Although the majority of extant theories of event-based PM assume that similar capacity-consuming control processes involved in monitoring for cues underlie cost effects in PM tasks, they differ in their supposition as to whether such processes are always necessary for successful PM retrieval. The preparatory attentional and memory (PAM) process theory posits that resource-demanding control processes are always needed to engage target-checking processes to determine whether or not the current stimulus requires a PM response (Smith, 2003; Smith et al., 2007). The two-process model of strategic monitoring additionally assumes that cost may arise from maintenance of a mental task set that treats ongoing task stimuli as potential PM retrieval cues (Guynn, 2003). Importantly, these theories generally assume that possessing an intention should always produce cost regardless of the nature of the ongoing or PM task demands.

Alternatively, the multiprocess view posits that although preparatory attentional processes are enacted to support cue detection under many circumstances, there are certain instances in which PM retrieval can occur spontaneously (i.e., without engagement of executive processing; McDaniel & Einstein, 2007). For example, PM retrieval can occur spontaneously (i.e., without cost) when there is only a single PM cue (Cohen & Gollwitzer, 2008) or during focal processing conditions (Einstein & McDaniel, 2005). Focal processing occurs when the ongoing task processing orients attention to the features of the PM cue (e.g., respond to “dog” during a LDT), whereas nonfocal processing occurs when the type of ongoing processing does not overlap with those required to process cues (e.g., respond to *any* animal during LDT). Spontaneous retrieval can occur via one of two mechanisms: 1) A reflexive-associative process may elicit spontaneous retrieval when there is a strong association between the cue (e.g., *spaghetti*) and the intended action (e.g., say “sauce”), such that processing the cue automatically activates the intended action; 2) A discrepancy-plus-search process may also produce spontaneous noticing when encountering a cue that produces discrepancy between the expected and actual quality (or speed) of processing, which may in turn stimulate search for the source of the (dis)fluency (McDaniel, Guynn, Einstein, & Breneiser, 2004). In either case, it is suggested that reactive processes following cue processing stimulates retrieval of the intended action without the engagement of preparatory attention.

Cognitive Control Processes in Prospective Memory

Despite the abundance of research that has fueled theoretical debates over the past two decades on *when* cognitive control processes are enacted during event-based PM (e.g., Einstein & McDaniel, 2010; Smith, 2010; Smith et al., 2007), relatively little is known about the nature of these control processes. One possible reason for the limited understanding of PM control processes is that the majority of extant research and theorizing has focused primarily on a single aspect of cognitive control (i.e., working memory; but see Schnitzpahn et al., 2013). However, more recently the dual mechanisms of control (DMC) framework has been developed to explain attention control in various cognitive tasks that may also be applicable to the understanding of PM monitoring and retrieval processes (Braver, 2012; Bugg, McDaniel, & Einstein, 2013; Bugg, McDaniel, Scullin, & Braver, 2011). Thus, I briefly review these two aspects of cognitive control and their relation to PM.

Working memory capacity. One of the most widely studied external correlates of PM is working memory capacity (WMC). Working memory is broadly defined as a general purpose system involved in both actively maintaining task-relevant information in primary memory in the face of internal or external distraction and controlled retrieval from secondary memory of momentarily displaced information (Baddeley, 2007; Engle & Kane, 2004; Unsworth & Engle, 2007). Importantly, it has been suggested that the control processes enacted to maintain task-relevant information in various attention tasks may underlie the relation between WMC and PM. In particular, it is suggested that control processes associated with working memory are enacted during PM tasks to actively maintain intention-relevant information and engage strategic monitoring processes to support cue detection (e.g., Einstein, Smith, McDaniel, & Shaw, 1997; Guynn, 2003; Marsh & Hicks, 1998; Smith, 2003). For example, Brewer, Knight, Marsh and Unsworth (2010) found that nonfocal cue detection was better for high than low WMC participants, but did not differ between groups for focal cue detection. Interestingly, there were no nonfocal ongoing task processing cost differences between groups as might be expected if goal-maintenance abilities underlie cost that contributes to

PM retrieval. Brewer et al. suggested that similar RTs might reflect that participants allocated attention equally across groups, but low WMC participants were more susceptible to internal interference (e.g., task-unrelated thoughts; West et al., 2005) that disrupted nonfocal cue detection. However, an alternative explanation is that high and low WMC participants relied on different types of cognitive control processes that both produced cost to ongoing task performance, yet were differentially effective for cue detection. This idea is consistent with previous research that has suggested that WMC limitations might increase reliance on less efficacious control processes to support ongoing task processing in other domains.

Dual mechanisms of control framework. The dual mechanisms of control (DMC) framework proposes that variation in working memory arises due to cognitive control processes that operate via two distinct modes, referred to as *proactive* and *reactive* control (Braver, 2012; Braver, Gray, & Burgess, 2007). Proactive control is involved in actively maintaining context information (e.g., task instructions, previous stimuli, cues, etc.) to optimally bias perception and action systems to facilitate goal-directed behavior (Braver et al., 2007). Proactive control is a top-down, early-selection process that serves to anticipate and prevent interference by sustaining activation of goal-relevant attentional states. In contrast, reactive control occurs via transient activation of bottom-up, late-correction processes that serve to reduce interference after its onset. Importantly, although under many circumstances proactive control is the optimal processing mode to facilitate goal-completion, sustained activation of contextual information is prohibitively costly. Thus, during tasks that require high cognitive control demands (e.g., nonfocal PM tasks), adopting a particular processing mode is based on a cost/benefit assessment of the ease with which actively maintaining context can be achieved and the expected gains that engaging such a control process will produce to ongoing task performance (Braver, 2012). Consequently, WMC may influence the reliance on proactive control as this ability reflects the efficacy with which context maintenance can be achieved (Kane & Engle, 2002).

Previous research suggests that low WMC participants are more likely to engage reactive control processes in the AX-continuous performance test (AX-CPT; MacDonald et al., 2005; Redick & Engle, 2011), a task commonly used to study proactive and reactive control. In this task, a 'target' response is required only when the probe *X* follows the cue *A* (AX trial), which occurs on the majority (70%) of the trials to produce expectancy. However, the cue *A* is followed by a probe other than *X* on 10% of the trials (AY trial), and the probe *X* follows a cue other than *A* on another 10% of the trials (BX trial). Additionally, on 10% of the trials neither an *A* or *X* are presented (BY trials). Importantly, on BX trials context information (the cue *B*) can be used to inhibit a dominant response tendency to make a target response when *X* is presented, whereas on AY trials context information (the cue *A*) serves to bias processing to subsequently (erroneously) make a target response. Thus, reliance on proactive control processes should facilitate performance on AX and BX trials, but can actually hurt performance on AY trials. Consistent with the idea that WMC may influence the reliance on proactive versus reactive control processes, low WMC participants are more likely to engage reactive control processes as evidenced by increased errors AX and BX trials, presumably due capacity limitations involved in actively maintaining context information (Redick & Engle, 2011).

Interestingly, there is considerable overlap between the cognitive control processes proposed in the DMC framework and those thought to underlie PM retrieval as proposed by the multiprocess view (see Bugg et al., 2013 for a more detailed discussion). In particular, both proactive control and preparatory attention involve sustained activation of a mental task set that biases attention towards goal-relevant information, whereas both reactive control and spontaneous retrieval involve transient activation of goal-relevant information triggered by particular characteristics of the stimuli. Thus, while reactive control processes may be sufficient to automatically trigger retrieval of the intended action during focal processing conditions, reliance on reactive control may be detrimental to nonfocal processing conditions thereby providing an explanation for the reported differences in prospective memory cue detection across focal versus nonfocal tasks. Consequently, it is generally assumed that the optimal processing mode for nonfocal cue detection is proactive control. This is evidenced by studies demonstrating that cost only occurs upon encountering ongoing task contexts in which cues are expected to appear, suggesting that preparatory attention (i.e., proactive control) is not necessary during contexts in which participants know cues will not appear (Knight et al., 2011; Marsh, Hicks, & Cook, 2006). However, recent ex-Gaussian fits to RT distributions in this task challenge the assumption that proactive monitoring processes are enacted continuously throughout the ongoing task, suggesting instead that these processes may be enacted more transiently (Ball, Brewer, Loft, & Bowden, 2014). Thus, ex-Gaussian analyses may provide a means to estimate proactive and reactive control processes in the context of PM.

Response Time Distribution Analyses

Analyzing RT distributions may help to better address these hypotheses regarding the regularity in which control processes are engaged to support cue detection. The ex-Gaussian function is a convolution of the Gaussian and Exponential distributions. At each time point *x*, the ex-Gaussian distribution is described by the mean (mu) and variance (sigma) of the Gaussian distribution, and the mean (and standard deviation) of the Exponential distribution (tau).

$$f(x|\mu,\sigma,\tau) = \frac{1}{\tau\sqrt{2\pi}} \exp\left(\frac{\sigma^2}{2\tau^2} - \frac{x - \mu}{\tau}\right) . \int_{-\infty}^{\left[\left(\frac{x-\mu}{\sigma}\right) - \left(\frac{\sigma}{\tau}\right)\right]} \exp\left(-\frac{y^2}{2}\right) \mathrm{dy}$$

The sum of mu and tau produces the mean of the overall distribution, and the sum of their squared standard deviations ($\text{sigma}^2 + \text{tau}^2$) produces the variance. Important for understanding the relation between ex-Gaussian parameter estimates and mean RTs, the sum of mu and tau estimates is approximately equal to the mean RT because the sum of the true values of mu and tau is equal to the true mean of the ex-Gaussian distribution. Figure 1 illustrates that an increase in mu leads to a distributional shift to the right, whereas an increase in tau leads to a positive distributional skew (see Balota & Yap, 2011 for more details on RT distribution analyses).

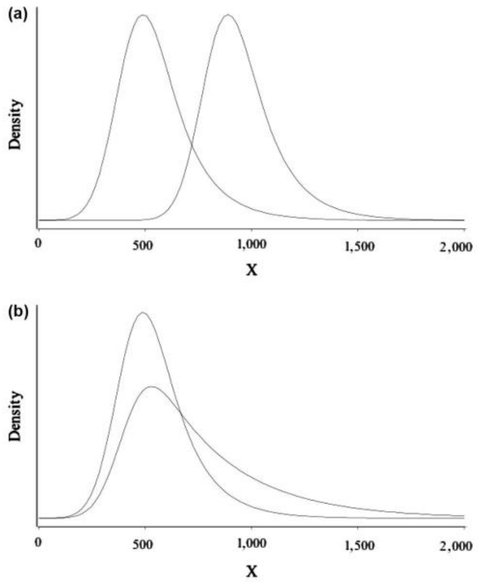

Figure 1. (a) Two hypothetical ex-Gaussian distributions with changes in mu only. (b) Two hypothetical ex-Gaussian distributions with changes in tau only.

Although it is important to note that ex-Gaussian parameters do not reflect underlying cognitive process (Matzke & Wagenmakers, 2009), previous research has suggested that these parameters are more affected by some manipulations than others. For example, interference effects due to response competition during various attention control tasks have been associated primarily with an overall shift in the RT distribution (e.g., De Jong, Berendsen, & Cools, 1999; Spieler, Balota, & Faust, 2000; Unsworth, Spillers, Brewer, & McMillan, 2011), whereas goal neglect due to periodic lapses of attention has been associated primarily with a positive skew in the tail of the distribution (e.g., Schmiedek et al., 2007; Tse et al., 2010; Unsworth et al., 2011; Unsworth, Redick, Lakey, & Young, 2010). Importantly, these findings suggest that theorizing of the underlying cognitive control processes that contribute to PM cost may be improved by disentangling these components of the RT distribution rather than simply relying on mean RT measures.

Brewer (2011) and Ball et al. (2014) recently fit the ex-Gaussian function to RTs during a LDT with a nonfocal intention. Somewhat surprisingly, RT distributions provided little evidence that the observed cost from possessing an intention was due to PM control processes that were enacted continuously throughout the task, as would be indicated by an overall shift in the distribution (i.e., mu; but see Loft, Bowden, Ball, & Brewer, 2014). Instead, ex-Gaussian analyses revealed that that cost was due entirely to an increase in the relative frequency of slow responses (tau). Based on these findings, it was suggested that in contrast to the general supposition that monitoring processes are enacted fairly continuously on a trial-by-trial basis throughout the ongoing task (e.g., Guynn, 2003; Einstein & McDaniel, 2010; Smith, 2003), cost may reflect transient moments in which the intention is sporadically brought to mind throughout the task that produces slowing on the subset of trials in which the intention is active (DeWitt, Hicks, Ball, & Knight, 2012; Einstein, McDaniel, Willifod, Pagan, & Dismukes, 2003). It is possible that participants tried to engage strategic monitoring processes but ongoing task demands displaced the intention from focal awareness. Thus, increases in tau may reflect control processes involved in periodic reactivation of the intention from long-term memory. Alternatively, the intention may be automatically reactivated via associative cueing from the ongoing task context or stimuli that stimulates engagement of control processes needed for attending to and interpreting the contextually cued retrieved intention (McDaniel & Einstein, 2000). In either case, periodic reactivation may serve keep the intention representation at an activation level that is sufficient to stimulate retrieval processes upon encountering PM cues. Importantly, these findings suggest that the monitoring processes underlying cost effects in PM may be more complex than has been previously suggested. However, because only recently have ex-Gaussian analyses been implemented to better understand the cognitive control processes involved in PM, and only under a select set of conditions, more research is needed to determine whether various portions of the RT distribution are meaningfully associated with various cognitive control processes that may facilitate PM.

CURRENT STUDIES

The results from ex-Gaussian analyses suggest that the monitoring processes underlying cost effects in PM may be more complex than has been previously suggested. However, because only recently have ex-Gaussian analyses been implemented to better understand the cognitive control processes involved in PM, and only under a select set of conditions, more research is needed to determine whether various portions of the RT distribution are meaningfully associated with various cognitive control processes that may facilitate PM. Furthermore, although the DMF framework dovetails nicely with current conceptualizations of PM, no studies to date have rigorously examined the role of proactive versus reactive control processes in the context of PM. Therefore, in Chapter 2 I use individual differences techniques in conjunction with RT distribution modeling to assess the working memory and DMC framework accounts of PM and explore the role of these processes with ex-Gaussian parameter estimates and cue detection processes. Additionally, I assess the role of other cognitive control constructs (inhibition and vigilance) to examine whether additional mechanisms may contribute to PM performance. In Chapters 3 and 4, I more directly test the DMC framework in the context of PM by assessing the role of proactive and reactive control processes on monitoring and cue detection across multiple experimental paradigms. In Chapter 3, I use quasi-experimental techniques to determine whether proactive control processes are mutable in the context of PM by examining PM conditions that place more or less demands on executive attention processes. In Chapter 4, I use neuroscience techniques (event-related potentials) to investigate the neural correlates of cue detection under conditions that promote reliance on proactive versus reactive control processes. Together, these findings will serve to provide a more complete understanding of the cognitive control processes underlying PM performance and inform extant theories of PM monitoring and cue detection.

Chapter 2

EXPERIMENT 1: OVERVIEW

Considerable research has implicated working memory as an integral process underlying successful PM retrieval (Ball, Knight, DeWitt, Brewer, 2013; Breneiser & McDaniel, 2006; Brewer et al., 2010; Marsh & Hicks, 1998; Smith & Bayen, 2005). However, PM is multifaceted and its success is likely determined by multiple cognitive processes acting in concert, or via different processes operating on different components of the PM task (i.e., intention formation, retention, initiation, and execution). Importantly, however, the majority of the extant PM research has either focused only on a single aspect of cognitive control (e.g., WMC; e.g., Breneiser & McDaniel, 2006) in PM or only assessed the role of multiple cognitive control processes in cue detection (e.g. Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010; Schnitzpahn et al., 2013). Furthermore, the studies that have examined the influence of cognitive control on PM cost have only examined mean RTs (e.g., Brewer et al., 2010). Thus, to provide a more nuanced understanding of the cognitive control processes underlying successful monitoring and cue detection, the current study implemented an individual differences approach to assess the relation between multiple cognitive control constructs, ex-Gaussian cost estimates, and cue detection.

Cognitive Control Processes in Prospective Memory

As described previously, WMC has been studied extensively in the context of PM (Ball et al., 2013; Brewer et al., 2010; Cherry & LeCompte, 1999; Marsh & Hicks, 1998; Reynolds, West, & Braver, 2009; Smith & Bayen, 2005; West, Bowry, & Kompinger, 2006). However, variation in WMC can explain differences in various lower-order cognitive processes, such as continuous performance task decrements (MacDonald et al., 2005; Redick & Engle, 2011) flanker interference and anti-saccade performance (Heitz & Engle, 2007; Unsworth, Schrock, & Engle, 2004), and psychomotor vigilance attentional lapses (Unsworth et al., 2010). Importantly, each of the aforementioned sets of tasks theoretically reflects different cognitive processes, and thus the exact mechanisms that contribute to the observed relation between WMC and PM are not entirely clear.

As described in the Introduction, the relation between proactive control and PM is largely unexplored. However, there is some evidence to suggest that inhibitory processes may be related to PM cue detection. In particular, Schnitzpahn et al. (2013) examined individual differences in inhibition, task switching, and updating and found that only the former two uniquely predicted cue detection abilities. It was suggested that inhibitory processes were needed to inhibit the prepotent response tendency of making the ongoing task, and that task-switching processes were needed to shift from the ongoing to the PM task to execute the intended action. However, the role of inhibitory processes in ongoing task latencies is unclear because the authors did not assess RTs. In regard to vigilance, it is often suggested that PM monitoring may reflect the ability to sustain attention for long durations in order for cues to be detected (Brandimonte, Ferrante, Feresin, & Delbello, 2001; Graf & Uttl, 2001; Smith, 2003). Consequently, vigilance should presumably play an important role in PM performance. Interestingly, however, research suggests that PM monitoring processes may actually be dissociated from those associated with vigilance (Brandimonte et al., 2001, 2001; Rose et al., 2010; Wang et al., 2012). It is suggested that this dissociation may occur because PM tasks are considered dual-task in nature (ongoing task + PM task), whereas vigilance tasks are considered only a single-task (ongoing task;

Graf & Uttl, 2001). Nevertheless, lapses of attention during the ongoing task may contribute to periodic missing of cues and slowing of RTs.

In regard to the current study, it was predicted that both WMC and proactive control would be associated with mu, as these processes underlie the ability to continuously maintain goal-relevant information (e.g., intention). However, because inhibition may only be needed for cue detection, and vigilance may merely reflect sustained attention to the ongoing task, these processes may not actually contribute to ongoing task latencies. In contrast, reactive control should be associated tau, as this process is associated with transient activation of stimulus-driven control that may serve to periodically reactive the intention during the ongoing task. If, however, tau merely reflects lapses of attention rather than processes associated with PM, then presumably vigilance should be associated with tau. In regard to cue detection, it is predicted that performance should be better for individuals more likely to engage continuous monitoring strategies, as this is more efficacious for nonfocal cue detection than is transient monitoring processes. Thus, cue detection should be greater for those with high in WM and proactive control. Furthermore, inhibition and vigilance should be associated with cue detection, as the prepotent response tendencies must be inhibited in service of making a PM response and sustained attention is needed to maintain focus throughout the duration of the task.

METHOD

Participants

One hundred and seventy two Arizona State University undergraduate students enrolled in an introductory psychology course participated in the study. Students received course credit for their participation in the study. Participants completed two working memory tasks (operation and reading span), two proactive control tasks (verbal and spatial AX-CPT), two inhibition tasks (antisaccade and flanker), two vigilance tasks (psychomotor vigilance and degraded mask), and two nonfocal PM task (animal and 'TOR').

Working Memory Tasks.

Operation span (Ospan). Participants solved a series of math operations while trying to remember a set of unrelated letters (F, H, J, K, L, N, P, Q, R, S, T, Y). Participants were required to solve a math operation and judge whether their answer matched either a correct or incorrect alternative (e.g. (1*2) + 1 = 3?"). After solving the operation and making their judgment, they were presented with a letter for 1 s. Participants were given feedback about the accuracy of their math operations and they had to maintain their performance level above 85%. Immediately after the letter was presented the next operation was presented. Three trials of each letter list-length (3-7) were presented, with the order of list-length varying randomly. At recall, letters from the current set were attempted to be recalled in the correct order by clicking on the appropriate letters (see Unsworth, Heitz, Schrock, & Engle, 2005). Participants received three sets (of list-length two) of practice. For all of the span measures, items were scored if the item was correct in the correct position. The score was the proportion of correct items recalled in the correct position.

Reading span (Rspan). Participants were required to read sentences while trying to remember the same set of unrelated letters as in the operation span task. For this task, participants read a sentence and determined whether the sentence made sense or not (e.g. “The prosecutor’s dish was lost because it was not based on fact. ?”). Half of the sentences made sense while the other half did not. Nonsense sentences were made by simply changing one word (e.g. “dish” from “case”) from an otherwise normal sentence. Participants were required to read the sentence and to indicate whether it made sense or not. After participants gave their response they were presented with a letter for 1 s. At recall, letters from the current set were asked to be recalled in the correct order by clicking on the appropriate letters. There were three trials of each list-length with list-length ranging from 3–7. Participants received practice on all components of the reading span task before beginning. The same scoring procedure as operation span was used.

Proactive Control Tasks

Verbal continuous performance task ($\mathbf{PC_{verb}}$). The PC_{verb} used in the current study was based on Redick and Engle (2011) as described previously. Participants used their right hand to make target responses to the letter X when it followed an A (probes on AX trials) with the right index finger and to make nontarget responses to all other stimuli that appeared (all cues and probes on AY, BX, and BY trials) with their left index finger. Letters were presented for 500 ms each, and participants had up to 1,000 ms from the onset of each letter to respond. Cues and probes were randomly determined for each nontarget. The cue–probe and intertrial intervals each lasted 1,000 ms. Participants completed practice blocks until they had achieved a mean probe accuracy of 75% before proceeding to the experimental blocks. There were a total of four experimental blocks, with a brief resting period in between each block. Within each block there were 40 cue-probe trials, with 28 AX trials (70%), 4 BX trials (10%), 4 AY trials (10%), and 4 BY trials (10%). Proactive control scores were calculated by computing the difference between proportional AX trial hits and BX trial false alarms. This measure was chosen as the dependent variable because previous research has suggested that working memory differences primarily arise for BX (and to a lesser degree, AX) trials (MacDonald et al, 2005; Redick & Engle, 2011).

Spatial continuous performance task (PC_{spat}). The procedure for the PC_{spat} was identical to the PC_{verb}. The only difference between the two tasks was that dots patterns in various spatial arrangements were used as cues and probes rather letters (see MacDonald et al., 2005 for more details). Valid cue and probe trials are displayed in Figure 2, along with several examples of invalid cue and probe trials. Target responses were required only when the valid probe was presented following the valid cue, which occurred on the majority of the trials (70%). Other than the stimuli being dot patterns, the procedure was identical to the PC_{verb}. Proactive control scores were calculated by computing the difference between proportional AX trial hits and BX trial false alarms.

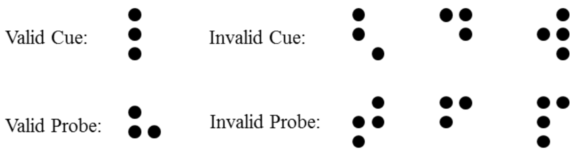

Figure 2. Examples of valid and invalid cue and probe trials during the spatial continuous performance task.

Inhibition Tasks

Antisaccade. Participants were instructed to stare at a fixation point onscreen for a variable amount of time (200-2200ms). A flashing white “=” was then flashed either to the left or right of fixation (11.33° of visual angle) for 100ms. This cue was followed by the target stimulus (a B, P, or R) onscreen for 100ms. The target was followed by masking stimuli (an H for 50ms and an 8 which remains onscreen until a response is given). The participants’ task was to identify the target letter by pressing a key for B, P, or R (the keys 1, 2, or 3). The target always appeared in the opposite location as the flashing cue. The dependent variable was the proportion of correct key presses.

Flanker. Participants were presented with a fixation point for 400ms followed by an arrow directly above the fixation point for 1700ms. Participants indicated the direction the arrow was pointing (pressing the F for left pointing arrows or pressing J for right pointing arrows) as quickly and accurately as possible. On 50 neutral trials the arrow was flanked by two horizontal lines on each side. On 50 congruent trials the arrow was flanked by two arrows pointing in the same direction as the target arrow on each side. On 50 incongruent trials the target arrow was flanked by two arrows pointing in the opposite direction as the target arrow on each side. All trial types were randomly intermixed. The dependent variable was the reaction time difference between incongruent and congruent trials.

Vigilance Tasks

Psychomotor Vigilance Task (PVT). Participants were presented with a row of zeros on screen and after a variable amount of time the zeros began to count up in 1ms intervals from 0ms. The participants’ task was to press the spacebar as quickly as possible once the numbers started counting up (roughly 75 total trials). After pressing the spacebar the response-time was left on screen for 1s to provide feedback to the participants. Interstimulus intervals were randomly distributed and ranged from 1 to 10s. The dependent variable is the number of lapses of attention (computed as RTs greater than 500 ms) throughout the task (Unsworth et al., 2010).

Degraded Mask (DGM). Participants were presented a series of degraded stimuli rapidly on a proactive control screen. A random sequence of centrally located digits, ranging from 0 to 9, were presented in monochrome. The digit “0” was designated as the target (probability = 0.25), whereas the letter “D” was the nontarget. Stimuli were presented at an even rate of one per second. Participants responded to the target and nontarget stimuli by pressing the “F” or “J” key, respectively, Instructions emphasized both response speed and accuracy. Task performance within each condition lasted for 10 minutes. The dependent variable was overall accuracy during the task.

Prospective Memory Tasks

Animacy Judgment Task (AJT). For the animacy judgment task (AJT), participants decided on each trial whether the presented word was living (e.g., fish) or not living (e.g., table). During the practice, control (prior to intention formation), and experimental (following intention formation) blocks there were 30, 70, and 210 trials, respectively, half of which were living and half of which were non-living. The 310 separate words were chosen from the Kucera and Francis (1967) norms. All of these stimuli were randomly assigned to a trial position within the experimental sequence for each participant tested. After this randomization, the software randomly assigned eight prospective memory cues to trials 25, 50, 75, etc. through trial 200. Each of the cues contained the syllable “tor” (e.g., doctor) and were chosen from the MRC database (Coltheart, 1981).

Participants read instructions for the experiment from the computer monitor. Ongoing task instructions for the practice, control, and experimental blocks informed participants that they were to respond (using the F and J keys) according to whether or not the word on a trial was living or not living. After each decision was made, a *waiting* message would appear to indicate to the participants to press the spacebar to continue to the next trial. After receiving instructions for the AJT, participants performed a 30 trial practice block followed immediately by a 70 trial control block. Following completion of the control block, participants were informed that in a few minutes they would AJT again. Additionally, they were instructed that if at any point during the AJT they encounter a word containing the syllable “tor”, they should make their animacy judgment per usual but then press the “/” during the waiting message instead of pressing the spacebar. After participants acknowledged that they understood the task instructions, they performed a 10-minute antisaccade task prior to beginning the experimental block so that the intention was not fully active when the experimental AJT was administered. Following completion of the 210 trial experiment AJT block participants were queried for their memory of the PM instructions. Participants that were unable to describe the nature of PM intention were excluded from all analyses, as this reflects a retrospective memory error rather than a PM error. Dependent variables included the proportion of cues detected, mean RT cost (experimental RT – control RT), mu cost (experimental mu – control mu), and tau cost (experimental tau – control tau). Derivation of ex-Gaussian parameter estimates are described below.

Syllable Judgment Task (SJT). The procedure for the SJT with an “animal” intention (e.g., horse) was nearly identical to the AJT. For the SJT task, participants decided on each trial whether the presented words contained one (e.g., hat) or two (e.g., peanut) syllables. For the practice, control, and experimental blocks, 310 words (not used in the AJT) were chosen from the Kucera and Francis (1967) norms. Following completion of the control block, participants were informed that they would later again perform the SJT and that if at any point during the subsequent SJT they encounter a word that denoted an animal (e.g., horse), they should make their syllable judgment per usual but then press the “/” during the waiting message instead of pressing the spacebar. After participants acknowledged that they understood the task instructions, they performed a 10-minute flanker task (described above) prior to beginning the experimental block so that the intention was not fully active when the experimental SJT was administered. Following completion of the 210 trial experimental SJT participants were queried for their memory of the PM instructions. Participants that were unable to describe the nature of PM intention were excluded from all analyses. The dependent variables included the proportion of cues detected, mean RT cost (experimental RT – control RT), mu cost (experimental mu – control mu), and tau cost (experimental tau – control tau). Derivation of ex-Gaussian parameter estimates are described below.

Response time analyses. Only correct (non-cue) trials within 2.5 standard deviations of each participant’s mean were included for the analyses. I also excluded the two trials following cue presentation in the experimental blocks because participants may have been still been engaging cue-related processes during these trials (e.g., Meier & Rey-Mermet, 2012). RTs were analyzed by calculating mean RTs during the ongoing task for each participant, separately for control and experimental blocks for both PM tasks. Ex-Gaussian analyses were performed on the same RTs using Quantile Maximum Probability Estimation (QMPE) software (Heathcote, Brown, & Cousineau, 2004) to obtain parameters estimates for each participant that best produced the observed data. Estimates of mu, sigma, & tau were derived separately for control and experimental blocks for each participant using the maximum possible number of quantiles (N-1). Acceptable model fits were obtained within 30 iterations for all participants.

RESULTS

Cognitive Control and Prospective Memory Measures

Descriptive statistics for each of the measures can be found in Table 1. Correlations between the each of the cognitive control measures, cue detection measures, and RT cost measures can be found in Table 2. As can be seen, performance across all measures within a construct was positively correlated, and generally correlations within a construct are more strongly correlated than measures across constructs. Given the positive correlations of measures within a construct, principal component analyses were separately performed on the two measures for each construct.

Table 1.

Descriptive Statistics for all Cognitive Control and Prospective Memory Tasks

	Mean	SE Mean	Min	Max	Skew	Kurtosis
WMC$_{OS}$	59.31	1.01	10.00	75.00	-1.42	2.08
WMC$_{RS}$	54.54	.80	21.00	74.00	-.58	.35
PC$_{VERB}$	2.60	.08	-.05	4.69	.10	-.43
PC$_{SPAT}$	2.56	.08	-1.03	4.69	-.35	.40
INH$_{ANTI}$	.65	.01	.32	.95	-.16	-.80
^{a}INH$_{FLK}$	-77.66	3.24	-17.94	220.73	.76	1.01
^{a}VIG$_{PVT}$	-11.66	.72	-45.00	0.00	-1.03	.67
VIG$_{DGM}$	.63	.01	.10	.98	-.58	-.16
PM$_{SJT}$	.56	.02	0.00	1.00	-.54	-.85
PM$_{AJT}$	.66	.02	0.00	1.14	-.81	-.06
IT$_{SJT}$	-3.01	8.45	-383.58	224.36	-.48	.48
IT$_{AJT}$	236.57	10.83	-168.36	688.62	.54	.90
MU$_{SJT}$	-.50	4.83	-237.53	157.24	-.30	.75
MU$_{AJT}$	84.25	5.31	-62.86	304.95	.83	1.00
TAU$_{SJT}$	-3.94	7.16	-345.47	207.07	-.68	1.51
TAU$_{AJT}$	151.54	8.85	-220.37	512.03	.36	1.47

Note. WMC = working memory capacity; proactive control = proactive control; INH = inhibition; VIG = vigilance; PM = prospective memory; IT = task interference (mean RT cost); MU = mu cost; TAU = tau cost. ^{a} INH$_{FLK}$ and VIG$_{PVT}$ were reverse scored such that higher values reflect more efficient processing.

Table 2**.**

Correlations between Cognitive Control and Prospective Memory Tasks

	WMC$_{OS}$	WMC$_{RS}$	PC$_{VERB}$	PC$_{SPAT}$	INH$_{ANTI}$	INH$_{FLK}$	VIG$_{PVT}$	VIG$_{DGM}$	PM$_{SJT}$	PM$_{AJT}$	IT$_{SJT}$	IT$_{AJT}$	MU$_{SJT}$	MU$_{AJT}$	TAU$_{SJT}$	TAU$_{AJT}$
WMC$_{OS}$	1.00															
WMC$_{RS}$	.52**	1.00														
PC$_{VERB}$	.31**	.17*	1.00													
PC$_{SPAT}$	.27**	.09	.59**	1.00												
INH$_{ANTI}$	.29**	.28**	.32**	.36**	1.00											
INH$_{FLK}$	.11	.14	.08	.14	.25**	1.00										
VIG$_{PVT}$	.18*	.05	.41**	.60**	.44**	.18*	1.00									
VIG$_{DGM}$	.12	-.03	.30**	.47**	.30**	.13	.47**	1.00								
PM$_{SJT}$	.25**	.24**	.20*	.23**	.23**	.19*	.22**	.08	1.00							
PM$_{AJT}$	.27**	.18*	.24**	.17*	.18*	.13	.12	.22**	.32**	1.00						
IT$_{SJT}$	.19*	.21**	.15*	.12	.19*	.10	.07	.03	.29**	.05	1.00					
IT$_{AJT}$	.04	.09	.05	-.02	.13	.02	-.03	.13	.18*	.27**	.32**	1.00				
MU$_{SJT}$	.15*	.14	.22**	.08	.13	.18*	.13	.03	.26**	.10	.56**	.25**	1.00			
MU$_{AJT}$	.19*	.18*	.22**	.17*	.18*	.12	.12	.07	.17*	.37**	.26**	.58**	.22**	1.00		
TAU$_{SJT}$	.12	.17*	.04	.09	.13	.00	-.01	.01	.18*	.00	.82**	.21**	-.02	.16*	1.00	
TAU$_{AJT}$	-.07	.00	-.07	-.13	.05	-.05	-.12	.11	.12	.11	.22**	.87**	.17*	.11	.15*	1.00

Note. WMC = working memory capacity; proactive control = proactive control; INH = inhibition; VIG = vigilance; PM = prospective memory; IT = task interference (mean RT cost); MU = mu cost; TAU = tau cost.

Individual Differences in Prospective Memory Performance

Correlations between the individual differences constructs, overall cue detection, and RT cost measures of interest can be found in Table 3. As can be seen, all cognitive control constructs were positively correlated with cue detection and not correlated with tau. In contrast, only certain cognitive control constructs were positively correlated with mean RT and mu cost. Thus, I performed a series of regression analyses to understand the unique role of these various cognitive control processes in PM monitoring and cue detection.

Table 3.
Correlations between Cognitive Control and Prospective Memory Constructs

	WMC	PC	INH	VIG	PM	IT	MU	TAU
WMC	1.00							
PC	$.27^{**}$	1.00						
INH	$.30^{**}$	$.32^{**}$	1.00					
VIG	.11	$.58^{**}$	$.39^{**}$	1.00				
PM	$.33^{**}$	$.29^{**}$	$.29^{**}$	$.23^{**}$	1.00			
IT	$.19^{*}$	.11	$.17^{*}$	.07	$.30^{**}$	1.00		
MU	$.24^{**}$	$.25^{**}$	$.25^{**}$	.13	$.35^{**}$	$.65^{**}$	1.00	
TAU	.08	-.03	.05	.00	$.17^{*}$	$.86^{**}$	$.18^{*}$	1.00

Note. WMC = working memory capacity; proactive control = proactive control; INH = inhibition; VIG = vigilance; PM = prospective memory; IT = task interference (mean RT cost); MU = mu cost; TAU = tau cost.

Cue Detection. The relation between the cognitive control constructs and cue detection was examined first. As mentioned previously, all constructs were positively correlated with cue detection (Table 3). However, a simultaneous regression analysis of PM performance on the cognitive control constructs ($R^2 = .179$, $F(4,164) = 8.94$, $p < .001$) revealed that only WMC uniquely predicted cue detection (Table 4). Thus, individuals with higher WMC detected more PM cues after controlling for other variables in the model.

Table 4.
Regression of Cue Detection on Cognitive Control Constructs

IV	**B**	**SE(B)**	***β***	***t***	***p***
WMC	.248	.08	.248	3.25	.001
PC	.134	.09	.134	1.49	.138
INH	.146	.08	.146	1.82	.071
VIG	.069	.09	.069	.76	.450

Mean RT cost. Next, the relation between the cognitive control constructs and mean RT cost was examined. As can be seen in Table 3, only WMC and inhibition were positively correlated with mean RT cost. However, a simultaneous regression analysis of mean RT cost on the cognitive control constructs ($R^2 = .05$, $F(4,164) = 2.16$, $p = .076$) revealed that none of the cognitive control constructs uniquely predicted cost (Table 5). Thus, the various cognitive control constructs did not account for a significant proportion of variance in mean RT cost, and none of the constructs were uniquely predictive of cost.

Table 5.
Regression of Mean Reaction Time Cost on Cognitive Control Constructs

IV	**B**	**SE(B)**	***β***	***t***	***p***
WMC	.143	.08	.143	1.75	.082
PC	.036	.10	.036	.37	.711
INH	.119	.09	.119	1.39	.167
VIG	-.012	.10	-.012	-.12	.903

Mu cost. Next, the relation between the cognitive control constructs and mu cost was examined. As can be seen in Table 3, WMC, proactive control, and inhibition were all positively correlated with mu cost. However, a simultaneous regression analysis of mu cost on the cognitive control constructs ($R^2 = .116$, $F(4,164) = 5.38$, $p < .001$) revealed only proactive control and inhibition uniquely predicted cost (Table 6). Thus, individuals higher in proactive control and inhibition, were more likely to exhibit greater mu cost after accounting for other variables in the model.

Table 6.

Regression of Mu Cost on Cognitive Control Constructs

IV	B	SE(B)	*β*	*t*	*p*
WMC	.148	.08	.148	1.87	.064
PC	.185	.09	.185	1.98	.049
INH	.168	.08	.168	2.02	.045
VIG	-.054	.09	-.054	-.57	.570

Tau cost. I next examined the relationship between the cognitive control constructs and tau cost. As can be seen in Table 3, none of the cognitive control constructs were associated with tau. Accordingly, a simultaneous regression analysis of tau cost on the cognitive control constructs ($R^2 = .012$, $F < 1$) revealed that none of the cognitive control constructs uniquely predicted cost (Table 7). Thus, the various cognitive control constructs did not account for a significant proportion of variance in tau cost, and none of the constructs were uniquely predictive of cost.

Table 7.

Regression of Tau Cost on Cognitive Control Constructs

IV	B	SE(B)	*β*	*t*	*p*
WMC	.088	.08	.088	1.06	.293
PC	-.072	.10	-.072	-.73	.465
INH	.045	.09	.045	.51	.609
VIG	.015	.10	.015	.15	.880

Supplemental Analyses

Somewhat surprisingly, there was no evidence of cost during the syllable judgment PM task (see Table 1). Thus, although the correlations between PM measures across both PM tasks were positive, it is possible that the previous results are masking task specific effects. Therefore, I reran the regression analyses separately for each PM task. Importantly, correlations between the composite cognitive control constructs and PM measures were similar across both tasks (as is somewhat apparent in Table 2), although slightly attenuated relative to the composite PM measures. Furthermore, the regression analyses run separately for each task were similar to the composite analyses. In particular, WMC was predictive of cue detection across both tasks. Furthermore, proactive control and inhibition were positively associated with mu across both tasks (although these effects were only marginal). The primary difference across the two tasks was that in the SJT, but not the AJT, inhibition was additionally predictive of cue detection and WMC was predictive of mean RT cost, which likely contributed to the marginal effects seen in the composite analyses for these variables. Nevertheless, these findings suggest that although there was no cost in the SJT, those that exhibited greater cost (in mean RT and mu) also tended to demonstrate more cost in the AJT. Furthermore, the cognitive control processes that contributed to cue detection and cost were similarly implemented across tasks.

DISCUSSION

The majority of extant research has concerned elucidating the cognitive control processes involved in cue detection, primarily investigating the role of working memory in successful noticing of the cue and retrieval of the intended action (Ball et al., 2013; Breneiser & McDaniel, 2006; Smith & Bayen, 2005, 2006). However, PM is multifaceted and likely relies on numerous control processes, not only for successfully detecting cues, but also maintenance of the intention and ongoing task instructions, target checking, and coordinating between the ongoing and PM task – all of which likely produce cost to ongoing task performance. Thus, the current study sought to examine the role of multiple cognitive control processes in both monitoring and cue detection using ex-Gaussian analyses to provide a more nuanced understanding of the regularity in which these control processes were enacted.

Consistent with previous research, WMC was positively correlated with proactive control (Redick et al., 2011), inhibition (Unsworth et al., 2011), and vigilance (Unsworth et al., 2010). Furthermore, each of these constructs was positively correlated with cue detection. Interestingly, however, only WMC uniquely predicted variation in cue detection. Although a positive relationship between WMC and PM is not particularly surprising (e.g., Brewer et al., 2010), this finding is inconsistent with previous studies demonstrating that inhibition is predictive of cue detection after controlling for individual differences in WMC (e.g., Kliegel et al., 2000; Schnitzspahn et al., 2013). Notably, in the study by Schnitzpahn et al. participants were instructed to make their PM response *instead* of the ongoing task response, whereas participants in the current study first made their ongoing task response followed by their PM response during the waiting message. Although in the current study one must still inhibit the dominant response during the waiting message (i.e., spacebar) and remember to make a PM response, inhibition may be relatively less important in actual cue detection with the given of procedure (see Bisiacchi, Schiff, Ciccola, & Kliegel, 2009). In any manner, it likely the case that the unique relationship found between WMC and cue detection may reflect long-term memory processes associated with remembering the intention or processes associated with task switching. That is, individuals with higher WMC may be better able to remember the contents of the intention after a delay (Ball et al., 2013) or switch from the ongoing task to the PM task to engage in execution of the intended action (Brom & Kliegel, 2014; Schnitzspahn et al., 2013). Future work is needed to investigate this further.

In regard to monitoring, it was found that both proactive control and inhibition uniquely predicted variation in mu cost. Proactive control is often studied in tasks that produce response conflict (e.g., Simon or Stroop task; Blais, Harris, Guerrero, & Bunge, 2012; Bugg et al., 2011) that requires inhibition of automatic response tendencies (e.g., word reading in Stroop task). In this regard, it is not necessarily surprising that both proactive control and inhibition were related to mu cost. However, the fact that both constructs uniquely predicted cost suggests that there may be two distinct processes associated with monitoring costs. Presumably, proactive control reflects continuous maintenance of a prospective retrieval mode that serves to treat incoming stimuli as potential cues (Guynn, 2003), whereas inhibition reflects processes associated with inhibiting the prepotent ongoing task response in order to engage target checking processes. Importantly, both of these processes should reduce the possibility of accidentally missing cues by producing slowing on all trials to engage appropriate target checks.

Somewhat surprisingly, none of the cognitive control constructs were predictive of tau cost. Given that vigilance is associated with sustained attention across long durations (Graf & Uttl, 2001), it was expected that vigilance may be negatively associated with tau (Unsworth et al., 2010). This finding, in conjunction with the fact the tau was positively correlated with cue detection, suggests that increases in tau may not reflect lapses of attention. However, it was also predicted that proactive control would be negatively correlated with tau cost, as reactive control processes involve reducing interference following stimulus onset (Braver, 2012). Thus, certain stimuli (e.g., words containing the phoneme “OR”) may produce fluency/discrepancy that may stimulate reactive target checks that produce slowing on a subset of trials. However, there was no relationship found between reactive control and tau. The exact reasoning behind the null relationship between tau cost and the various cognitive control constructs is not entirely clear. However, it is likely the case that the RTs in the tail of the distribution reflect a combination of both PM-specific and PM-independent processes, which may explain the relatively small correlation (*r* = .15) between tau across both PM tasks. That is, the positive correlation between tau cost and PM suggests that slower RTs may reflect PM related process (e.g., target checking) that benefits cue detection, but lapses of the entire task set (i.e., ongoing task + PM task) may also produce slowing in the tail of the distribution that actually hampers cue detection.

Chapter 3

EXPERIMENTS 2A AND 2B: OVERVIEW

The DMC framework posits that various situational and individual differences factors produce biases in reliance on proactive and reactive control processing modes in various cognitive control tasks (Braver, 2012). Importantly, these same factors likely influence reliance on various processing strategies in the context of PM. However, because no previous studies have investigated the relation between proactive control abilities and PM performance, it is not entirely clear under what conditions proactive versus reactive control strategies may serve to optimize PM performance. Furthermore, it is not clear whether proactive control strategies are mutable in the context of PM tasks, or if capacity limitations (or other important factors) prevent engagement of strategic monitoring processes in those low in proactive control abilities. Thus, the purpose of current set of studies is to extend the results of Experiment 1 by comparing PM performance between high and low proactive control participants on tasks that do or do not encourage reliance on strategic monitoring processes.

EXPERIMENT 2A

The findings from Experiment 1 suggest that proactive control may be an important predictor of whether or not participants engage continuous monitoring processes to support PM retrieval. Thus, in Experiment 2A I sought to examine whether encoding instructions could increase reliance on more efficacious monitoring strategies in low proactive control participants. Previous research has demonstrated that emphasizing the importance of the PM intention facilitates subsequent cue detection relative to standard encoding instructions under conditions that require strategic monitoring processes (Kliegel, Martin, McDaniel, & Einstein, 2001, 2004). However, this comes at a cost to ongoing task processing (i.e., slower responding). These findings suggest that importance may increase reliance on more continuous monitoring processes. Consequently, importance instructions may serve to increase cue detection for low proactive control participants, presumably via reliance on more continuous monitoring processes. However, if high proactive control participants are already engaging continuous monitoring processes, importance instructions should have little influence on cue detection or cost measures.

METHOD

Participants

Two hundred and seventy Arizona State University undergraduate students enrolled in an introductory psychology course participated in the study. Students received course credit for their participation in the study. Participants were randomly assigned to the standard (N = 131) or importance (N = 139) PM encoding conditions. All participants completed two proactive control tasks (verbal and spatial AX-CPT) and either version of the nonfocal PM task.

Materials and Procedure

All participants first performed the PM task (standard or importance), followed by the verbal and spatial proactive control tasks.

Proactive control tasks. The materials and procedure for the proactive control tasks (verbal and spatial AX-CPT) were identical to Experiment 1.

Prospective memory task. The materials and procedure for the PM task were identical to the animacy judgment PM task (‘TOR’ intention) used in Experiment 1, except that between the control and experimental blocks participants instead performed a brief (1-2 minute) questionnaire as a distractor task. The only difference between the two PM conditions was that following the standard PM instructions, participants in the importance condition were additionally instructed that performance on the PM task (i.e., detecting cues) was more important than doing well on the ongoing task performance (Kliegel et al., 2001).

Response time analyses. RT analyses were identical to those of Experiment 1. RTs were analyzed by calculating mean RTs during the ongoing task for each participant, separately for the control and experimental nonfocal PM.

RESULTS

Proactive Control

Performance on the two continuous performance tasks was positively correlated in both the standard ($r = .604$, $p < .001$) and importance ($r = .576$, $p < .001$) conditions. Thus, a principal component analysis was separately run for each condition on the two proactive control tasks to form composite scores for the proactive control construct.

Individual Differences in Prospective Memory

For the subsequent analyses, PM variables of interest were separately submitted to a univariate analysis of covariance (ANCOVA) with condition (standard vs. importance) as a between-subjects variable and proactive control ability entered as a covariate. All analyses were conducted on the entire set of participants. However, in the case of any significant interactions with proactive control ability, subsequent analyses were conducted on a subset of participants that fell in the upper (high) and lower (low) 25% of the proactive control ability distribution for each condition (for visual purposes, these data are plotted for each analyses conducted).

Cue detection. The analysis of mean cue detection (Figure 3) revealed an effect condition, *F*(1,266) = 12.84, $p < .001$, $\eta_p^2 = .046$, with better performance in the importance (*M* = .81, *SE* = .02) than standard (*M* = .72, *SE* = .02) condition. There was also an effect of proactive control ability, *F*(1,266) = 16.85, $p < .001$, $\eta_p^2 = .06$, with better performance for those with higher proactive control abilities. However, the interaction of condition and proactive control ability was not significant, *F*(1,266) = 1.15, $p = .286$, $\eta_p^2 = .004$.

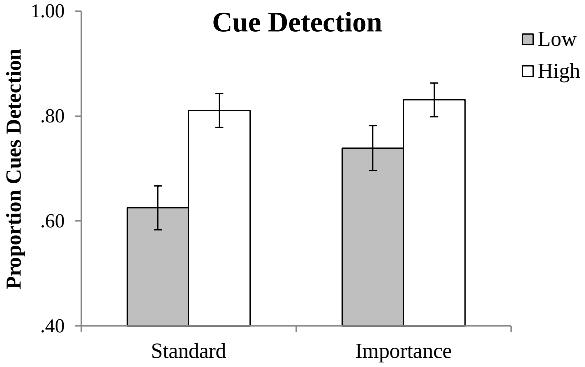

Figure 3. Proportion of cues detected in Experiment 2A as a function of condition and proactive control ability.

Mean RT cost. The analysis of mean RT (Figure 4) cost failed to reveal any significant effects, *F*’s < 2.52, p’s > .113.

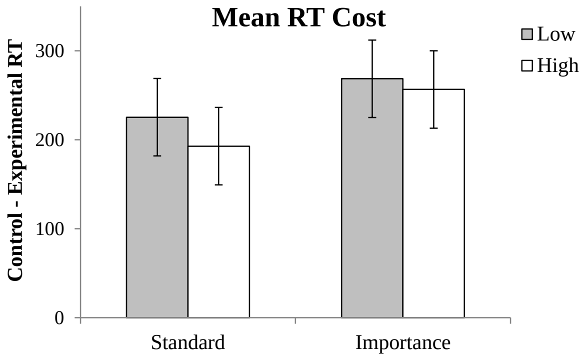

Figure 4. Mean reaction time cost in Experiment 2A as a function of condition and proactive control ability.

Mu Cost. The analysis of mean mu cost (Figure 5) revealed an effect condition, *F*(1,266) = 12.19, p = .001, η_p^2 = .044, with higher mu in the importance (*M* = 79, *SE* = .02) than standard (*M* = 46, *SE* = .02) condition. However, there was no effect of proactive control ability and no interaction of condition and proactive control ability, *F*'s < 1.5, p's > .259.

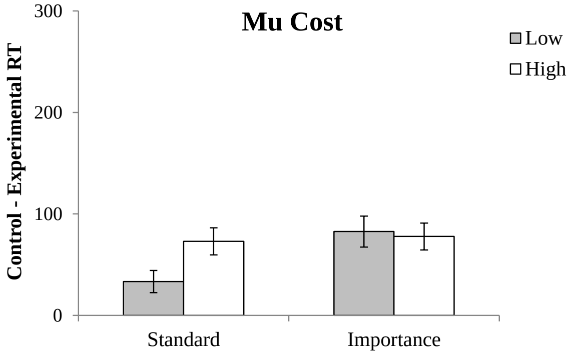

Figure 5. Mean mu cost in Experiment 2A as a function of condition and proactive control ability.

Tau Cost. The analysis of mean tau cost (Figure 6) revealed no effect of condition and no effect of proactive control ability, *F*'s < 2.41, p's > .123. However, there was a marginal interaction of condition and proactive control ability, *F*(1,266) = 3.38, p = .067, η_p^2 = .013. This interaction primarily reflects that while there were no tau differences between low and high proactive control participants in the importance condition, *F* < 1, low proactive control participants exhibited more tau cost than high proactive control participants in the standard condition, $F(1,64) = 4.82$, $p = .032$, $\eta_p^2 = .07$.

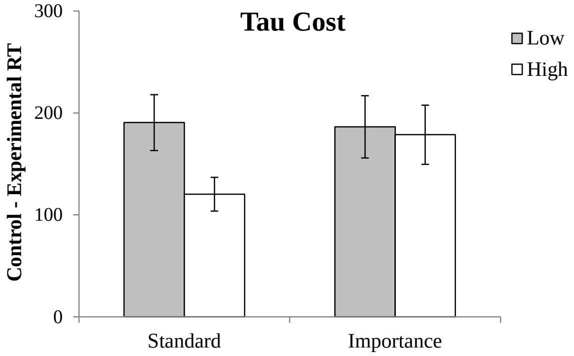

Figure 6. Mean tau cost in Experiment 2A as a function of condition and proactive control ability.

DISCUSSION

The results from Experiment 2A are consistent with previous research demonstrating that importance instructions increase cue detection (Kliegel et al., 2001, 2004). Somewhat surprisingly, however, the increase in cue detection as a result of importance instructions did not come at a cost to mean RTs during the experimental block. However, ex-Gaussian analyses showed that importance instructions actually served to increase mu (but not tau) cost relative to standard encoding instructions. Interestingly, while mu cost was positively correlated with cue detection ($r = .302$, $p < .001$), tau cost was not ($r = .014$, $p = .815$). Together with the finding that importance instructions eliminated the differences in tau between low and high proactive control participants, these findings suggest that importance instructions may serve to increase reliance on more continuous monitoring processes that serves to optimize cue detection.

These findings also highlight the importance of implementing ex-Gaussian analyses in the context of PM tasks.

EXPERIMENT 2B

Experiments 1 and 2A demonstrated that proactive control processes may be important in engaging continuous monitoring processes that contributes to cue detection. However, reliance on continuous monitoring processes may not always be efficacious, particularly under conditions that do not require costly monitoring processes. Thus, Experiment 2B sought to examine to role of proactive control abilities on cue detection and cost during focal and nonfocal processing conditions. Importantly, previous research has demonstrated that during focal processing conditions cue detection can occur without the engagement of costly cognitive control processes (Einstein & McDaniel, 2005). That is, high levels of cue detection can occur without cost to ongoing task performance due to spontaneous retrieval processes. Thus, presumably there should be no differences in cue detection between high and low proactive control participants during focal processing conditions. However, if high proactive control participants are unable to regulate their monitoring strategies and continue to engage continuous monitoring processes, these individuals may be more likely to exhibit mu cost despite that fact that strategic monitoring is unnecessary.

METHOD

Participants

One hundred and sixty seven Arizona State University undergraduate students enrolled in an introductory psychology course participated in the study. Students received course credit for their participation in the study. All participants completed two proactive control tasks (verbal and spatial AX-CPT), one nonfocal PM task, and one focal PM task.

Materials and Procedure

All participants first performed the practice and control phase of the PM task, followed by the two experimental blocks of the PM tasks (the order of which were counterbalanced across participants), followed by the verbal and spatial proactive control tasks. For example, a participant would perform the tasks in the following order: PM practice phase, PM control block, questionnaire 1, nonfocal PM experimental block, questionnaire 2, focal PM experimental block, verbal AX-CPT, spatial AX-CPT. Upon completion of the first experimental PM block, participants were given instructions for the new PM task and told that the previous intention was no longer important.

Proactive control tasks. The materials and procedure for the proactive control tasks (verbal and spatial AX-CPT) were identical to Experiment 2A.

Prospective memory practice and control blocks. The materials and procedure for the practice phase and control block of the PM were identical to those used in the standard condition of Experiment 2A.

Nonfocal prospective memory (experimental block). The materials and procedure for the experimental block of the nonfocal PM task were identical to the standard condition of Experiment 2A.

Focal prospective memory (experimental block). The materials and procedure were nearly identical to that of the nonfocal condition, except instead of the “TOR” intention participants were instructed to press the “/” key any time the words “packet” or “dancer” appeared during the focal experimental block. For the experimental block, 210 words (not used in the practice, control, or experimental nonfocal blocks) were chosen from the Kucera and Francis (1967) norms.

Response time analyses. RT analyses were identical to those of Experiment 2A. RTs were analyzed by calculating mean RTs during the ongoing task for each participant, separately for the control, experimental nonfocal PM, and experimental focal PM blocks of the PM task.

RESULTS

Proactive Control

Performance on the two continuous performance tasks was positively correlated ($r = .630$, $p < .001$). Thus, a principal component analysis was performed on the two proactive control tasks to form composite scores for the proactive control construct.

Individual Differences in Prospective Memory

For the subsequent analyses, PM variables of interest were separately submitted to a repeated measures analysis of covariance (ANCOVA) with PM task (nonfocal vs. focal) as a within-subjects variable and proactive control ability entered as a covariate. All analyses were conducted on the entire set of participants. However, in the case of any significant interactions with proactive control ability, subsequent analyses were conducted on a subset of participants that fell in the upper (high) and lower (low) 25% of the proactive control ability distribution for each condition (for visual purposes, these data are plotted for each analyses conducted).

Cue detection. The analysis of mean cue detection (Figure 7) revealed an effect of PM task, $F(1,165) = 67.48$, $p < .001$, $\eta_p^2 = .290$, with better performance in the focal (*M* = .77, *SE* = .02) than nonfocal (*M* = .92, *SE* = .01) condition. There was also an effect of proactive control ability, $F(1,165) = 7.78$, $p = .006$, $\eta_p^2 = .045$, with better performance for those with higher proactive control abilities. However, the interaction of condition and proactive control ability was not significant, $F < 1$.

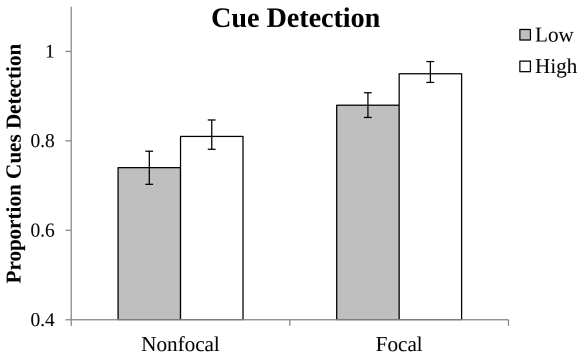

Figure 7. Proportion of cues detected in Experiment 2B as a function of prospective memory tasks and proactive control ability.

Mean RT cost. The analysis of mean RT cost (Figure 8) revealed an effect of PM task, $F(1,165) = 232.32$, $p < .001$, $\eta_p^2 = .585$, with more cost in the nonfocal (*M* = 165, *SE* = 10) than focal (*M* = 37, *SE* = 9) task. As might be expected, cost reliably differed from zero in the nonfocal condition, $F(1,165) = 285.61$, $p < .001$, $\eta_p^2 = .632$. Somewhat surprisingly, however, there cost also reliably differed from zero in the focal condition,

$F(1,165) = 18.77$, $p < .001$, $\eta_p^2 = .102$. However, there was no effect of proactive control ability on cost, $F(1,165) = 2.21$, $p = .139$, and only a nominal interaction of PM task and proactive control ability, $F(1,165) = 2.88$, $p = .091$.

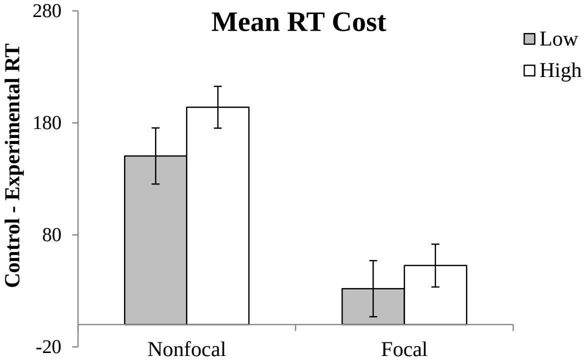

Figure 8. Mean reaction time cost in Experiment 2B as a function of prospective memory tasks and proactive control ability.

Mu Cost. The analysis of mean mu cost (Figure 9) revealed an effect of PM task, $F(1,165) = 232.32$, $p < .001$, $\eta_p^2 = .585$, with more cost in the nonfocal ($M = 41$, $SE = 5$) than focal ($M = -5$, $SE = 4$) PM task. As might be expected, this cost reliably differed from zero in the nonfocal condition, $F(1,165) = 66.21$, $p < .001$, $\eta_p^2 = .286$. However, cost did not reliably differed from zero in the focal condition, $F(1,165) = 1.29$, $p = .258$. Although there was no effect of proactive control ability on cost, $F(1,165) = 1.94$, $p = .165$, there was a significant interaction of PM task and proactive control ability, $F(1,165) = 19.24$, $p < .001$, $\eta_p^2 = .104$. To explore this interaction, I compared performance between participants following in the upper and lower 25% of the proactive control ability distribution.

To explore the interaction of PM task and proactive control ability, mean mu cost was submitted to a 2 (PM task: nonfocal vs. focal) x 2 (PC: high vs. low) mixed-factorial ANOVA. Similar to the unrestricted analysis, this analysis revealed an effect of PM task, *F*(1,80) = 77.87, $p < .001$, $\eta_p^2 = .493$, with more cost in the nonfocal than focal PM task. Although there was no effect of proactive control ability, *F*(1,80) = 1.58, $p = .213$, there was a significant interaction of PM task and proactive control ability, *F*(1,80) = 13.54, $p < .001$, $\eta_p^2 = .145$. This interaction primarily reflects that while high proactive control ability participants exhibited more cost than low proactive control participants in the nonfocal condition, *F*(1,80) = 6.83, $p = .011$, $\eta_p^2 = .079$, there were no cost differences between high and low proactive control participants in the focal condition, $F < 1$. Furthermore, cost did not reliably differ from zero for either group in the focal condition, $F < 1$.

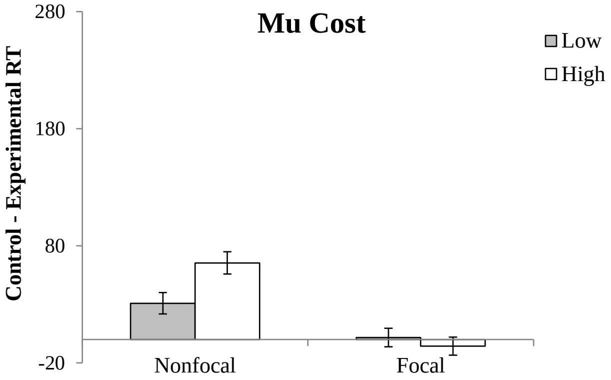

Figure 9. Mean mu cost in Experiment 2B as a function of prospective memory tasks and proactive control ability.

Tau Cost. The analysis of mean tau cost (Figure 10) revealed an effect of PM task, *F*(1,165) = 145.63, $p < .001$, $\eta_p^2 = .471$, with more cost in the nonfocal (*M* = 123, *SE* = 9) than focal (*M* = 39, *SE* = 8) PM task. As might be expected, cost reliably differed from zero in the nonfocal condition, *F*(1,165) = 199.49, $p < .001$, $\eta_p^2 = .546$. Additionally, cost reliably differed from zero in the focal condition, *F*(1,165) = 25.02, $p < .001$, $\eta_p^2 = .131$. This finding suggests that the mean RT cost in the focal condition was primarily due increases in tau. However, there was no effect of proactive control ability on cost, *F*(1,165) = 2.21, p = .139, and no interaction of PM task and proactive control ability, *F*'s < 1.

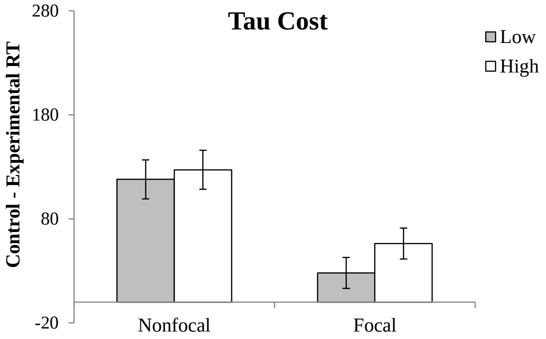

Figure 10. Mean tau cost in Experiment 2B as a function of prospective memory tasks and proactive control ability.

DISCUSSION

The results from Experiment 2B are generally consistent with those from Experiment 2A. High proactive control individuals were more successful at detecting cues than were low proactive control participants. Furthermore, high proactive control participants were more likely to engage continuous monitoring processes in the nonfocal cue condition, as evidenced by greater mu relative to low proactive control participants. Additionally, in the nonfocal cue condition mu was positively correlated with cue detection (*r* = .172, p = .026), but tau was not (*r* = .078, p = .316). These findings again suggest that proactive control processes may be beneficial for engaging continuous monitoring processes to support cue detection during nonfocal processing conditions. Importantly, however, high proactive control participants did not appear to inappropriately engage continuous monitoring processes during the focal processing condition. Although there was cost in the focal condition (which likely has to do with the number of cues[1] and the counterbalancing procedure), this cost was due entirely to increases in tau. These findings suggest that high proactive control participants are able to appropriately disengage continuous monitoring processes under scenarios that do not require costly monitoring.

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[1] Typically during focal processing conditions participants are given only a single PM cue (e.g., packet). However, in the current study I instructed participants to respond to two PM cues (e.g., packet and dancer). This was done because in the nonfocal condition, replicating the previous studies four of the "TOR" cues were living (e.g., doctor), whereas four of the "TOR" cues were nonliving (e.g., tractor). Thus, I did not want participants in the focal condition to increase processing for only a single item type (e.g., living things) and the expense of the other item type (e.g., nonliving) if the only cue that was to appear was something living (e.g., dancer).

Chapter 4

EXPERIMENTS 3A AND 3B: OVERVIEW

Each of the previous studies examined how individual differences in proactive control abilities affects reliance on continuous versus transient monitoring processes and whether or not certain experimental manipulations (i.e., importance instructions, focal versus nonfocal PM) could change the type of processing that is implemented to support cue detection. However, while ex-Gaussian analyses can be used to infer the regularity in which control processes enacted, they do not provide any information on the retrieval processes that are enacted upon encountering cues. Thus, the purpose of Experiments 3A and 3B was examine the behavioral consequences and neural correlates of cue detection, within the same individual, across ongoing task contexts that affect reliance on proactive versus reactive control processes.

One task that has been used to bias reliance on proactive versus reactive control processes is a modified version of the Simon Task in which proportion congruency is context specific (e.g., Blais & Bunge, 2010). In the modified Simon Task, the letter X or O is presented in one of four locations (top-left, top-right, bottom-left, or bottom-right) and participants are to press the left button when an X appears and the right button when an O appears. Half of the trials are congruent where the stimulus is consistent with response mapping (e.g., X appears on left side of display), whereas the other half are incongruent (e.g., X appears on right side of screen). Critically, proportion congruency is manipulated such that the stimuli presented on the top half of the display are *mostly congruent*, whereas the stimuli on the bottom half of the display are *mostly incongruent*. It is typically found that the size of the Simon Effect (i.e., slower responding on incongruent trials) is larger in the mostly congruent context than the mostly incongruent context. It is suggested that this proportion congruency effect occurs because during mostly incongruent blocks participants implicitly adopt a proactive control strategy to minimize interference due to response competition (Blais et al., 2012; De Pisapia & Braver, 2006; Kane & Engle, 2003). Thus, it is possible that embedding PM cues in either mostly congruent or mostly incongruent contexts may stimulate different PM retrieval processes.

EXPERIMENT 3A

Experiment 3A was conducted to examine the behavioral consequences of cue detection depending on whether PM cues were presented in mostly congruent or incongruent contexts. In the PM version of the modified Simon task, the standard ongoing task trials consisted of a series of X’s and O’s presented all in the same color (e.g., red). For the PM intention, participants were instructed to make a PM response (instead of the normal ongoing task response) any time a stimulus was presented in a specified color (e.g., blue). Due to the saliency of the PM cues (i.e., a rare blue stimulus amidst mostly red stimuli), they should be noticed fairly easily. However, to successfully respond to PM cues participant must inhibit their prepotent ongoing task response tendency to instead make a PM response. Thus, because participants are adopting a proactive control strategy to reduce interference in the mostly incongruent context, it should be easier to inhibit a prepotent response tendency in service of the PM intention. In contrast, because participants rely on more reactive control processes to reduce interference on the small number of trials that are incongruent in the mostly congruent context, participants may be more likely to accidently make a target response on cue trials.

METHOD

Participants

Thirty-four participants were recruited for participation in a behavioral version (i.e., no EEG) of the experiment that lasted approximately 30 minutes.

Materials and Procedure

Subjects participated in a modified Simon task, as follows. A central fixation marker remained on the screen for the duration of the block. The letter X or O was presented in one of four locations (top-left, top-right, bottom-left, or bottom-right). Subjects were asked to respond to the letter on the screen by pressing a left or right-hand button (counterbalanced across individuals) with the appropriate index finger. The target remained on the screen until the response was executed. The response was immediately followed by a uniformly distributed variable intertrial interval lasting between 500 ms and 1000 ms inclusive, in 17 ms increments, during which the fixation marker remained on the screen. Thus, from the point of view of the participant, there was a + sign on the center of the screen and then approximately every 1.5 s (depending on their RT) an X or O appeared in one of four corners.

There were 116 trials total in each block of the experiment, with 10 total blocks. Two of the blocks were “control” blocks in which there was no PM intention (block number 1 and 6), whereas the remaining 8 blocks contained PM cues. For the control blocks, participants were instructed to perform the task normally and that the colors were irrelevant to the task, whereas for the PM blocks participants were instructed to press the spacebar with their thumb whenever a stimulus of a specified color (e.g., red) was encountered. There were a total of 96 standard (non-cue) trials, 8 control (non-cue) trials, and 8 PM cue trials. PM cues did not occur until 20th trial, and then appeared every 12 trials for the remainder of the block.

Stimuli were either presented in red, blue, or yellow, which were unique to each of the different trial types, counterbalanced across participants. Half of the trials were congruent and the other half were incongruent. A congruent trial was one in which the location of the stimulus was consistent with the response mapping. For example, if the participant was to press the left button when he or she saw an X, then a congruent trial occurred when the X is presented on the left half of the screen, and the O was presented on the right half of the screen. Whether the stimulus was on the top or bottom of the screen affected the probability of the stimulus being congruent. For half of the participants, items appearing on the top of the screen were 75% congruent (i.e., 36 congruent trials and 12 incongruent trials) and items appearing on the bottom of the screen were 25% congruent (i.e., 12 congruent trials and 36 incongruent trials). For the other half of the participants, the proportion congruency across top and bottom halves of the screen was the opposite. For the control and cue trials, one of each was presented as and X and an O in one of the 4 quadrants, half as a congruent and half as an incongruent trial.

RESULTS

Ongoing task performance. To examine the context specific proportion congruency effect and the ongoing task cost due to possessing an intention, I submitted mean RTs[2] on correct standard trials to a 2 (block: control vs. experimental) x 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) repeated-measures ANOVA (Figure 11). This analysis revealed an effect of block, $F(1,33) = 14.98$, $p < .001$, $\eta_p^2 = .312$, and congruency, $F(1,33) = 28.96$, $p < .001$, $\eta_p^2 = .467$, with faster RTs in the control block and on congruent trials. Although there was no effect of context, $F < 1$, there was an interaction of context and congruency, $F(1,33) = 7.05$, $p = .012$, $\eta_p^2 = .176$. This interaction reflects the typical CSPC effect whereby the Simon effect (i.e., incongruent RT – congruent RT) is greater for the mostly congruent (M = 32, SE = 5) than the mostly incongruent (M = 17, SE = 5) context. There were no other significant interaction effects (all p's > .07). In summary, these results found that there was cost to ongoing task performance as a result of possessing an intention, and that the Simon effect is greater in the mostly congruent context.

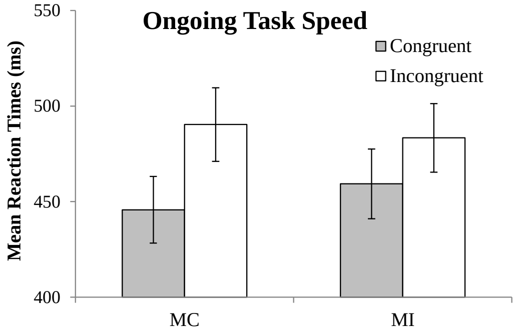

Figure 11. Mean reaction time on standard trials in Experiment 3A as a function of congruency and context.

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[2] Analyses of ongoing task accuracy generally parallel those of the mean reaction times, so for simplicity I only report the latter here and in subsequent analyses.

Cue detection. The proportion of successfully detected cues in the experimental block was submitted to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) repeated-measures ANOVA (Figure 12). This analysis revealed an effect of context, $F(1,33) = 4.60$, $p = .039$, $\eta_p^2 = .122$, with greater cue detection in the mostly incongruent context. There was also an effect of congruency, $F(1,33) = 5.0$, $p = .032$, $\eta_p^2 = .132$, with greater cue detection on incongruent than congruent trials. However, there was no interaction of context and congruency, $F < 1$. The main effects of context and congruency mainly reflect that cue detection was worst on congruent trials in the mostly congruent context, whereas performance was the best on incongruent trials in the mostly incongruent context. Post-hoc analyses revealed that there was only an effect of congruency on cue detection in the mostly congruent context, $F(1,33) = 4.50$ $p = .041$, $\eta_p^2 = .120$, and not in the mostly incongruent context ($F < 1.2$).

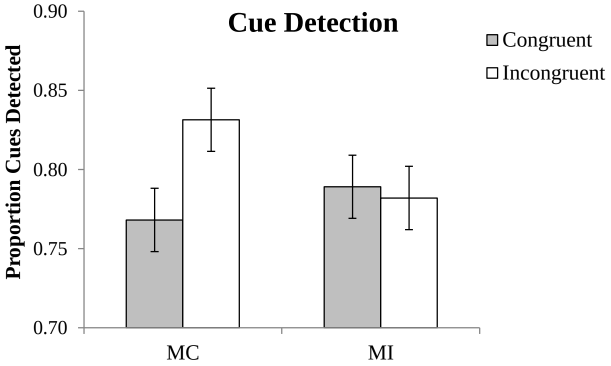

Figure 12. Mean cue detection in Experiment 3A as a function of congruency and context.

Prospective Memory RTs. I also examined whether participants differentially slowed when making their PM response as a function of item type by submitting cue detection RTs to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency:

congruent vs. incongruent) repeated-measures ANOVA. However, this analysis revealed no effects of context or congruency, and no interaction between the two (all p's > .23).

I also compared RTs across item type by submitting mean RTs to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) x 3 (item type: PM vs. control vs. standard) repeated-measures ANOVA. This analysis revealed an effect of congruency, $F(1,33) = 12.54$, $p = .001$, $\eta_p^2 = .275$, with faster RTs on congruent than incongruent trials. There was also an effect of item type, $F(1,33) = 170.63$, $p < .001$, $\eta_p^2 = .914$. The effect of item type reflects both PM ($M = 673$, $SE = 14$) and control ($M = 672$, $SE = 22$) trial RTs were significantly slower than standard ($M = 490$, $SE = 10$) trials RTs, $F(1,33) = 206.78$, $p < .001$, $\eta_p^2 = .862$, and $F(1,33) = 146.58$, $p < .001$, $\eta_p^2 = .816$, respectively. However, there were no RT differences between PM and control trials, $F < 1$.

DISCUSSION

The results from the behavioral task are fairly straight forward. Consistent with previous research (Blais & Bunge, 2010), on standard ongoing task trials participants demonstrated the typical context specific proportion congruency (CSPC) effect whereby the Simon effect was larger in the mostly congruent than mostly incongruent context. As is typical, this effect was primarily driven by increases in RTs on incongruent trials in the mostly congruent context. This finding suggests that participants were engaging more reactive control processes that involve trying to reduce interference after its onset on the rare trials in which incongruent trials occurred. In regard to PM performance, cue detection was better overall on incongruent trials and in the mostly incongruent context.

Interestingly, however, cue detection only differed between the congruent and incongruent stimuli in the mostly congruent context. In conjunction with the CSPC effect, these findings suggest that participants may have been engaging more reactive control processes in the mostly congruent context and were therefore more likely to miss cues (particularly when cues appeared on congruent trials). In contrast, when participants were engaging more proactive control processes in the mostly incongruent context, they were more likely to be prepared for response conflict and were therefore better able to fulfill the intention regardless of item congruency.

EXPERIMENT 3B

Experiment 3B was conducted to examine the behavioral consequences and neural correlates of cue detection depending on whether or not cues were presented on mostly congruent or incongruent contexts. Presumably, if engagement of proactive versus reactive control processes bias the cognitive system to process incoming stimuli differently, differences in the neural correlates of PM noticing and retrieval processes may be observed when cues are presented in mostly congruent relative to incongruent contexts.

In particular, there are two neural signatures that have been commonly associated with PM. The N300 is negative deflection over occipital-parietal regions that is greater for PM cues than standard trials. The N300 is thought to reflect detection of the cue (West, 2011). Additionally, the parietal positivity is a sustained positive going deflection that occurs approximately 400 ms post-stimulus onset and is a result of three distinct components: the P3b (novelty detection), parietal old/new effect (recognition memory; West & Krompinger, 2005), and the prospective positivity. Of particular interest in the current study is the prospective positivity, which occurs approximately 400-800 ms post-stimulus onset over parietal regions and is thought to reflect coordination between PM and ongoing task and post-retrieval monitoring processes (Bisiacchi et al., 2009). Bisiacchi et al. compared ERPs in two different types of PM tasks, one that required making the PM response *instead* of the ongoing task response (task-switching), and one that required first making the ongoing task response followed by the PM response (dual-task). Although there were no N300 differences associated with noticing the cue, the prospective positivity was greater in the task-switching condition that placed greater demands on inhibitory processes needed to execute the intended action. Based on these findings, it was predicted that in the current study the prospective positivity would be greater for successfully detected cues in mostly congruent relative to the mostly incongruent context. The rationale behind this is that participants in the mostly incongruent context are already engaging proactive control processes to reduce interference, and therefore it should be easier to switch from the ongoing to PM task in this context.

METHOD

Participants

Twenty Arizona State University undergraduate students enrolled in an introductory psychology course participated in the study that last approximately 75 minutes. Students received course credit for their participation in the study. However, two participants were excluded from all analyses due excessive artifact during EEG recording.

Materials and Procedure

The materials and procedure were nearly identical to the behavioral study, but was lengthened to get more measurements per participant. The only differences between the behavioral and EEG studies were that in the latter, there were 15 blocks (3 control, with one in each third of the experiment) each containing 160 trials. Each block consisted of 128 standard (non-cue) trials, 16 control (non-cue) trials, and 16 PM cue trials. PM cues did not appear until the 32nd trial and were presented every 8 trials for the remainder of the block.

BEHAVIORAL RESULTS

Ongoing task performance. To examine the context specific proportion congruency effect and the ongoing task cost due to possessing an intention, I submitted mean RTs on correct standard trials to a 2 (block: control vs. experimental) x 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) repeated-measures ANOVA (Figure 13). This analysis revealed an effect of block, $F(1,17) = 60.32$, $p < .001$, $\eta_p^2 = .78$, and congruency, $F(1,17) = 155.72$, $p < .001$, $\eta_p^2 = .902$, with faster RTs in the control block and on congruent trials. Although there was no effect of context, $F < 1$, there was an interaction of context and congruency, $F(1,17) = 10.78$, $p = .004$, $\eta_p^2 = .388$. This interaction reflects the typical CSPC effect whereby the Simon effect (i.e., incongruent RT – congruent RT) was greater for the mostly congruent (M = 42, SE = 4) than the mostly incongruent (M = 22, SE = 3) context. There were no other significant interaction effects (all p’s > .16). In summary, these results found that there was cost to ongoing task performance as a result of possessing an intention, and that the Simon effect is greater in the mostly congruent context.

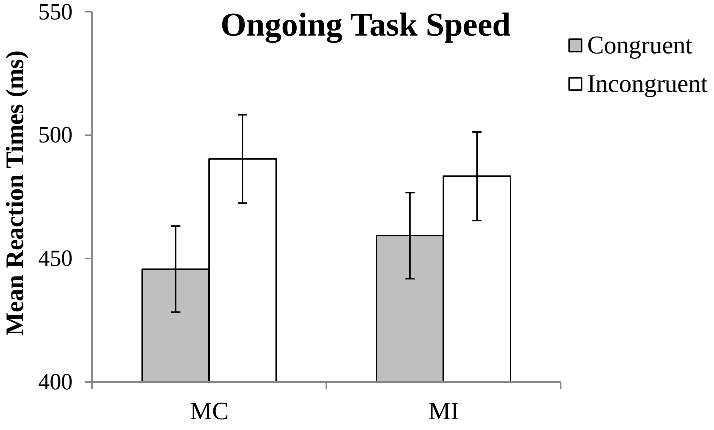

Figure 13. Mean reaction time on standard trials in Experiment 3B as a function of congruency and context.

Cue Detection. The proportion of successfully detected cues in the experimental block was submitted to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) repeated-measures ANOVA (Figure 14). This analysis revealed no effect of context, $F < 1$, but an effect of congruency, $F(1,17) = 4.76$, p = .043, $\eta_p{}^2 = .219$. There was also a marginal interaction of context and congruency, $F(1,17) = 3.79$, p = .068, $\eta_p{}^2 = .182$. The marginal interaction primarily reflects that there was an effect of congruency on cue detection in the mostly congruent context, $F(1,17) =$ 8.04 p = .011, $\eta_p{}^2 = .321$, and not in the mostly incongruent context , $F < 1$.

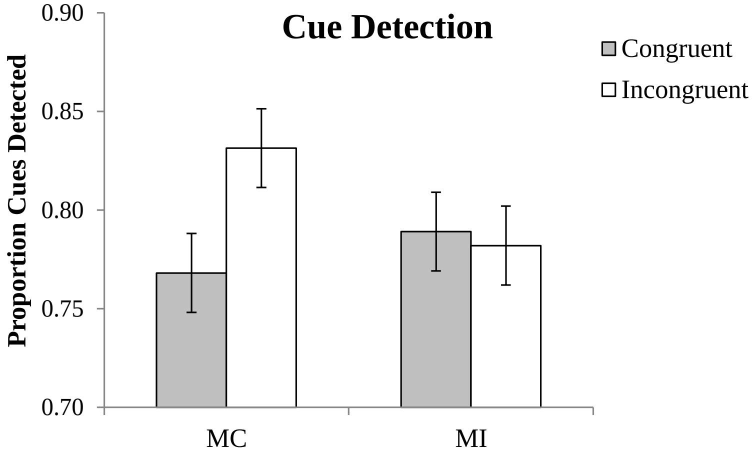

Figure 14. Mean cue detection in Experiment 3A as a function of congruency and context.

Prospective Memory RTs. I also examined whether participants differentially slowed when making their PM response as a function of item type by submitting cue detection RTs to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) repeated-measures ANOVA. However, this analysis revealed no effects of context or congruency, and no interaction between the two (all p's > .26). Thus, participants were equally slowed in making their PM responses regardless of trial type.

I also compared RTs across item type by submitting mean RTs to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) x 3 (item type: PM vs. control vs. standard) repeated-measures ANOVA. This analysis revealed an effect of congruency, $F(1,17) = 16.72$, $p = .001$, $\eta_p^2 = .496$, with faster RTs on congruent than incongruent trials. There was also an effect of item type, $F(1,17) = 52.14$, $p < .001$, $\eta_p^2 = .867$. The effect of item type reflects both PM ($M = 646$, $SE = 34$) and control ($M = 539$, $SE = 23$) trial RTs were significantly slower than standard ($M = 462$, $SE = 17$) trials RTs, $F(1,17) = 63.10$, $p < .001$, $\eta_p^2 = .788$, and $F(1,17) = 98.32$, $p < .001$, $\eta_p^2 = .853$, respectively. Additionally, PM RTs were slower than control RTs, $F(1,17) = 27.26$, $p < .001$, $\eta_p^2 = .616$. There was also an interaction of item type and congruency, $F(1,17) = 17.03$, $p < .001$, $\eta_p^2 = .680$, and of context and congruency, $F(1,17) = 7.98$, $p = .012$, $\eta_p^2 = .319$. No other effects or interactions were significant (all p's > .35). Follow-up analyses in which PM was separately compared to control and standard trials revealed that the nature interaction in both cases was due to the fact that congruency had no influence on PM RTs (as demonstrated in the previous analyses only examining PM RTs), whereas congruent trials were faster than incongruent trials for both control and standard trials. In sum, the analyses of PM RTs revealed no differences in RTs across context or congruency, but overall these RTs were slower than both control and standard trials.

ERP RESULTS

Prospective positivity. As can be seen in Figure 15, there were large differences in ERP amplitude across trial types that emerged around 300 ms and continued for another 500 ms (Figure 15). Based on previous research and visual inspection of ERP onset across item types, the prospective positivity was quantified as the mean amplitude between 300-400 ms[3] over the parietal area (electrode Pz). Mean amplitude was analyzed in a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) x 3 (item type: PM Hit vs. control vs. standard) repeated-measures ANOVA[4]. This analyses revealed an effect of item type, $F(1,17) = 10.33$, p = .001, $\eta_p{}^2 = .564$. However, there was no effect of context or congruency, and no higher order interactions, *F's* < 2.73, p's > .09. Follow-up analyses revealed that there were no amplitude differences between control and standard trials, *F's* < 1. However, mean

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[3] Although the prospective positivity typically emerges approximately 400-500 ms post-stimulus onset (West, 2007), the reaction times in the current study were considerably faster than other studies examining the effect. Thus, based on reaction time differences and visual inspection of the onset of the positivity across all items types, the time-window for analyses was selected to be 300-400 ms.

[4] Although PM misses are plotted in the Figure 15, these trial types were not analyzed. Overall, cue detection was high so there were relatively few misses in general. Furthermore, there were several participants with perfect cue detection, and others with perfect cue detection on certain trial types (e.g., incongruent trials in mostly congruent).

amplitude was greater for PM hits than control and standard items, $F(1,17) = 21.94$, p < .001, $\eta_p^2 = .563$, and $F(1,17) = 18.91$, p < .001, $\eta_p^2 = .527$, respectively.

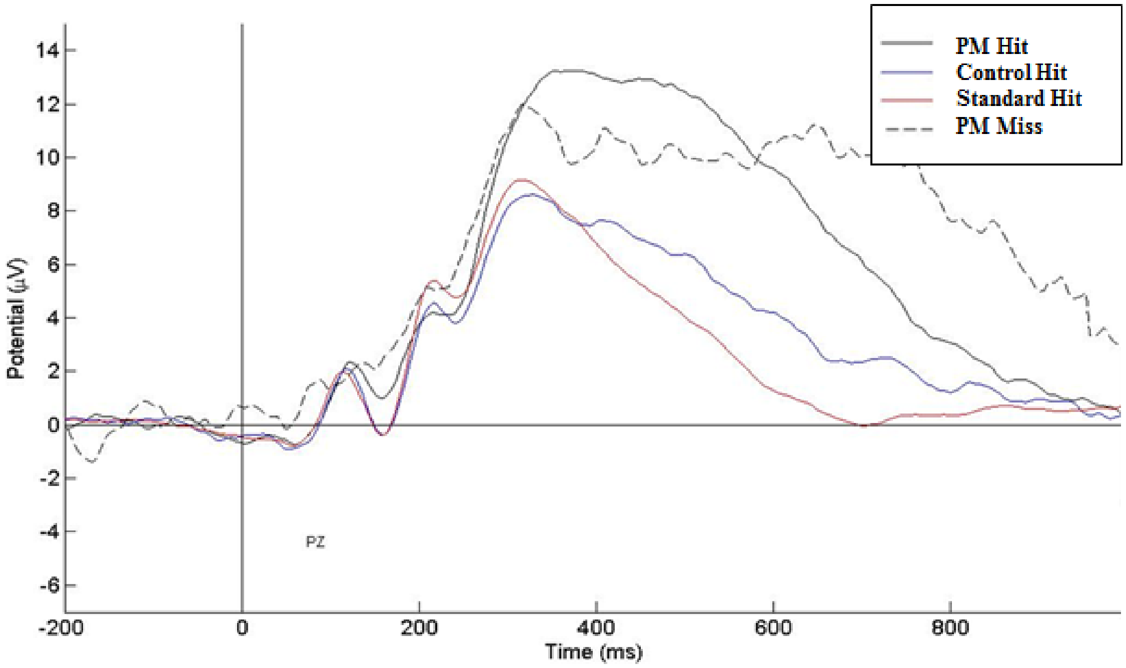

Figure 15. Grand-averaged ERPs collapsed across congruency and context portraying the prospective positivity (300-400 ms) for prospective memory (PM) hits, prospective memory (PM) misses, control items, and standard items at electrode Pz.

Of particular interest in the context of the current study was the effect of context and congruency on PM hits (Figure 16). Thus, we additionally submitted mean amplitude for PM hits to a 2 (context: mostly congruent vs. mostly incongruent) x 2 (congruency: congruent vs. incongruent) repeated-measures ANOVA. However, this analysis failed to reveal an effect of context or congruency, F's < 1, and no interaction between the two, $F < 1$.

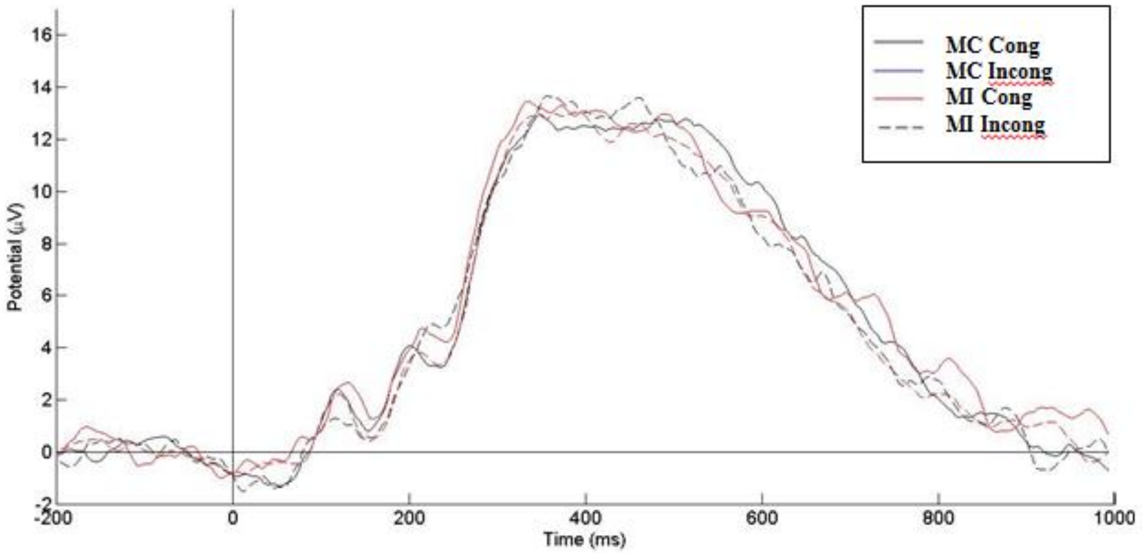

Figure 16. Grand-averaged ERPs collapsed portraying the prospective positivity (300-400 ms) for prospective memory hits as a function of congruency and context at electrode Pz. MC = mostly congruent context; MI = mostly incongruent context; Cong = congruent trial; Incong = incongruent trial.

EXPERIMENT 3B: DISCUSSION

The behavioral results Experiment 3B are generally consistent with those found in Experiment 3A. In particularly, participants demonstrated a CSPC effect on standard trials, and cue detection only differed across item types in the mostly congruent context. Again, these findings suggest that participants in the mostly congruent context may have been engaging more reactive control processes that resulted in more missed cues on congruent relative to incongruent trials. In contrast, when engaging more proactive control processes, item type did not have an influence on cue detection.

In regard to the ERP analyses, it was found that prospective hits distinguished between standard and control trials starting around 300 ms post-stimulus onset and was maximal over parietal regions. This finding is consistent with previous studies demonstrating a prospective positivity around the same latency and topography. It has previously been suggested that the prospective positivity reflects coordination processes necessary to inhibit ongoing task responding and switching from the ongoing task to the PM task (Bisiacchi et al., 2009). Thus, it was predicted that the prospective positivity would be larger on PM hits in the mostly congruent than mostly incongruent context, as it would take more control to inhibit the prepotent response tendency in the reactive context. However, when comparing the prospective positivity for PM hits across item types, no significant effects emerged. One possibility for the null effects was that ERPs were only compared on trials in which processing and intention execution was successful (i.e., PM hits). However, given the small sample size and small number of PM misses, it was not possible to compare hits versus misses across item types.

Chapter 5

GENERAL DISCUSSION

The lion’s share of research on PM costs has been geared toward addressing theoretical debates about *when* cognitive control processes are enacted during event-based PM (e.g., Einstein & McDaniel, 2010; Smith et al., 2007; Smith, 2010). However, relatively little is known about the *nature* of these control processes and the *regularity* in which they are enacted. While the study of mean RTs has undoubtedly contributed to our understanding of PM, I argue that these measures may not fully capture the underlying dynamics of PM monitoring processes involved in detecting cues and retrieving intentions. This point is particularly salient in the context of the current studies where the interpretation of the results considerably differs depending on which individual differences measures and cost metrics are evaluated. Consistent across Experiments 1 and 2, when examining only mean RTs proactive control was not associated with PM costs. From these findings alone, it would be tempting to conclude that the proactive control construct may be capturing attention or memory processes independent of those that produce cost. However, ex-Gaussian analyses revealed that the null relation between proactive control and mean RTs was due to PM costs being produced primarily by increases in mu and a general decrease in tau for high relative to low proactive control participants. Together, these findings suggest that natural variation in proactive control abilities may affect reliance on continuous (i.e., proactive) and transient (i.e., reactive) monitoring processes to support cue detection. Furthermore, it was demonstrated using both individual differences (Experiments 1 and 2) and experimental (Experiment 3) techniques that proactive control was the optimal processing mode for cue detection.

Furthermore, it was also found that reliance on these various types of processing modes is mutable in the context of PM (Experiment 2). These results highlight the importance of the converging operations approach towards understanding PM phenomenon, and that ex-Gaussian analyses may serve to improve current theorizing of the mechanisms underlying PM performance.

I have previously argued that variation in continuous and transient monitoring processes are captured by mu and tau, respectively, in the ex-Gaussian analyses. Interestingly, although the optimal processing strategy during nonfocal PM conditions is continuous monitoring, previous instantiations of ex-Gaussian analyses somewhat surprisingly revealed that cost was solely due to increases in tau (Ball et al., 2014). However, more recently Loft et al. (2014) found that cost was due to increases in both mu and tau (see also Abney, McBride, & Petrella, 2013). The finding of increased mu is more consistent with extant theories of monitoring suggesting that cognitive control processes (e.g., preparatory attention, retrieval mode maintenance, target checking, strategic monitoring) are enacted on a trial-by-trial basis (Einstein & McDaniel, 2005; Guynn, 2003; Smith, 2003), whereas the increase in tau suggests that there were additional control processes are enacted on subset of trials. Similarly, the results from the current set of studies found that cost was typically associated with increases in both mu and tau. Interestingly, however, only variation in mu reliably predicted cue detection across studies, suggesting that a continuous monitoring strategy is associated with increased levels of cue detection. It is likely the case that differences in the current studies relative to previous findings reflects differences in the nature of the ongoing task and the PM cues to be encountered (see Loft et al., 2014 for a more detailed discussion) and the fact that the current studies had greater power to detect relatively smaller changes in mu given the large sample size. Perhaps more importantly, however, the results from the current set of studies suggest that there may be important individual differences variables that may affect the reliance on continuous versus transient monitoring processes. Furthermore, these findings suggest that these processes may be mutable in the context of PM and therefore can be altered to optimize PM performance.

Cognitive Control Processes in Prospective Memory

Experiment 1 examined the role of working memory, proactive control, inhibition, and vigilance in PM monitoring and cue detection. WMC uniquely predict cue detection, whereas both proactive control and inhibition uniquely predicted variability in mu. As mentioned previously, the relation between WMC and cue detection may reflect long-term memory (Ball et al., 2013) or task-switching (Scnhitzpahn et al., 2013) processes. Importantly, however, these processes can only occur following noticing of the cue. Thus, it is likely the case the proactive control and inhibitory processes are involved in continuous monitoring that, although causes slowing on the majority of ongoing task trials, substantially increases the likelihood of noticing cues. The results from Experiment 3 using the modified Simon task suggest a possible mechanism by which proactive control processes may be operating in the animacy judgment task used in Experiments 1 and 2. In the mostly incongruent context of the Simon task, participants engage proactive control to try to reduce interference for the highly likely incongruent stimuli. Consequently, the cognitive system is already optimally biased to deal with interference on trials in which PM cues that also produce response conflict (i.e., press different key) appear. Such a processing mode decrease the likelihood that the ongoing task response will mistakenly be made instead of a PM response. Likewise, in the nonfocal animacy judgment task, participants may adopt a more cautious response strategy that allows for target checks to be me made that decreases the likelihood of mistakenly making the prepotent ongoing task response prior to engaging target checks (Heathcote, Loft, & Remington, 2015; Loft & Remington, 2013).

Although speculative, the distinction between proactive versus reactive control processes in context of PM may reflect front-end versus back-end checking processes, respectively. Front-end checking would involve checking the stimulus for intention relevant information prior to deciding whether the item is living or not (e.g., “Does stimulus contain *TOR* syllable? Yes. Is it living? Yes.”), whereas back-end checking processes would involve first making the animacy decision followed the target check (e.g., “Is stimulus living? Yes. Does it contain *TOR* syllable? Yes.”). Front-end checking mechanisms would allow for inhibitory processes to be instantiated to increase the likelihood of making the PM response and signal for WMC processes associated with task-switching to coordinate processing from the ongoing to PM task. Importantly, although the front-end checking mechanisms would be more efficacious for cue detection, they should also produce more substantial slowing on a majority of trials. In contrast, the back-end checking mechanisms may reduce interference on the majority of ongoing task trials, but nevertheless produce substantial slowing on trials in which the PM intention was reactivated (similar to slowing seen on incongruent trials in the mostly congruent context). Importantly, back-end checking processes may increase the probability that a cue would be missed or the prepotent ongoing task response tendency is executed prior to the intention. Of course, the correlation between reactive control abilities was inconsistent across studies. Thus, future work is needed to better understand the relation between the cognitive control processes associated with more transient monitoring processes.

Improving Prospective Memory

The DMC framework posits that various situational and individual differences factors produce biases in reliance on proactive and reactive control processing modes in various cognitive control tasks (Braver, 2012). Consistent with this idea, the studies presented here demonstrated that situational (e.g., importance instructions) and individual differences factors (e.g., proactive control abilities) influenced reliance on proactive control processes in the context of PM. Importantly, however, reliance on proactive versus reactive control processes appear to be mutable. This idea is consistent with previous PM theorizing that suggests that participants are sensitive to demands of the PM task and that they adjust their attentional-allocation policies accordingly to optimize performance (Marsh, Hicks, & Cook, 2005). The results from Experiments 2A and 2B demonstrated that performance between low and high proactive control participants were similar if given the right type of encoding instructions (e.g., emphasizing importance of the intention) or PM intention (e.g., focal intention). Although previous research has shown similar findings in regard to individual differences in WMC (at least in regard to focal PM; Brewer et al., 2010), the results from these studies more specifically suggest that proactive control and inhibition processes should be targeted to improve PM. Furthermore, although it is generally the case that tau is predictive of various performance across a variety of attention control studies (e.g., Schmiedek et al., 2007; Tse et al., 2010; Unsworth et al., 2011; Unsworth et al., & Young, 2010), the results from the current set of studies suggest that identifying variables that influence mu may be most beneficial for understanding that mechanisms that contribute to PM. Finally, the results from the current set of studies suggest that proactive control variation may be useful for classifying which participants will rely on proactive and reactive monitoring processes during nonfocal processing conditions in which proactive control is optimal. Future experimental and individual differences will hopefully bring more theoretical clarity to the underlying cognitive control processes that support prospective memory along with providing critical information for application focused PM interventions.

Conclusions

In conclusion, the current set of studies used experimental, individual differences, quasi-experimental, and neuroscience techniques in conjunction with RT distribution fitting to provide novel insights about the *nature* of PM costs and the *regularity* in which cognitive control processes are enacted. PM costs occur in many different contexts and they lead to ongoing task decrements that may be detrimental to many aspects of healthy living. Accounting for the underlying cognitive control processes that create these costs can provide researchers with tools for developing strategic interventions that can facilitate ongoing task cognitive processing that is unrelated to PM while simultaneously improving PM abilities. Individual differences studies may also be useful for tailoring these interventions in nuanced ways that appropriately calibrate an individual's recognition of the situational factors and their reliance on the appropriate cognitive control strategies that will ultimately facilitate their prospective memory abilities.

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