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Is Task Interference in Event-Based Prospective Memory Dependent on Cue Presentation?

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Abstract

Whether having an intention produces a performance cost to ongoing activities (task interference) is central to theoretical claims regarding the mechanisms underlying cue detection in event-based prospective memory. Recent evidence suggests that task interference primarily reflects an attention allocation policy stored in memory when intentions are encoded. The present study examined whether these policies can change with ongoing task experience. In Experiment 1, task interference was reduced when expected cues were not presented compared to when expected cues were presented. Experiment 2 replicated this effect when the importance of the prospective memory task was emphasized. In Experiment 3, task interference decreased with time, and this decrease was larger when expected cues were not presented compared to when expected cues were presented. Cue presentation is crucial to maintenance of attention allocation policies established by task instructions. This is the first paper to demonstrate changes in task interference with ongoing task experience without forewarning individuals of the relevance of upcoming ongoing task trials to intentions.

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In recent years, researchers have shown increasing interest in memory tasks that require individuals to remember to perform an action at a designated point in the future. The term prospective memory (PM) is used to refer to both the tasks used and the type of memory assumed to underlie performance. Most work conducted in this area has examined event-based PM, in which the occurrence of a PM cue signals that it is appropriate to perform an intended action. For example, in order to execute the delayed intention of stopping to buy medicine during the drive home from work, PM is required to recognize the cue (pharmacy) as relevant to the intention (buy medicine), while attention is focused elsewhere (driving). Event-based PM laboratory paradigms simulate these conditions. Participants are required to perform a specific action (e.g., press the F1 key) upon cue presentation (e.g., the word *donkey)*, whilst performing an ongoing task (e.g., rating words) (Einstein & McDaniel, 1990).

A current issue in the PM literature concerns the extent to which the processes underlying cue detection require centrally-mediated attentional resources. According to the preparatory attention and memory (PAM) theory, cue detection *always* requires significant processing resources (Smith & Bayen, 2004; Smith, Hunt, McVay, & McConnell, in press). In support, PM task demands embedded in ongoing tasks slow performance on non-cue trials of ongoing tasks (e.g., Loft & Yeo, 2007; Marsh, Hicks, Cook, Hansen & Pallos, 2003; Smith, 2003). This effect is often referred to as *task interference* (Hicks, Marsh & Cook, 2005). Task interference is obtained on trials where PM cues do not occur, and thus does not reflect a cost associated with carrying out the intended action. In contrast, the multiprocess view argues that under some task conditions cue detection requires no resources and can occur automatically (Einstein & McDaniel, 2005; McDaniel & Einstein, 2007). In support, Einstein et al. (2005) found high rates of cue detection under some conditions where no evidence of task interference was found. The multiprocess view claims that specific task conditions determine the extent to which individuals are predisposed to rely on automatic retrieval processes to detect the PM cue, or instead allocate attentional resources to the process of cue detection.

The important point is that the presence (or absence) of the task interference effect is central to theoretical claims made by both PAM theory and the multiprocess view. Hence, there are theoretical ramifications for understanding the conditions under which the task interference effect will and will not be observed, and for specifying the cognitive mechanisms that give rise to it. One currently held view is that task interference primarily reflects an *attention allocation policy* stored in memory when intentions are encoded (Hicks et al., 2005; Marsh, Hicks & Cook, 2005). As attention is presumed to be a limited-capacity resource, there can be an ongoing task-processing cost associated with allocating attention to the PM task, assuming that shared resources are involved. However, given that ongoing task conditions can change from those expected when intentions are encoded, it would be advantageous if attention allocation policies could be adjusted with ongoing task experience such that the degree to which intentions interfere with ongoing activities could be modified. For example, there are undoubtedly many ongoing tasks found in the real world for which individuals hold intentions for lengthy periods of time during which expected PM cues are not encountered, and it would be reasonable to expect that individuals may adjust their allocation of attention such that ongoing tasks are not unduly compromised. Three studies are reported that test this premise by examining whether the magnitude of task interference is dependent on the presentation of PM cues in ongoing tasks. We approached this research question in the following way: Will intentions interfere less with ongoing tasks when expected cues are not presented compared to when expected cues are presented?

There is an emerging body of evidence to suggest that at least part of the task interference effect reflects an attention allocation policy that participants establish at the outset of the entire task set (Hicks et al., 2005; Marsh et al., 2005). According to proponents of this view, individuals assign a relative weighting of attention to the ongoing task and the PM task. Support has come from showing that more difficult PM sets produce greater task interference. For example, poorly-specified intentions (responding to a category of PM cues) cause greater task interference than well-specified intentions (responding to a specific cue; Hicks et al., 2005), and responding to multiple cues cause greater task interference than responding to a single cue (Einstein et al., 2005), presumably because participants believe that completing the former intentions will be more difficult. The attention allocation policy view is in line with the claims of the PAM theory that task interference reflects a single preparatory allocation of attention away from the ongoing task and toward the PM task (Smith & Bayen, 2004). According to PAM, preparatory attention serves the function of mapping ongoing task stimuli onto intentions, thus ensuring that a recognition check (the memory component of PAM) is initiated when a cue is presented. Other theoretical proposals in the literature are also consistent with the view that task interference is driven by a single parameter established at encoding. For example, Guynn (2003) proposed that individuals maintain their memory system in a retrieval mode, which she describes as a general preparedness or readiness to treat ongoing task stimuli as PM retrieval cues (cf. Tulving, 1983). These retrieval modes may involve increased levels of activation of cues that persist until intentions are complete or the goals/context of the task change (Goschke & Kuhl, 1993; Lebiere & Lee, 2001), thereby leaving less capacity for processing ongoing activity.

Given the number of intentions that we hold on an everyday basis, it may be unrealistic to expect that all our unfilled intentions are maintained at the state of readiness set by attention allocation policies at encoding. It is more likely that we deal with our multiple intentions by varying their activation throughout our day according to their relevance to ongoing task contexts. This notion was supported by recent evidence that task interference can be reduced by warning participants on a trial by trial basis of the relevance of ongoing task stimuli to PM cue detection (Marsh, Cook, & Hicks., 2006a), and even eliminated by informing participants that cues will not be presented in an upcoming block of trials (Marsh, Hicks, & Cook, 2006b). For example, Marsh et al. (2006a) had participants link their intention to detect cues to a particular stimulus class (pictures versus words) and found reductions in task interference when participants were reliably informed that the stimulus class about to be presented on the next trial (or block of trials) was irrelevant to cue detection. These findings are important because they indicate that attention allocation policies are flexible and can be adjusted. However, it is critical to note that reductions in task interference demonstrated by Marsh et al. (2006a, 2006b) varied as a function of the extent to which participants were instructed in advance of the relevance of upcoming trials to cue detection. When Marsh et al. (2006a) presented picture and word stimuli randomly no reduction in task interference was observed.

The current paper extends the work of Marsh et al. (2006a, 2006b) by examining whether reductions in task interference can occur without forewarning individuals of the relevance of upcoming ongoing task trials to intentions, and in doing so, identifies a crucial factor that drives the maintenance of task interference. Specially, we examine whether the allocation of attention to PM tasks, as presumably determined by attention allocation policies, will be reduced if these policies are not periodically reinforced by the presentation of PM cues. If this is the case, less task interference should occur under conditions where expected cues are not presented, compared to conditions where expected cues are presented. Such an outcome would help understand the extent to which everyday intentions might interfere with ongoing activity in everyday settings. As an illustrative example, consider an applied setting where PM is crucial, such as air traffic control (Dismukes, in press; Loft, Humphreys, & Neal, 2003). A controller may intend to assign an atypical flight altitude when accepting 747 model aircraft into their airspace because of an impeding thunderstorm. In addition to some ongoing tasks being more relevant to this intention than others (i.e., Marsh et al., 2006a, 2006b), the frequency in which 747 aircraft enter the sector could vary widely. There are also countless examples in everyday life where expected cues are not encountered, such as intending to give a message to several people at a party that do not actually show up. As argued further in the General Discussion, the outcomes of the current study also help inform future versions of the PAM model and the multiprocess view, as at the time of this writing these theories do not make definitive predictions regarding local adaptations in attention allocation to PM tasks with ongoing task experience.

As a precursor to the current study, Loft and Yeo (2007) found that task interference varied as a function of the frequency of the presentation of PM cues. However, lower probability cues were associated with greater average spacing between cues. Thus, participants in the Loft and Yeo study could have adopted a deliberate strategy, adjusting their attention allocation policies according to their observations regarding the average spacing between cue presentations. In this manner, cue spacing was an implicit indicator of the probability of cue presentation in upcoming ongoing task trials (although this indicator was not explicit like those provided by Marsh et al., 2006a, 2006b). In contrast, participants in the PM-no-cue group of the current study are never presented cues, and thus will have no data available regarding the ‘frequency’ of cue presentation. Instead, it could be quite conceivable to them that they are missing cues and that they subsequently need to maintain attention to the PM task. Given that cues will be learnt to criterion at study, other participants may be confident that they are not missing cues. However, given that these participants will be expecting up to eight cues to be presented during the ongoing task, it should be conceivable to them that cues will be bound to be presented "at any moment now", and thus that attention to the PM task should be maintained.

The current paper presents three experiments. Experiment 1 provided an initial test of whether task interference would be reduced under conditions when expected PM cues were not presented, compared to conditions when expected cues were presented. Experiment 2 examined whether this reduction in task interference varied according to task importance manipulations. Of central interest here was whether task interference would still be significantly reduced when no cues were presented but when the importance of the PM task had been emphasized at encoding. Experiment 3 closely examined how task interference changed over the course of the ongoing task as a result of the presence or absence of cues, and if participants continue to allocate attention to the PM task after a considerably long period without cue presentation.

Experiment 1

In Experiment 1 participants performed an ongoing lexical decision task. In addition, participants studied eight cue words and were instructed that they would be required to press the F1 key whenever presented with these words during the lexical decision task. These general task conditions have been proven to produce robust task interference effects (e.g., Loft & Yeo, 2007; Marsh et al., 2003, 2005; Smith, 2003). Participants completed a block of lexical decision trials alone and then received the PM instructions before completing a second block of lexical decision trials. The first block of lexical decision trials provided a within-subjects measure of baseline performance. There were two PM conditions in Experiment 1. In the PM-cue condition participants were presented with eight PM cues over the course of the ongoing task. In contrast, the PM-no cue condition participants were presented with none of the eight expected cues during the ongoing task. The purpose was to examine whether less task interference would occur on the second block of trials (compared to the baseline) under conditions where expected cues were not presented, compared to conditions where expected cues were presented.

A further research question concerned whether holding event-based intentions interferes with the ongoing task when cues are not presented in the ongoing task. A control condition was included to address this question. Participants in the control condition performed two blocks of lexical decision trials but were not given the PM instruction. Data from the control condition was used to contrast the effects of embedding the PM task in the ongoing activity with the effects of performing the lexical decision task twice without the PM task.

Method

Participants. Sixty students enrolled in undergraduate psychology courses at the University of Queensland were reimbursed $10 each for their participation. There were 20 participants in each condition. Participants in all three experiments were native English speakers.

Materials. The presentation of stimuli and collection of responses were accomplished through E-prime (Schneider, Eschman, & Zuccolotto, 2002). A pool of 320 medium frequency words (4-8 letters in length) were randomly chosen from the 1994 issues of The Sydney Morning Herald (TSMH) Word Database (Dennis, 1995). The 320 non-words were created by removing the first syllable of each word and placing it at the end of the letter string (Hunt & Toth, 1990). Words and non-words were randomly assigned to one of two lists (List 1 or List 2), creating two sets of 320 letter strings, with each set containing 160 words and 160 non-words. Two list orders were created: Order A, in which List 1 was presented in the first block of lexical decision trials and List 2 in the second block, and Order B, in which this order was reversed. Half the participants in each condition received the lists in Order A, half in Order B.

Eight words were randomly selected from Block 2 to serve as PM cues. Eight additional control words, matched to cues on frequency and length, were selected from TSMH Word Database. The order of presentation of trials was random except for the presentation of cues (or control words), which occurred on trials 20, 60, 100, 140, 180, 220, 260 and 300 in Block 2. Cues (or control words) were presented in a random order. Participants in the PM-cue condition studied eight cue words at encoding, and were presented with these words in Block 2 of the lexical decision trials. The PM-no cue condition studied these same eight cue words, but were presented with eight control words in Block 2 of the lexical decision trials, and therefore were not presented with the cue words which they had studied. The control condition also studied eight cue words, and was presented with control words in Block 2.

Procedure. After consent was obtained, participants were informed that letter strings would be displayed on a computer screen and they were required to decide as quickly and accurately as possible whether or not each string was a word. Responses were made by pressing one of the two home keys (D = word, K = non-word). Each trial contained three displays. The first display instructed participants to press the space bar to initiate the next trial. The second display was a focus point (+) displayed in the centre of the screen in black on a white background. The display time for each focus point was randomly selected from a set of possible display times (437, 500, 562, 625, 687, 750, 822, or 886 ms) to ensure participants could not anticipate the appearance of letter strings. The third display was a string of letters which remained on the screen until the participant made an appropriate response. After these instructions had been read and understood, participants completed the 320 lexical decision trials that comprised Block 1. On the completion of Block 1, participants were told they had completed the first half of the session, and that there would be a 3-minute break before commencing the second half of the session.

Next, participants in the PM conditions were given PM instructions. The experimenter told participants that she was interested in their ability to remember to perform actions in the future. Participants were instructed that whenever a PM cue was detected they should respond first to the lexical decision task, and make their PM response during the subsequent waiting message between trials (Hicks et al., 2005; Loft & Yeo, 2007; Marsh et al., 2005). Participants in the PM conditions were then given the eight cue words to study. Participants in the control condition also studied eight cue words, and were told that the purpose was to test their memory at the end of the session. Next, participants were given a word-stem memory test. In this test, participants were given the first one or two letters of each cue, and were required to complete the words. Participants who could not accurately complete all cue words were asked to study the list again. Next, in order to avoid ceiling effects, participants completed a five minute computer card task. After this retention interval, Block 2 of the lexical decision task was initiated for the PM conditions, without further reference to the PM task. The control group was instructed to complete a second block of lexical decision trials. After completion, all participants were re-administered the word-stem memory test.

Results and Discussion

An alpha level of .05 was used for all statistical tests. There was no significant difference between the three conditions in the proportion of PM cues recalled (M = .92, SD = .11) on the final word-stem memory test, $F(1,57) = 1.72$, MSE = .02. PM performance was scored as the proportion of cue trials that received an F1 key response. Participants in the PM-cue condition detected 0.73 (*SD* = .23) of the cues presented in Block 2.

There was no evidence of task interference when the accuracy of lexical decisions was examined, and lexical decision accuracy was near ceiling (96.3%). Thus, consistent with previous research that has examined task interference using lexical decisions (e.g., Hicks et al., 2005; Marsh et al., 2003), the average response time for words trials was the primary dependent measure. Several trials were excluded; (a) the initial four trials of each block; (b) trials that contained PM cues, and non-cue trials where the F1 key was incorrectly pressed (false alarms), to avoid response costs associated with performance of the intention (see Loft & Yeo, 2007; Marsh et al. 2003), (c) the four trials that followed these aforementioned trials to avoid response costs associated with post-output cue detection monitoring processes (see Einstein et al., 2005), (d) trials where response times were greater than 3*SDs* from a participant's grand mean, and (e) trials containing incorrect lexical decisions.

The data are summarized in Table 1. The first column labeled Block 1 gives the average response time on word trials for Block 1 (baseline). The second column labeled Block 2 gives the average response time on word trials for Block 2. The cost associated with the embedded PM tasks is evaluated by calculating individual *task interference scores*. For the two PM conditions, task interference scores reflected the change in response times from Block 1, where the ongoing task was performed alone, to Block 2 where participants held intentions. Greater (more positive) task interference scores reflect a greater allocation of attention to the PM task. Task interference scores for the control group reflect the change in response time due to repeated performance of the ongoing task.

An ANOVA was conducted on response times on Block 1. This analysis of baseline performance was not significant (F<1). Thus, all three conditions were matched with respect to response times on Block 1. As predicted, there was significantly less task interference under conditions where expected PM cues where not presented compared to conditions where expected cues were presented, $t(38) = 2.83$, $p<.01$. In this analysis we had excluded the four trials that followed cue trials and trials where the F1 key was pressed. Thus, this effect is unlikely to reflect post-output cue detection monitoring processes allocated by participants in the PM-cue condition. In order to decrease the likelihood of post-output monitoring, we conducted a more stringent analysis by including only those non-cue trials that were presented at least 30 trials after presentation of preceding cue trials (trials 10-19, 50-59, 90-99, 130-139, etc). In this analysis, there was significantly less task interference under conditions where expected cues were not presented (+24ms) compared to conditions where expected cues were presented (+91ms), $t(38) = 2.29$, $p<.05$[1]. The task interference scores from this truncated analysis were highly comparable to those from the full task interference analysis presented in Table 1. Taken together, these findings demonstrate that the maintenance of attention allocation policies were at least partially dependent on the presentation of PM cues in the ongoing task.

The control condition demonstrated the expected practice effect with faster response times on Block 2 compared to Block 1, $t(19) = 3.54$, $p<.01$. Task interference for the PM-no cue condition was significantly larger than the control condition, $t(38) = 3.65$, $p <.01$. Therefore, holding an intention still significantly interfered with the ongoing task even when the PM cues were never presented.

Experiment 2

Experiment 1 provided evidence that task interference can be reduced under conditions where expected PM cues are not presented, compared to PM conditions where expected cues are presented. It is well documented that the relative importance of the PM task also influences the size of the task interference effect (Loft & Yeo, 2007; Kliegel, Martin, McDaniel & Einstein, 2004; Smith & Bayen, 2004). The increase in task interference with PM task importance is consistent with the idea that task interference reflects an attention allocation policy established at encoding, and that individuals assign a higher weighting of attention to the PM task at encoding when it is considered important (Hicks et al., 2005; Marsh et al. 2005). We conducted a second experiment to both replicate Experiment 1 and examine whether the relationship between cue presentation and task interference varied as a result of task importance manipulations.

Reduction of task interference in the absence of PM cues may be less pronounced when instructions emphasize the importance of the PM task compared to when they emphasize the importance of the ongoing task. When the *PM task* is important, participants may be more likely to maintain their attention allocation policies due to the perceived importance of detecting cues, thereby keeping attention allocated to the PM task despite the absence of cues. In contrast, when the *ongoing task* is important, participants may be less willing to compromise performance on the ongoing task, and thus less likely to continue allocating attention to the PM task in the absence of cues (as in Experiment 1). If so, there should be an interaction between importance and cue presentation, in that the difference in task interference between the PM-no cue and PM-cue conditions will be less pronounced when instructions emphasize the importance of the PM task compared to when they emphasize the importance of the ongoing task.

Alternatively, modifications to attention allocation policies made with ongoing task experience may have a strong, perhaps automatic, adaptation component that responds to cue absence similarly despite the stated importance of tasks. Thus, the reduction in attention allocation to PM tasks when expected cues are not encountered in ongoing tasks may be the same regardless of the initial relative importance of the tasks. If this is the case, an interaction between importance and PM cue presentation would not be expected. In addition, we should find a significant difference in task interference between the PM-cue and PM-no cue conditions when the importance of the PM task has been emphasized, indicating that the maintenance of attention allocation policies is dependent to some degree on the presentation of cues even when the importance of detecting cues has been previously stressed to participants.

Method

Participants. A total of 83 students enrolled in undergraduate psychology courses at the University of Queensland were reimbursed $10 each for their participation (cell N's are given in Table 2). Two participants were excluded because of extremely high false alarm rates to the PM task component (>136 false alarms).

Materials and Procedure. Materials and procedures were identical to Experiment 1, with the addition of task importance instructions. After testing for cue recollection, the experimenter verbally delivered the task importance instructions, emphasizing the importance of either the PM task or the ongoing task (Loft & Yeo, 2007; Smith & Bayen, 2004).

Results and Discussion

A 2 (importance) X 2 (cue presentation) ANOVA was conducted on the number of PM cues recalled on the final memory test. The proportion of cues recalled (M = .92, SD = .13) was not affected by importance, F <1, or cue presentation, F<1, and there was no interaction, $F(1,77)$ = 2.29, MSE = .04, *ns.* A directional independent groups t-test revealed that participants detected more cues when the PM task was important (M = .78, SD = .17) compared to when the ongoing task was important (M = .64, SD = .27), $t(38) = 1.92$, p <.05. There was no evidence of task interference when the accuracy of lexical decisions was examined, and lexical decision accuracy was near ceiling (95.4%).

The response time data are summarized in Table 2. Planned comparisons conducted on response times in Block 1 revealed no significant effects (all ps>.10). Thus, the four PM conditions were matched with respect to response times on Block 1. The cost associated with the PM task was again evaluated by calculating individual task interference scores. Task interference scores were analyzed with a 2 (importance) X 2 (cue presentation) ANOVA. Consistent with previous research (Loft & Yeo, 2007; Smith & Bayen, 2004), there was less task interference when the ongoing task was important (+39ms), compared to when the PM task was important (+112ms), $F(1,77) = 20.20$, MSE = 105147.95, p<.01. Consistent with Experiment 1 there was significantly less task interference under conditions where expected cues were not presented (+50ms) compared to conditions where expected cues were presented (+101ms), $F(1,77) = 9.85$, MSE = 51279.91, p<.01.

There was no evidence at all of an interaction between importance and cue presentation, F=.02. Inspection of task interference data in Table 2 indicates that differences in task interference between the PM-cue and PM-no cue conditions were highly similar regardless of the relative importance of the two tasks. Furthermore, a follow up simple effects test revealed that there was significantly less task interference under PM-no cue conditions compared to PM-cue conditions when the PM task was important, $t(39) = 2.03$, p<.05. Even when the importance of detecting PM cues had been stressed to participants, the maintenance of attention allocation policies was at least partially dependent on the presentation of cues. The data indicated that task importance manipulations did not affect the sensitivity of attention allocation policies to the absence of cues. This is consistent with the notion that, in addition to deliberate strategies of attention allocation set at encoding as a result of importance manipulations, modifications in attention allocation to the PM task made with ongoing task experience may have a strong adaptation component that responds to cue absence similarly despite this stated importance.

As in Experiment 1 we conducted a follow-up analysis for non-cue trials that were presented a minimum of 30 trials away from the presentation of preceding PM cue trials. A 2 (importance) X 2 (cue presentation) ANOVA revealed a significant main effect for task importance (LD important, +40ms vs. PM important, +111ms), $F(1,77) = 18.07$, MSE = 99317.56, $p<.01$. The main effect for cue presentation was also replicated (PM-no cue, +49ms vs. PM-cue, +102ms), $F(1,77) = 10.55$, MSE = 57975.26, $p<.01$. There was again no evidence of an interaction, $F=.10$. Finally, the follow-up simple effects test again indicated significantly less task interference for the PM-no cue condition compared to the PM-cue condition when the PM task was important, $t(39) = 2.22$, $p<.05$. In sum, the task interference scores from this truncated analysis were highly comparable to those from the full task interference analysis presented in Table 2.

Experiment 3

The primary goal of Experiment 3 was to examine how attention allocation policies change over the course of the ongoing task as a result of the presence or absence of cues. In the previous experiments, we made the reasonable assumption that attention allocation policies set by participants in the PM-cue and PM-no cue conditions at encoding would be highly similar because they received identical task instructions. One explanation for the effects of cue presentation on task interference then is that subsequent attention allocation to the PM task decreased when no expected cues were presented, and in contrast, was maintained at the same level set at encoding when expected cues were presented. However, Einstein et al. (2005) found evidence that attention allocation to PM tasks can also decrease over the course of the ongoing task when expected cues are presented.

In the previous experiments the first PM cue was presented to the PM-cue condition after only 20 trials. Given that the first four trials and all non-words were excluded, the remaining valid trials were unlikely to provide a reliable measure of baseline attention allocation policies. In Experiment 3, the PM-cue and PM-no cue conditions were both presented a larger block of 100 trials (Block 1) without cue presentation, in order to obtain a reliable estimate of baseline attention allocation policies. Response times for these two PM conditions in Block 1 should be highly similar, and both should be larger than response times for the control condition. After the presentation of Block 1, participants were presented a second block of 540 trials. In Block 2, participants in the PM-cue condition were presented cues while those in the PM-no cue condition were not. In a final block of 100 trials (Block 3) no cues were presented for either PM condition. Block 1 provides a more robust baseline measure of attention allocation policies than previous experiments. Block 3 provides a subsequent measure of these policies after a period of time with or without cue presentation. Differences in response times between Block 3 and Block 1 (task interference *change scores*) reflects *changes* in attention allocation to the PM task as a result of the presence or absence of cues in Block 2. Participants in a control condition performed the entire lexical decision task without PM instruction, providing a suitable single-task baseline.

Einstein et al. (2005) found reduced task interference for participants who held intentions as a function of time spent on the ongoing task, indicating that attention allocation to PM tasks can decrease over the course of the ongoing task regardless of cue presentation. On this basis, we predicted that attention allocation to the PM task by participants in the PM conditions would decrease over the course of the ongoing task. If this is the case, task interference change scores should be larger for the PM conditions than control condition. In addition, on the basis of findings from Experiments 1 and 2, we predicted that this decrease in attention allocation to the PM task over the course of the ongoing task would be larger when participants were not presented cues as compared to when participants were presented cues. If this is the case, task interference change scores should be larger for the PM-no cue condition than the PM-cue condition.

While task interference for the PM-no cue conditions was significantly reduced in Experiment 1 it was not entirely eliminated. In Experiment 3, we presented a considerably large second block of trials in order for the effects of time on task interference, with or without the presence of PM cues, to be more fully realized. A secondary goal of Experiment 3 was to examine whether participants in the PM-no cue conditions continue to allocate attention to the PM task after this significantly long period without cue presentation (Block 1 + Block 2 = 640 trials without cue presentation). If attention is still allocated, response times in Block 3 should be larger for the PM-no cue condition than the control condition.

Method

Participants. A total of 93 students enrolled in undergraduate psychology courses at the University of Queensland participated in return for course credit (cell N's are given in Table 3).

Materials. The same pool of 320 words and 320 non-words used in previous experiments was presented. An additional 50 words (4-8 letters in length) were randomly chosen from TSMH Word Database (Dennis, 1995), and 50 non-words created using the Hunt and Toth (1990) method. A random subset of these words and non-words were assigned to List 2, creating one set of 540 letter strings with each set containing 270 words and 270 non-words. List 2 was always presented in the second block of lexical decision trials. The remaining words and non-words were randomly assigned to one of two lists (List 1 and List 3), creating two sets of 100 letter strings, with each set containing 50 words and 50 non-words. Two list orders were created: Order A, in which List 1 was presented in the first block of lexical decision trials and List 3 in the third block, and Order B, in which this order was reversed. Half the participants in each condition received the lists in Order A, half in Order B.

Eight words were randomly selected from List 2 to serve as PM cues in Block 2. The same eight additional control words used in Experiments 1 and 2 were used. The order of presentation of trials was random except for the presentation of cues (or control words), which occurred on trials 10, 50, 90, 130, 170, 210, 250, 290, 330, 370, 410, 450, 490, 530 in Block 2. Six cues (or six control words) were presented twice each in Block 2, and the remaining two cues (or two control words) once each. Cues (or control words) were presented in a random order, with each cue (or control word) presented once before any cue or control word was repeated. Participants in the PM-cue condition studied eight cue words, and were presented with a total of fourteen cues in Block 2 of the lexical decision trials. The PM-no cue condition studied these same eight cue words, but were presented with control words in Block 2, and were therefore not presented with the cue words which they had studied. The control condition also studied eight cue words, and was presented with control words in Block 2.

Procedure. After the lexical decision instructions, participants in the PM conditions were given PM instructions. These instructions were identical to previous experiments, except that participants were told that the eight cues 'may be presented more than once each' during the ongoing task. Participants in the PM conditions were then given the eight cue words to study. Participants in the control condition also studied the eight cue words, and were told that the purpose was to test their memory at the end of the session. Participants were given two minutes to study these words (a word-stem memory test could not be conducted due to time restrictions). After a five minute computer card task, the lexical decision trials were initiated, without further reference to the PM task. All three blocks of lexical decisions were performed without break. After completion, all participants were completed the word-stem memory test for the cues.

Results and Discussion

There was no significant difference between the three conditions in the proportion of PM cues recalled (M = .79, SD = .23) on the final memory test, F<1. Participants in the PM-cue condition detected 0.70 (SD = .25) of cues presented in Block 2. As in previous experiments, lexical decision accuracy was near ceiling (95.6%). However, a 3 (Group; PM-cue, PM-no cue, Control) x 2 (Block; Block 1, Block 3) mixed ANOVA revealed that participants were more accurate in Block 1 (M = .96, SD = .03) than Block 3 (M = .95, SD = .04), $F(2, 90) = 17.04$, MSE = .01, p <.01. This reduction in lexical decision accuracy with time is possible due to the fatigue induced by the unusually long length of the lexical decision task. There was no evidence of an interaction between group and block, F(<1). Although the PM conditions were less accurate in Block 3 than Block 1, the control condition was equally less accurate. Thus, there is no evidence that this decrease in accuracy for participants in PM conditions reflected changes in task interference. Most importantly, the decrease in accuracy for participants in the PM-cue and PM-no cue conditions did not significantly differ.

The response time data are summarized in Table 3. The first column labeled Block 1 gives the average response time on word trials for Block 1 where no cues were presented, but for which the intention to respond to PM cues was active for the PM conditions. Response times at Block 1 provide a reliable baseline measure of attention allocation policies before cue presentation. As expected, there were no differences between the response times of the PM-cue and PM–no cue conditions in Block 1 (*t*<1), indicating that participants in the two conditions set a similar weight of attention to the PM task at encoding (this comes at no surprise as participants in the PM-cue and PM-no cue conditions received identical task instructions). As predicted, response times in Block 1 were significantly higher for both the PM-cue condition, $t(60) = 4.48$, $p<.01$, and the PM-no cue condition, $t(59) = 5.34$, $p<.01$, compared to the control condition. Participants in both PM conditions were allocating a significant amount of attention to the PM task in Block 1.

The second column in Table 3 labeled Block 2 gives the average response time on word trials for Block 2 where cues were presented to the PM-cue condition but not the PM-no cue condition. The third column labeled Block 3 gives the average response time on word trials for Block 3 when neither PM conditions were presented cues. *Task interference change scores* were calculated by subtracting response times in Block 3 from response times in Block 1. More negative changes scores reflect greater changes in allocation of attention to the PM task from Block 1 to Block 3 as a result of the presence or absence of cues in Block 2.

In contrast to Experiment 1, the control condition did not demonstrate a practice effect (*t*<1), with response times to Block 1 comparable to those for Block 3. When taken together with the decrease in accuracy from Block 1 to Block 3, this suggests that performing 740 lexical decisions without break was fatiguing. However, as predicted, task interference change scores were significantly larger for the PM conditions than the control condition, $t(91) = 2.96$, $p<.01$, indicating that attention allocation to the PM tasks significantly decreased over the course of the ongoing task for the PM conditions (consistent with Einstein et al., 2005). In addition, these change scores were significantly larger for the PM-no cue than the PM-cue condition, $t(61) = 2.04$, $p<.05$, indicating that this decrease in attention allocation to the PM task was larger for participants not presented cues compared to participants presented cues. Finally, response times in Block 3 were significantly larger for the PM-no cue condition than the control condition, $t(59) = 2.25$, $p<.05$. Participants were still allocating attention to the PM task in Block 3, even after 640 trials (Blocks 1 & 2) without a single cue presentation.

General Discussion

The general message that can be taken away from these experiments is that task interference can be at least partially dependent on the presentation of PM cues in ongoing tasks. In Experiment 1, less task interference was found when expected cues were not presented, compared to when expected cues were presented. This effect of cue presentation was replicated in Experiment 2, despite the importance of detecting cues being emphasized at encoding. In Experiment 3, task interference decreased over the course of the ongoing task, and this decrease in task interference was larger for participants not presented cues compared to participants presented cues. However, while task interference for participants not presented cues was significantly reduced it was never entirely eliminated, even after a considerably long period without cue presentation. To our knowledge, the current paper is the first to report reductions in task interference without forewarning participants of the relevance of upcoming trials to intentions. The remainder of the General Discussion provides an evaluation of the theoretical implications of these findings.

Something of a consensus has recently developed around the idea that task interference reflects an attention allocation policy (Hicks et al., 2005; Marsh et al., 2005, 2006a), preparatory attention (Smith & Bayen, 2004), or instantiation of retrieval mode (Guynn, 2003), that is established at encoding and that divides a limited pool of resources between the ongoing task and the PM task. In the current study, participants in the PM-cue and PM-no cue conditions would be expected to have set highly similar attention allocation policies (or preparatory attention, retrieval modes) because they received identical task instructions, and this was confirmed by the analysis of response times in Block 1 of Experiment 3. We reasoned that the potential to adjust policies set at encoding would be advantageous because conditions in ongoing task environments can invariably change from those initially expected (Hicks et al., 2005). In support of this proposition, the current data suggest that attention allocation policies can be adjusted with experience in ongoing task environments where no expected PM cues are presented. The finding that task interference decreased over the course of the ongoing task, even when cues were periodically presented and mostly detected, is consistent with the idea that it is difficult to maintain controlled self-regulatory processes over extended periods of task time (see Bargh & Chartrand, 1999; McDaniel & Einstein, 2007). Furthermore, the current data demonstrated that the allocation of attention to PM tasks as set by attention allocation policies at encoding can decrease at an even faster rate over the course of the ongoing task if these policies are not periodically reinforced by the presentation of cues.

At the outset of these studies, there were two reasons why it was not immediately clear whether task interference would be reduced when expected PM cues were not presented relative to when expected cues were presented. First, participants were not explicitly (Marsh et al. 2006a, 2007b) or implicitly (Loft & Yeo, 2007) forewarned of the relevance of upcoming ongoing task trials to intentions. As such, participants should have expected cues to be presented on *any* upcoming trials, or felt that they had been missing cues. Second, even if participants were confident that they had not missed cues, the expectation that eight cues (that were learnt to criterion) would eventually be presented should have been strong, particularly in Experiment 2 when the experimenter had emphasized the importance of detecting cues. Despite these aforementioned factors, the task interference data suggest that participants not presented cues developed an expectation over the course of the task that the probability of cue presentation (or the temporal imminence of cue presentation) was different to that which they had expected when forming their attention allocation policy at encoding. Thus, attention allocation policies set by participants in PM task paradigms can be *adapted* on the basis of the local history of the ongoing task environment. This proposal is consistent with many theoretical approaches to human decision making, including theories of information foraging (Pirolli & Card, 1999), reinforcement learning (Estes, 1950), and more general theories of bounded rationality (Simon, 1956) and human cognition (Anderson, 1991), all which share the general assumption that humans can adapt their behavior on the basis of prior contextual experience in specific tasks.

The findings that holding an intention still interfered with the ongoing task when PM cues were not presented, and even after cues had not been presented over a large number of ongoing task trials, suggest that a significant portion of attention to PM tasks was fixed for the duration of the ongoing task period for which the intention to detect cues was relevant. These findings are consistent with PAM theory and proposals in the literature that PM representations (such as those instantiated by retrieval modes; Guynn, 2003) hold a special status in memory that persist at *some* level until intentions are complete or the goals/context of tasks change (Goschke & Kuhl, 1993; Lebiere & Lee, 2001). Moreover, it indicates that these special status memory items persist in representations that affect task processing. That is, they share limited-capacity resources with task operations.

The PAM model is a multinomial model for cue detection and thus is not intended to predict actual response time values. Nevertheless, the preparatory attention parameter can be used to reliably estimate general differences in task interference observed as a function of task factors (such as cue presentation). For example, Smith and Bayen (2004) found that manipulating the categorical similarity between cues and non-cues increased the preparatory attention parameter estimate and task interference. However, *local adaptations* in the allocation of preparatory attention over the course of ongoing tasks cannot currently be captured by the PAM model, as it has a single preparatory attention parameter that is set to be equal for all trial types (see p. 759; Smith & Bayen, 2004). Nonetheless, PAM represents a good vantage point to start tackling the issues raised by the current paper and the Marsh et al. (2006a) paper within a formal mathematical modeling framework. For example, PAM could model the Marsh et al. data by using two preparatory attention parameters, one for relevant trials and one for irrelevant trials. In contrast, to capture the *variations* in preparatory attention that occurred from Block 1 to Block 3 in Experiment 3, the preparatory attention parameter would need to allow preparatory attention estimates to vary according to some function of the history of experienced task conditions, and the general passage of time.

According to the multiprocess view, there are several specific task parameters (e.g., strength of association between PM cues and responses, saliency of cues, focal processing) that determine whether a given context is likely to encourage automatic cue detection, and thus whether individuals are likely to allocate attention to the PM task (McDaniel & Einstein, 2007). Given that participants generally have knowledge of such conditions at the time task instructions are given, the multiprocess framework’s interpretation of task interference bears similarity to the attention allocation policy view in that it assumes that participants decide how much attention to the PM task will be required for cue detection after being instructed of the task conditions to be expected. However, in a situation where cues are unexpectedly but consistently presented in a salient manner (e.g., red font), the multiprocess view would presumably predict that participants would be able to rely more on automatic retrieval processes and thus reduce (or eliminate entirely) their attention to the PM task (but see findings of Smith et al., in press). However, there are no mechanisms specified in the current version of the multiprocess view that would account for such local adaptations in attention allocation to PM tasks with ongoing task experience.

The current findings also have implications for understanding real-world situations that may be especially prone to PM failure. PAM theory argues that preparatory attention is functionally related to PM performance. To the extent that preparatory attention is required for cue detection, the probability of cue detection should decrease with time spent in relevant ongoing task contexts (see Einstein et al. 2005), and this decrease in cue detection should be particularly large when no expected cues have been encountered. However, task interference does not always guarantee that cues will be better detected (Loft & Yeo, 2007; Marsh et al., 2005), as this depends on how attention resources are deployed and whether those resources are actually useful to cue detection. It is appropriate at this point to be clear that the current paper was not designed to enter the debate between PAM theory and the multiprocess view regarding whether PM retrieval can be totally resource free. Nonetheless, the multiprocess view would argue that attention to a cue can lead to automatic cue detection under certain conditions, and that although participants may allocate attention to the PM task because they think that it is required, the passage of time or lack of cue presentation may actually have no effect on cue detection.

On a final note, it must be acknowledged that it is difficult to pinpoint the precise nature and function of the cognitive mechanisms that give rise to task interference (for some discussion see Hicks et al., 2005; Loft, Humphreys & Whitney, in press). PAM theory claims that preparatory attention serves the function of mapping ongoing task stimuli onto intentions thus promoting the recognition of cues (Smith et al., in press). However, in addition to preparatory attention and other processes such as retrieval modes (Guynn, 2003), at least part of the task interference effect can potentially be driven by the stimulus. One mechanism that has been proposed is some form of post-stimulus processing check (Guynn, 2003; Marsh & Hicks, 1988). In addition, part of the task interference effect may be created by a sense of significance or familiarity with stimuli that initiates a memory retrieval process required to identify a cue (Loft et al., in press; McDaniel, Guynn, Einstein, & Breneiser; 2004). The fact that Marsh et al. (2006a) did not observe reductions in task interference for irrelevant trials randomly mixed with relevant trials does not support the post-stimulus processing view. In contrast, we cannot rule out post-stimulus processing as the word stimuli we used were all relevant to cue detection.

In conclusion, three experiments were presented that demonstrated that task interference was dependent on the presentation of PM cues, indicating that cue presentation affected the extent to which attention was recruited away from the ongoing task and allocated to the PM task. In this paper we have argued for the existence of some mechanism that adjusts the allocation of attention to PM tasks on the basis of task experience. We propose that this adaptive mechanism serves to protect ongoing tasks as much as possible from disruption, without comprising the flexibility that allows the rapid execution of intended actions when appropriate. Continued investigation into the reciprocal relationship between cue presentation and task interference is likely to be an important theoretical endeavor, and may provide insight into how individuals prevent long term intentions from interfering with everyday and professional work activities.

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Footnote

[1] We included a second set of PM-cue and PM-no cue conditions in Experiment 1. The original plan was to examine the influence of cue presentation on task interference using two common PM instruction protocols. In the two PM conditions we report in Experiment 1, participants were explicitly instructed to make their PM response *after* their ongoing task response. In the two additional PM conditions we do not report in Experiment 1, it was not specified to participants whether to make their PM response before or after their ongoing task response. Task interference effects were replicated in these latter conditions. There was significantly less task interference under conditions where expected cues were not presented (+60ms) compared to where expected cues were presented (+171ms), $t(39) = 3.29$, $p<.01$, and this effect held true for the analysis where only non-cue trials presented a minimum of 30 trials away from cue trials were included, $t(39) = 2.2$, $p<.05$. Further, task interference for the PM-no cue condition (+60ms) was significantly larger than for the control condition (-41ms), $t(38) = 4.63$, $p <.01$.

Table 1: *Average Time (in ms) to Respond to the Ongoing Task (and Task Interference) as a Function of Cue Presentation in Experiment 1. Control Condition also included.*

	N	Block 1	Block 2	Task Interference
PM-Cue	20	624	718	+94
PM-No Cue	20	618	647	+29
Control	20	613	572	-41

Table 2: *Average Time (in ms) to Respond to the Ongoing Task (and Task Interference) as a Function of Cue Presentation and Task Importance in Experiment 2.*

		Importance		
Cue Presentation	N	PM Important		
		Block 1	Block 2	Task Interference
PM-Cue	20	569	707	+138
PM-No Cue	21	595	680	+85
		LD Important		
		Block 1	Block 2	Task Interference
PM-Cue	20	607	670	+63
PM-No Cue	20	579	594	+15

Table 3: *Average Time (in ms) to Respond to the Ongoing Task (and Task Interference Change Scores) as a Function of Cue Presentation in Experiment 3. Control Condition also included.*

	N	Block 1 (100 trials)	Block 2 (540 trials)	Block 3 (100 trials)	Task Interference Change Scores
PM-Cue	32	777	770	735	-42
PM-No Cue	31	761	727	663	-98
Control	30	616	617	611	-5

Note- Task Interference Change Scores = Block 3 minus Block 1.