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Delaying Execution of Intentions: Overcoming the Costs of Interruptions

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SUMMARY

In real-world settings, execution of retrieved intentions must often be briefly delayed until an ongoing activity is completed (*delayed-execute* prospective memory tasks). Further, in demanding work settings, the ongoing activity itself can be interrupted. Experiment 1 examined the effects of the delay length (5, 15, 40 s), the presence of an interruption within that delay, and the length of the interruption on prospective memory performance. Delay length did not significantly affect performance, but interruptions produced significant decrements in performance relative to a delay alone. The length of the interruptions (10 vs. 20 s) did not significantly affect performance. Experiment 2 replicated the negative effects of interruptions, and found that these effects could be overcome with a simple external mnemonic. We suggest that in demanding work environments where interruptions are likely, external cues are advisable, especially where prospective memory failures have critical consequences. Copyright © 2004 John Wiley & Sons, Ltd.

Our lives are replete with formulating intentions and remembering to perform them. In recent years, there has been increased interest in experimentally investigating this type of memory (typically called prospective memory; see the special issue of *Applied Cognitive Psychology*, 2000). Experimental paradigms of prospective memory typically involve busily engaging participants in an ongoing task while at the same time asking them to perform an action upon seeing a particular target item. For example, participants might be asked to rate words for pleasantness (the ongoing task), and also to perform the prospective memory task of remembering to press a designated key on the keyboard when they see a particular target word. A characteristic of these experiments is that participants are allowed to perform the action immediately upon seeing the target word. In many respects this is representative of real-world prospective memory tasks. For example, you may intend to give your colleague a message, and upon seeing that colleague, if you remember to do it, you can immediately communicate the message. Upon reflection, however, the real world is filled with delays and interruptions that often prevent a person from executing an intended action as soon as it is retrieved. In our prosaic example, it is very likely that upon

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seeing your colleague and retrieving the intention to give a message, you need to delay execution because your colleague is busily engaged in conversation or someone greets you and engages you in conversation. We have labelled these prospective-memory situations *delayed-execute prospective memory* tasks (McDaniel, Einstein, Stout, & Morgan, 2003).

There are some important differences between the delayed-execute prospective memory task and the kind typically studied in the laboratory (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). In a typical laboratory paradigm, participants are given prospective memory instructions, with ample time to encode the target item and associated intended action, and informed that the target item might occur in some later task (often 10 to 30 min later; Einstein, Holland, McDaniel, & Guynn, 1992). Further, the event signalling that the moment is appropriate for performing the task is typically a specific target item. In delayed-execute laboratory tasks, by contrast, participants must retrieve the intention when a salient cue occurs and prepare for the additional prospective memory demand (respond at the end of a short delay) in the midst of performing an ongoing activity. Also, the delays are much briefer (5 to 40 s in the present research) and the target for executing the action is typically less specific (e.g. the end of the conversation your colleague is engaged in). These features of a delayed-execute task might encourage more active maintenance of the intention over the brief delay than is ordinarily engaged in the standard laboratory prospective memory task (Einstein, McDaniel, Lyle, Pagan, & Dismukes, 2003). In as much as performance may be influenced by different factors in these two kinds of prospective memory situations, the delayed-execute task merits empirical attention.

The above point is especially germane from an applied standpoint because delays and interruptions of this type are particularly prevalent in demanding work settings where forgetting can have critical consequences (Loukopoulous, Dismukes, & Barshi, 2001). Consider a setting in which a controller forms the intention to reroute an airplane but cannot do so immediately because of ongoing demands. This is illustrated by a real-life example in which one of our friends was piloting a light aircraft under instrument conditions. He was being vectored by air traffic control to intercept the final approach course for landing. Just at the point at which the controller would normally clear the pilot to turn onto final approach, another aircraft declared an emergency. In responding to that emergency, the controller forgot to issue the first aircraft the normal instruction to fly into final course, leaving that aircraft headed across the course line and toward mountainous terrain (Dismukes, personal communication). This is not an atypical scenario for pilots and air traffic controllers, who routinely face interruptions and delays (Dismukes, Young, & Sunwalt, 1998).

In the face of the ubiquitous presence of interruptions in everyday contexts and in work settings, there is a serious gap in our understanding of how such interruptions affect prospective remembering. To address this issue, Einstein et al. (2003) developed a laboratory paradigm in which they embedded interruptions in a delayed-execute task. To approximate a dynamic work setting, they involved participants in a series of 1 min tasks that lasted over a 32 min period. Participants were told that whenever they saw a red screen, they should press a designated key on the keyboard but not until they completed the current task and the next task was presented (i.e. a task change). They manipulated the delay between the offset of the red target screen and the occurrence of the task change, with the delay varying between 5 and 40 s. In addition some of the 40 s delay periods had interruptions representing a new task that had to be performed embedded in them. These 15 s interruptions produced significant declines in prospective memory performance. Indeed, the 15 s interruption embedded in the 40 s delay lowered performance an additional 25% over the 40 s delay alone, which produced a drop of 20% from perfect performance.

The purposes of the present research were to replicate this initial finding, to examine the effects of the length of the interruption, and to begin to explore techniques for overcoming the negative mnemonic effects of interruptions.

EXPERIMENT 1

There are reasons to question whether the initial report of the negative effects of interruptions (Einstein et al., 2003, Experiment 1) is reliable. From several perspectives this decrement associated with an interruption is somewhat unexpected. First, the interruption has not increased the delay. Also, the interruption is like the ongoing task that it replaced, in as much both are unrelated to the prospective memory intention. Thus, given that the interruption did not influence the delay length and may not have influenced the amount of interference, one might expect no effect of interruption.

Second, some recent research by Hicks, Marsh, and Russell (2000) showed that multiple tasks intervening during the delay between the prospective memory instruction and the occurrence of the target event improved prospective remembering relative to a single intervening task. Hicks et al. interpreted this result as suggesting that transitions between tasks might increase the frequency of thinking about the prospective memory intention. Based on this reasoning, one might have expected that interruptions could actually improve prospective remembering. Along these lines, Mantyla and Sgaramella (1997) reported that interruptions to the ongoing task while the prospective cue was presented improved prospective memory relative to when the ongoing task was not interrupted during prospective-cue presentation.

On the other hand, other perspectives could lead one to expect negative effects of interruptions on prospective remembering. An interruption requires task switching, and there is an extensive literature showing that task switching requires resources (e.g. Monsell, Sumner, & Waters, 2003; Waszak, Hommel, & Allport, 2003; see Marsh, Hancock, & Hicks, 2002, in particular for costs of task switching on prospective memory performance). Assuming limited cognitive resources and also that resources are required to maintain an intention in a delay-execution prospective memory task (see Einstein et al., 2003), then interruptions would exact costs that would interfere with maintaining the intention. Another possibility is that an uncompleted intention produces some general level of tension that persists until the task is performed (Mantyla, 1996; Ziegarnik, 1927; see also Mantyla & Sgaramella, 1997). Perhaps performing any new task that arises, like that during the interruption, somehow reduces tension associated with the need to perform some other task—for instance the unfulfilled intention. Another way to conceptualize this is that perhaps intentions are stored at a general level (e.g. 'I've got something to do') and that performing a new task during the interrupted activity fulfils this general-level intention. From these latter two perspectives, interruptions may pose special challenges above that introduced by delays per se.

Given the conflicting expectations just outlined, it is important to establish the reliability of the Einstein et al. (2003, Experiment 1) finding of negative effects of an interruption on prospective memory, and this was one of the objectives of the first experiment.

Assuming that interruptions produce reliable decrements in prospective memory, several unexplored issues arise. One important empirical and applied question is whether the length of the interruption itself has an effect on performance. To address this question and to begin to examine the boundary conditions for interruption effects, we varied the interruptions so that they were either 10 or 20 s in length. We chose our shortest 10 s delay as a limiting case, assuming that nearly all real-world interruptions would be at least of this duration. Interestingly, by the task switching and tension reduction views mentioned that anticipate negative effects of interruptions, one would expect prospective memory decrements even with brief 10 s interruptions and no additional decrements with 20 s interruptions.

On the other hand, there is some suggestion that longer interruptions lead to greater costs in task switching (cf. Trafton, Altmann, Brock, & Mintz, 2003). If so, then the 20 s interruption could produce greater costs upon returning to the ongoing task demands, and consequently produce worse prospective-memory performance than the 10 s interruption.

Method

Design and participants

The design of this experiment was a 2×4 mixed factorial in which the length and type of delay (5 s, 15 s, 40 s, 40 s with interruption) were varied within subjects and the length of the interruption (10 s or 20 s) was varied between subjects. Participants were volunteers from the summer school population at Furman University, and they received $6 for their participation. Twenty participants were assigned to each of the two interruption conditions. Each participant was tested individually.

Procedure and materials

Our goal was to create an experimental procedure that was demanding and complex, and accordingly in addition to the primary ongoing activities we had participants perform a digit-monitoring task throughout part of the experiment (but not on the delayed-execute prospective-memory trials). Because of the potential confusion in performing several different tasks simultaneously, the instructions for each task were presented thoroughly and for one task at a time. First, the participant read each set of instructions off a written packet. The experimenter then explained the instructions further and gave examples or practice with the task. Participants were also prompted to ask questions between each set of instructions to clarify any aspect they did not understand. They were told that every part of the experiment was equally important, and thus they should try to perform equally well on all the tasks.

Participants were first told about the nine ongoing tasks that would be presented on the computer screen. These tasks consisted of the following activities: (a) categorize or rate on a five-point scale how well an object fits a given dimension; (b) answer four-choice trivia questions; (c) compute simple maths problems and select the answer among the five choices; (d) choose the best synonym (among five choices) for a given word; (e) judge which of two lines is longer; (f) rate the pleasantness of a word on a five-point scale; (g) identify a partially occluded object by choosing among three alternatives; (h) rate the similarity of a pair of words on a five-point scale; and (i) choose the letter (among three choices) that is not included in a given word. A heading (e.g. ‘TRIVIA’) appeared at the top of each screen to identify the task. During the instructions, participants were shown an example of each kind of task and given the opportunity to ask questions.

Participants were asked to enter their responses using the numeric keys on the right side of the keyboard. Right-handed participants were instructed to use their right hand for these responses, and left-handed participants were instructed to use their left hand; the keyboard was moved to a comfortable position for each participant.

Ongoing tasks were presented in sets of 12 trials with each trial presented for 5 s. Therefore, a given ongoing task lasted 1 min, which was followed by a new ongoing task. Each ongoing task was presented four times for a total of 36 min of ongoing-task trials.

Next, participants were told about the digit-monitoring task. Specifically, participants were told that during some trials, they would hear a series of single digits presented at the rate of one every 2 s and that they should press a counter (held in their non-preferred hand) every time they heard two odd-digit numbers consecutively. They were told to hold the digit counter throughout the entire experiment, and they were strongly encouraged to detect every occurrence of the consecutive odd-numbered digits. Participants were allowed to practice the digit-monitoring task with a sample tape until they were comfortable with the task (usually about 30 s).

Participants were then given the prospective memory instructions. They were told that during some of the trials, a red screen would appear on the computer screen for 1 s, and when this occurred, they were to press the slash key (/) on the computer keyboard, *but not until they finished the current task*. To ensure that participants understood the instructions, they were given a practice trial (with no digit monitoring) in which the experimenter paced them through sheets in a folder that contained two maths problems followed by a red sheet, followed by four maths problems, followed by a trivia item. Participants were told that in this set of trials, they should press the slash key when the task changed, which in the case of the practice trial occurred at the change from the math to the trivia items. Participants were asked to locate the slash key on the keyboard, and the experimenter clarified any questions they had at this point. They were asked to press this key with their dominant hand (i.e. the same one used to respond to the ongoing task items). To prevent participants from using their hand as an external cue (e.g. putting their hand over the slash key when the red screen occurred), they were told to put their non-dominant hand on their lap for the duration of the experiment.

Finally, the participants were told about the interruption task. Specifically they were told that on some trials, another screen would appear displaying the message ‘GO TO FOLDER.’ Whenever they encountered this screen, they were to stop performing the current ongoing task, open the folder (located beside the computer keyboard) containing a pattern comparison test (a test developed by Salthouse & Babcock, 1991). They were told to continue performing this task as long as the ‘GO TO FOLDER’ message remained on the screen. The items in the pattern-comparison test involved judging whether paired line drawings were the same or different by writing either an ‘S’ or ‘D’ in the blanks provided. While participants were performing this activity, they also had to monitor the computer screen to determine whether they needed to resume the ongoing task. These folder interruptions occurred twice during the experiment, and each time occurred during a 40 s prospective memory delay trial.

For half of the participants, the folder interruptions lasted 20 s; for the other half, they lasted only 10 s. The exact sequence on these trials was as follows: four trials of a new ongoing task (5 s per trial), the occurrence of the red screen (1 s), two trials of the ongoing task (5 s each), followed by either (1) the ‘GO TO FOLDER’ screen for 10 s followed by four trials of the ongoing task for 5 s each, or (2) the ‘GO TO FOLDER’ screen for 20 s followed by two trials of the ongoing task for 5 s each. Next, participants switched to a set of 12 trials with the new ongoing task (5 s each). In the instructions, participants were reminded that the folder task did not count as a 'change of task' as far as the prospective memory task was concerned. In other words, they were told that going to the folder task did not mean that it was time to press the slash key and that they must wait for the computer to switch to a new set of ongoing task trials. After receiving the general instructions for the interruption task, participants were shown examples of the pattern comparison task items and given the opportunity to ask questions.

Before beginning the experiment, the participants were reminded of the location of the number and slash keys on the keyboard and asked to tell the experimenter when they were supposed to press the slash key. They were also reminded of the importance of monitoring the computer screen during the 'GO TO FOLDER' task, so that they would not miss any of the ongoing task trials. They were then given the opportunity to ask any final questions before beginning the test trials.

As noted earlier, each set of 12 trials for an ongoing task lasted 1 min, and each of the nine tasks was presented four times for a total of 36 min. The four presentations of each ongoing task were spread out across the experiment, and the order of these tasks was determined randomly and constant for all participants. The signal to form an intention over a delay (a red screen) occurred during tasks 4, 8, 13, 18, 21, 25, 30, and 35. Thus, four of these (one of each type: 5 s, 15 s, 40 s, and 40 s with interruption) occurred within the first 18 tasks and four within the last 18 tasks. To control for factors such as fatigue, practice, and the tasks that the different delays were associated with, we created four counter-balancing orders such that across orders each type of delay occurred equally often at each task position (i.e. tasks 4, 8, 13, 18, 21, 25, 30, and 35). One quarter of the participants in each condition was assigned to each of these orders.

For all participants, the digit-monitoring task was present during 16 of the 36 tasks (i.e. 2, 3, 6, 10, 11, 12, 16, 17, 20, 23, 27, 28, 29, 32, 33, 34), and was never present during the occurrence of a red screen and the subsequent task change. The purpose of including the digit-monitoring task was to increase the overall demands of the computer tasks, so as to better approximate a complex and demanding work setting. Participants received no more than three consecutive tasks with digit detection or three consecutive tasks without digit detection, and the digit-monitoring task was limited to 16 of the 36 tasks so as to avoid a perfect association between the end of the digit task with the onset of the red screen trial.

Following the 36 test trials, participants completed a brief questionnaire that prompted them to write down what they were supposed to do whenever a red screen occurred and when they were supposed to make this response. This question was intended to ensure that failure to perform was not related to problems in remembering the general task instructions (a retrospective memory problem), but in remembering to perform the delayed intention (a prospective memory problem). Participants were also asked to indicate how often they rehearsed the intention on a 5-point Likert scale with '1' indicating constant rehearsal and '5' indicating that the intention always popped into mind (no rehearsal).

Results

An alpha level of 0.05 was used for all statistical analyses. We tabulated the proportion of correct prospective memory responses by counting the proportion of times (out of two) that participants remembered to perform the correct action anytime within the execution phase for each of the four delay conditions (5 s, 15 s, 40 s, and 40 s with interruption)

Table 1. Proportion prospective memory responses as a function of delay, interruption, and length of interruption in Experiment 1

Condition	Length of delay			
	5 s delay	15 s delay	40 s delay	40 s delay with interruption
10 s interruption	0.80 (0.07)	0.93 (0.05)	0.80 (0.06)	0.60 (0.07)
20 s interruption	0.85 (0.07)	0.85 (0.05)	0.90 (0.06)	0.73 (0.07)

Note: Standard deviations are in parentheses.

of the two experimental groups (with different interruption lengths). Table 1 provides the means and standard deviations. We scored a prospective memory response as correct if it occurred any time within the first 5-s trial of the execution period. Relaxing this scoring criterion to count responses made within the entire 1-min period of the new ongoing task did not change the results. Ninety-eight per cent of all of the responses occurred during the first 5-s interval.

First, to assess the effects of interruptions and interruption length we compared the performance levels of the two groups on the 40 s trials. The proportions of on-time responses were subjected to a 2×2 mixed analysis of variance (ANOVA) including the between subjects variable of interruption length (10 s and 20 s) and the within-subjects variable of the presence of an interruption in the 40 s delay condition (with or without interruption). As can be seen in Table 1, the mean proportion of correct responses was greater for the 40 s delays that did not have interruptions ($M = 0.85$) than for the 40 s delays with interruptions ($M = 0.66$). This main effect was significant, $F(1, 38) = 9.15$, $p < 0.01$. The main effect of interruption length was not statistically significant, $F(1, 38) = 2.66$, $p > 0.05$, and the interaction effect was not significant ($F < 1$).

Next, to assess the effect of the delay per se, the scores were subjected to a 2×3 mixed ANOVA that included the between subjects variable of interruption length (essentially identical conditions for the non-interrupted delays examined here) and the within-subjects variable of delay length (5 s, 15 s, and 40 s). As can be seen from Table 1, there was little change in performance as a function of delay length, resulting in nonsignificant effects for this analysis (F (2, 76) $= 1.57$, for the interaction; Fs < 1 for the main effects).

Other measures

Responses to the post-experimental probe to determine the degree to which participants remembered what it was they were supposed to do on prospective memory trials (retrospective memory for the task) confirmed that all participants remembered the content of the prospective memory instructions. A one-way ANOVA was computed for participants' self-reports regarding rehearsal of the intention (5 point scale, with '1' representing 'constantly rehearsed' and '5' representing 'always popped into mind'). There was no significant difference between the 10 s interruption group ($M = 2.80$, $SD = 1.38$) and the 20 s group ($M = 3.05$, $SD = 1.64$) in terms of reported rehearsal ($F < 1$).

Discussion

This experiment reinforces previous work showing that good levels of prospective remembering occur even when there are delays before execution, at least for younger adults under demands that are not extreme (more extreme demands could involve divided attention during the delay-execute prospective memory task; cf. Einstein et al., 2000, 2003). In the delays with no interruptions, participants remembered to execute the prospective memory response over 80% of the time. Interestingly, and consistent with the results of Einstein et al. (2003), there was no effect of the length of the delay before executing the intended action. The absence of the effect of delays ranging from 5 to 40 s contrasts with the typically found effects of delays of this magnitude in the retrospective memory literature (e.g. Peterson & Peterson, 1959; Washburn & Astur, 1998).

Important from an applied perspective is that this finding also would probably contrast with peoples' intuitions. To test this impression, we asked 34 new participants (from the same participant pool used in this experiment) to make estimates in the following situation, 'Imagine that you are working on an essay question and get the thought to add an argument to a previous question. Before adding that argument, however, you first want to finish answering the current question. Based on what you know about how your own memory works, rate how likely (from 0% to 100%) you are to remember to add the argument to the earlier question when it takes you 5, 15, or 40 s to finish the current question.' Participants were asked to make their ratings under ' hurried exam conditions.' These participants viewed the 5 s delay as minimally problematic and expected to remember 90.4% of the time. Participants had lower estimates of 79.1% at the 15 s delay and 62.9% at the 40 s delay. Thus, people expect that brief 5 s delays are not as problematic as 40 s delays.

Given these expectations of decline over delays, people may be likely to engage rehearsal or other cognitive strategies for remembering intentions over brief delays. In doing so, participants may overcome normal effects of memory disruption with time (e.g. Baddeley, 1990; Schweickert & Boruff, 1986). To the extent that these participants rely on rehearsal to maintain activation of the intention over the delay (McDaniel et al., 2003), the present results imply that short delays over which the ongoing activity remains the same does not pose dramatic challenges for intention maintenance (unless it is critical not to make this kind of error, in which case even low levels of forgetting would be problematic; see Einstein et al., 2003).

By contrast, when an interruption was introduced into the delay, there was a negative effect on maintaining the intention, as prospective memory performance significantly declined. This replication of the interruption effect indicates that it is a robust phenomenon. The interruption did not increase the length of the delay interval (i.e. for the 40 s delay conditions, with the interruption the delay remained 40 s in length), so the negative effect could not have been due to an increased delay. Another idea raised in the introduction is that multiple transitions between ongoing tasks present opportunities for retrieving the prospective-memory task demands (Hicks et al., 2000). Counter to this idea, quickly paced transitions caused by interruptions interfere with delayed-execute prospective memory performance. The apparent discrepancy between the Hicks et al. report of positive effects of multiple transitions and the present finding of negative effects of interruptions (multiple transitions) underscores our analysis at the outset suggesting fundamental differences between the typical laboratory paradigm and delayed-execute tasks.

Our finding of negative effects of interruptions also contrasts with the Mantyla and Sgaramella (1997) report that interrupting the ongoing task at the time the prospective memory cue is present improved prospective memory performance. There are a number of differences in the paradigms that could be critical for these divergent effects of interruptions, including the present focus on a delayed-execute task. Another clear difference between Mantyla and Sgaramella's interruptions and those in the current experiment is that the interruptions in Mantyla and Sgaramella's study coincided with the period at which the prospective memory action was to be performed (during presentation of the prospective memory cue), whereas in the present experiment the interruptions occurred prior to the point at which the prospective memory action was to be performed. Identifying the critical parameter(s) responsible for these divergent patterns remains for future research.

One possible interpretation for the present finding is that interruptions create task-switching costs (e.g. Marsh et al., 2002; Monsell et al., 2003; Waszak et al., 2003). Assuming that maintaining the intention over the delay requires resources (Einstein et al., 2003), these task-switching costs could account for the decline in prospective memory after interruptions. Another possible explanation is that performing an interrupting activity mistakenly reduces tension for the prospective memory intention (e.g. perhaps represented as a general goal to perform an action in addition to the normal ongoing activity).

Moreover, the magnitude of the negative effect was similar for the 10-s and 20-s interruptions. Thus, our results indicate that this effect occurs even with brief interruptions as short as 10 s. This pattern fits well with the task-switching interpretation because regardless of the length of the interruption there were two task switches. The tension reduction interpretation also is consistent with no effect of interruption length. Further research to inform these theories could examine variables like the number of task switches and whether or not interruptions involved accomplishing a goal. Experiment 2 turns to the more applied issue of improving performance in the face of interruptions.

EXPERIMENT 2

The results of Experiment 1, along with those of Einstein et al. (2003, Experiment 1) using a somewhat different paradigm, established that interruptions to ongoing activity produce significant declines in remembering to perform intended actions that must be briefly delayed. These types of interruptions are prevalent in everyday activities and perhaps particularly so in many demanding work settings, like the aviation context noted in the introduction where forgetting to perform briefly-delayed intentions can have serious consequences. Accordingly, a compelling issue that has important real-world implications is to the extent to which certain techniques can mitigate the prospective memory failures associated with interruptions. This experiment evaluated the effectiveness of one kind of technique that a priori seemed to hold promise in this situation.

For several reasons, we were discouraged about the potential of cognitive techniques such as rehearsal or perhaps forming implementation intentions at the outset of the interruption (implementation intentions involve forming a specific condition-action encoding, which seem to benefit older adults in more standard prospective memory paradigms; Chasteen, Park, & Schwarz, 2001). Einstein et al. (2003, Experiments 2 and 3) found that neither rehearsal instructions nor implementation-intention instructions produced gains in delayed-execute performance under demanding divided attention conditions. Moreover, Experiment 1 suggested that interruptions might interfere with the maintenance of the intention in focal awareness, so even if participants were instructed to rehearse, they might not be able to implement rehearsal processes during the interruption. We therefore considered the possibility that a noticeable external signal associated with the uncompleted intention might overcome the negative effects of brief interruptions. In line with this possibility, Sharps and Price-Sharps (1996) have shown that an external visual cue—in this case an ugly green plate placed on the table—was an effective reminder for helping older adults with everyday prospective memory tasks. However, Vortac, Edwards, and Manning (1995), in a laboratory prospective memory paradigm based on an air-traffic control simulation, found no benefits of a continuous external cue for remembering to change the course of an airplane at some point later in the task. The Vortec et al. paradigm differed in several critical ways from the present focus, however, so it is not clear how an external cue would affect performance for a delayed-execute task like that used here. For instance, in Vortec et al. there were no unrelated tasks that interrupted the ongoing air-traffic control task, as in the case of the present interruption paradigm. In other cases as well, however, reminder cues have been found not to be effective (cf. Guynn, McDaniel, & Einstein, 1998). Thus, whether or not an external reminder would attenuate the negative effects of interruptions is uncertain.

In the present experiment in the external mnemonic condition, the offset of the red screen was accompanied by the onset of a small but noticeable blue dot positioned in the lower right-hand corner of the display. Participants in this condition were informed that the blue dot was a reminder to remember to press the slash key.

Method

Design and participants

The design was a 2×4 mixed factorial, with the reminder condition (no reminder, reminder) varied between participants and the length and type of delay (5 s, 15 s, 40 s, 40 s with interruption) varied within participants. Participants were either introductory psychology students or students enrolled in other psychology classes (junior level courses or lower) at the University of New Mexico who received course credit for participating. In initial work with this paradigm we had observed that low-working memory participants (working memory scores below 13 from the Operation Span task developed by Turner & Engle, 1989) tended to disregard the delay-execute instructions and respond immediately upon presentation of the red target screen (M. A. McDaniel, G. O. Einstein, T. Graham, & E. Rall, Poster presented at the meeting of the Psychonomic Society, Orlando, FL, 2001). Accordingly, we restricted participants to those with an Operation Span score of 13 or higher. Of these 51 participants, three were dropped for failing to follow instructions. The remaining 48 participants were equally divided between the two reminder conditions.

Procedure

Upon completing an informed consent form, participants were first tested on the Operation Span working memory task (Turner & Engle, 1989). Participants' Operation Span scores were quickly determined, and participants who scored 13 or higher were included in this experiment. Participants also completed a Stroop colour-word interference task for purposes unrelated to the present study. After completing the Stroop task participants were given the same instructions for the ongoing task, prospective memory task and the folder-interruption task as in Experiment 1. In this experiment, however, the digit detection task was omitted. Participants were given examples of the tasks but no practice on any portion of the experiment. The experimenter gave a spoken summary of the instructions after participants finished reading each section of the instructions, and participants were prompted in each section to ask questions to clarify the instructions.

For participants in the reminder condition, during the prospective memory instructions, the experimenter mentioned that a small blue dot would appear in the lower right-hand corner of the screen for a little while after each red screen. They were told that, 'the dot is there to help you remember to press the slash key but the dot will not tell you when it is appropriate to do so.' The ongoing tasks and prospective memory task were the same as those used in Experiment 1, except that eight rather than nine ongoing tasks were used and the interruption was 15 s.

As noted earlier, each set of 12 trials for an ongoing task lasted 1 min, and each of the eight tasks was presented four times for a total of 32 min. Each type of ongoing task was represented once within each block of eight tasks, the order of these tasks was determined randomly and constant for all participants. The signal to form an intention over a delay (red screen) occurred for eight of the 32 ongoing-task periods. For all participants one of each type of delay (5 s, 15 s, 40 s, and 40 s with interruption) occurred within the first 16 tasks (during tasks 3, 6, 11, 15), and another one of each type occurred within the last 16 tasks (18, 21, 26, and 30). To control for factors such as fatigue, practice, and the tasks that the different delays were associated with, we created four counter-balancing orders such that across orders each type of delay occurred equally often at each task position (i.e. tasks 3, 6, 11, 15, 18, 21, 26, and 30). One quarter of the participants in each condition was assigned to each of these orders.

Additionally, for the reminder condition, after each red screen a small blue dot (slightly less than 1 cm in diameter) was presented in the lower right-hand corner of the screen along with the stimulus items that were presented in the delay period following the red screen. For the interruption trials, the blue dot was present while the 'folder' stimulus word appeared, and for all prospective memory trials the blue dot remained until the second question after the target task change.

Finally, in this experiment participants called out responses to the ongoing task items, and participants were also asked to left-click the mouse as they called out their response. The mouse response was included to lead participants to believe that we were recording the speed of their responding, though no response was recorded (cf. Einstein et al., 2003, Experiment 1). All other procedures and materials were the same as those used in Experiment 1.

Results

Participants' prospective memory scores were tabulated as in Experiment 1 to create a proportion correct for each level of the within-subjects variable. Identical to Experiment 1, when prospective memory responses were made, over 98% of the time they occurred within the first 5-s trial of the new ongoing task. The means of these responses made during the first trial of the new task are presented in Table 2. Paralleling the Experiment 1 analyses, we first examined the interruption effect and the degree to which the reminder

Table 2. Proportion prospective memory responses by interruption and reminder conditions in Experiment 2

Condition	Length of delay			
	5 s delay	15 s delay	40 s delay	40 s delay with interruption
No reminder	0.96 (0.14)	0.92 (0.19)	0.94 (0.17)	0.79 (0.33)
Reminder present	0.90 (0.21)	1.00 (0.00)	0.94 (0.17)	0.96 (0.14)

Note: Standard deviations in parentheses.

attenuated the interruption effect. The scores were thus submitted to a 2×2 mixed ANOVA that included the between subjects variable of reminder group (no reminder, reminder) and the within-subjects variable of interruption condition for the 40 s delay (40 s, 40 s + interrupt). The interruption tended to lower performance, $F(1, 46) = 2.90$, $p < 0.10$ and the reminder condition tended to increase level of performance, $F(1, 46) = 2.80$, $p = 0.10$. Examination of Table 2 reveals that both of these trends were based entirely on the pattern that the interruption lowered performance for the no reminder but not the reminder group, $F(1, 46) = 5.15$, $p < 0.05$, for the interaction. Simple effects tests confirmed that in the no-reminder group, the interruption significantly decreased performance relative to the non-interrupted delay, $F(1, 46) = 7.88$, $p < 0.01$. By contrast, for the group given the reminder, the interruption produced absolutely no decrement in performance relative to the non-interrupted condition ($F < 1$).

To assess the effect of the delay per se and possible effects of reminders when there were no interruptions, a 2×3 mixed ANOVA was computed that included the between subjects variable of reminder group and the within-subjects variable of delay length (5 s, 15 s, and 40 s). Neither delay nor reminder produced general effects (both Fs < 1). There was a marginally significant interaction, $F(1, 92) = 2.71$, $p < 0.08$, such that at the 5 s delay, the no reminder group was somewhat better than the reminder group but with the longer 15 s delay this trend reversed. Probably not much can be made of this pattern, because at the third delay (40 s) there was no difference at all between the groups.

Other measures

Responses to the questionnaire at the end of the experiment indicated that all the participants remembered what it was that they were supposed to do when they saw a red screen.

To ascertain whether having a reminder present affected participants' propensity to rehearse, we conducted several analyses. We first tabulated the number of patterns correctly completed during the interruptions, with the assumption that increased rehearsal would reduce the number of patterns completed. There was no evidence of increased rehearsal with the reminder, as performance was slightly higher in the reminder group ($M = 17.12$) relative to the no-reminder group ($M = 16.71$; $F < 1$). Second, we submitted participants' ratings to the questionnaire item regarding the degree to which they relied on rehearsal (with '1' indicating constant rehearsal). Across the reminder groups there was no significant difference in indicated use of rehearsal ($F(1, 46) = 2.10$, $p > 0.15$), though the reminder group ($M = 2.21$, $SD = 0.98$) reported nominally more rehearsal than the no reminder group ($M = 2.62$, $SD = 1.01$).

Discussion

Several notable findings emerged from this experiment. First, for the non-interrupted delays, increasing the length of the delay again produced no decline in executing the prospective memory task. Prospective memory performance after delays ranging from 5 to 40 s was consistently high (Ms $= 0.93$, 0.96, and 0.94 for 5 s, 15 s and 40 s delays, respectively, and all over 0.90 in the no reminder condition). Indeed, relative to Experiment 1 (in which performance was generally under 0.90), the level of performance tended to be higher. Perhaps the elimination of the digit-monitoring task on non-prospective memory trials reduced possible fatigue or perhaps restricting participants to those with fairly good working memory, or both, enhanced rehearsal during the delay. Regardless, the present findings imply that in at least some circumstances delaying execution of a retrieved intention until the ongoing activity can be completed produces little penalty in terms of completing the prospective memory task.

Second, delayed-execute tasks become problematic when there are interruptions to the ongoing activity during the delay, as evidenced once again in the present experiment. Moreover, this experiment demonstrated that interruptions are problematic even for participants with relatively good working memory resources. Because the working memory measure used here assessed people's ability to retain information in the face of distraction (Turner & Engle, 1989), the negative effects of interruptions in this experiment suggest that interruptions introduce a level of distraction that is incompatible with human cognitive capabilities. Thus, external mnemonic techniques may be necessary to avoid delayed-execute prospective memory failures in a demanding work environment in which interruptions can occur.

The third and most novel finding from this experiment is that the negative effects of an interruption can be completely overcome with a simple external mnemonic. Thus, the present research suggests important benefits of an external cue for delayed-execute prospective memory situations. Further research is needed to identify the parameters of external cueing that maximize effectiveness. At this point, we suggest that an important dimension of an effective external prospective memory signal is that it be used relatively infrequently so that it is relatively distinctive. In this experiment the blue dot was on the screen for 4 min out of a 32-min task. This contrasts with Vortac et al.'s (1995) use of external cues for prospective remembering in an air traffic control simulation, in which an external cue (reminder) was present throughout most of the experiment. They found that this prolonged external cue provided no advantage for prospective memory performance relative to a control condition in which no cue was provided.

From an applied perspective, an important aspect of this successful 'blue-dot' mnemonic is that it is a device that can be easily implemented in real-world settings. One could imagine having a 'prospective memory' light (e.g. bulb on a panel, coloured dot on a monitor) that an individual could turn on either upon forming an intention or upon being interrupted. Theoretically, however, it might be unadvisable to wait until being interrupted to activate the light because interruptions are often unpredictable and capture attention fully. This idea is in line with Trafton et al.'s (2003) report that returning to interrupted activities (in the present case the prospective memory intention) can be facilitated when participants are able to prepare for the interruption prior to its occurrence.

CONCLUSIONS

Several new findings emerged in this study. First, when the ongoing task is not overly demanding, young adults like those in the present research do fairly well (by typical memory standards) at remembering to perform intended action regardless of delay. Of course, in real-world settings where failures can have catastrophic consequences, the relatively small forgetting rate is unacceptable. Second, by comparison, brief interruptions during the delay to the ongoing activity produce substantial decrements, despite not increasing the length of the delay. Third, length of interruption, at least within the ranges examined herein, do not themselves influence the magnitude of interruption effect. Even brief interruptions to the ongoing activity produce significant declines in prospective remembering. Fourth, the prospective memory decrements due to interruption can be eliminated, however, with a modest external cue. Fifth, interruptions are problematic even for those with medium to high working memory capabilities (Experiment 2). Thus, highly cognitively capable people (high working memory has positive relations to other higher-order cognitive abilities; Engle, Tuholski, Laughlin, & Conway, 1999) are not immune to the negative effects of interruption on remembering delayed intentions. Even for professions that rely extensively on these kinds of individuals, there is cause for concern with regard to the level of successful delay-execute prospective memory performance possible when interruptions are present.

The applied implications are that in a demanding work environment where interruptions are likely, implementing a system of external cueing might be advisable to prevent prospective memory errors when execution is delayed. Importantly, the external reminder improved performance without interfering with performance of the interruption activities. Thus, there appear to be no negative costs to including a visual external reminder. Such a system would seem to be especially important in work settings where prospective memory failures are costly or have critical consequences. As noted earlier, in air traffic control settings or other aviation settings, even a small percentage of delayed-execute errors may be unacceptable.

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