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Interruptions Create Prospective Memory Tasks

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SUMMARY

When the theory of prospective memory is brought to bear on the ubiquitous experience of failing to resume interrupted tasks, the cognitive reasons for these failures may be understood and addressed. We examine three features of interruptions that may account for these failures: (1) Interruptions often abruptly divert attention, which may prevent adequate encoding of an intention to resume and forming an implementation plan, (2) New task demands after an interruption's end reduce opportunity to interpret resumption cues, (3) The transition after an interruption to new ongoing task demands is not distinctive because it is defined conceptually, rather than by a single perceptual cue. Hypotheses based on these three features receive support from two experiments that respectively manipulate encoding and retrieval conditions. The data support our contention that interrupted tasks are a special case of prospective memory, and allow us to suggest practical ways of reducing vulnerability to resumption failure. Copyright © 2008 John Wiley & Sons, Ltd.

Everyday tasks and specialized workplace tasks are interrupted frequently. Individuals are vulnerable to forgetting to resume interrupted tasks in a timely manner (Dismukes & Nowinski, 2006; Dismukes, Young, & Sumwalt, 1998); when they do resume they may struggle to mentally reconstruct the status of the interrupted task, and they are vulnerable to increased error rates (Monk, Boehm-Davis, & Trafton, 2004; Speier, Valacich, & Vessey, 1999; Trafton, Altmann, Brock, & Mintz, 2003).

Forgetting to resume an interrupted task after an interruption is annoying in everyday life, but in some workplace settings forgetting to resume can be fatal. For example, in 1987 an airline crew taxiing for departure was interrupted repeatedly by various tasks and by a change in runway assignment as they prepared the aircraft for takeoff. When they were cleared for takeoff they failed to recognize that they had not set the flaps to takeoff position and had not completed the checklist that would have alerted them to the flap position. Unfortunately on this occasion the warning circuit that would have alerted them to the flap problem failed, and they crashed shortly after leaving the ground, killing all but one person on board (NTSB, 1988. Also see Loukopoulos, Dismukes, & Barshi, 2003, for further examples and discussion of the cognitive demands of cockpit interruptions).

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Interruptions are also ubiquitous in some aspects of medical practice, such as emergency medicine, and these interruptions are associated with various forms of error, including forgetting to perform intended actions (Chisholm, Collison, Nelson, & Cordell, 2000).

In spite of the sometimes drastic consequences of failing to remember to resume interrupted tasks on safety and effective performance, the prospective memory literature has examined interruptions only to a very limited extent. Mäntylä and Sgaramella (1997) interrupted ongoing tasks in an investigation of Zeigarnik-like effects, however this study did not use resumption of the interrupted task as the prospective memory task. Interruptions have also been used in the context of the *delayed-execute* paradigm (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003; McDaniel, Einstein, Graham, & Rall, 2004a). In this paradigm, participants were told to press a slash key when they encountered a specific target cue while performing an ongoing task, however they were to delay pressing the slash key until completing the ongoing task. On some trials, after receiving the target cue, but before completing the ongoing task, participants were interrupted by another ongoing task, which they performed until signalled to return to the original ongoing task. This form of interruption substantially impaired delayed execution of the prospective memory task.

In these delayed-execute studies, interruptions were used as a manipulation within the paradigm, similar to switching of ongoing tasks during the retention interval in other prospective memory studies (Finstad, Bink, McDaniel, & Einstein, 2006; Hicks, Marsh, & Russell, 2000). These studies did not use resumption of an interrupted ongoing task as the prospective memory task, nor did they explore the properties of interruptions *per se*. Given the real-world consequences of failing to remember to resume interrupted tasks, it is important to study this type of situation empirically and directly.

We argue that interrupting an ongoing task intrinsically creates a prospective memory task (Dodhia & Dismukes, 2003): The individual must remember to resume the interrupted task without explicit prompting, a defining characteristic of prospective memory tasks (Einstein, Smith, McDaniel, & Shaw, 1997; Graf & Uttl, 2001; Mäntylä, 1993; Maylor, 1993). Although the cognitive processes involved in prospective memory are not fully understood, considerable progress has been made in recent years (McDaniel & Einstein, 2000; Marsh, Cook, & Hicks, 2006; McDaniel & Einstein, 2007). From a theoretical perspective it would be useful to know if the cognitive processes involved in attempting to remember to resume an interrupted task resemble those identified in typical prospective memory paradigms. Also, demonstrating manipulations that would help individuals remember to resume interrupted tasks would have great practical importance.

Our paper explores why individuals often fail to resume interrupted tasks even though they intend to complete these tasks. Drawing on ethnographic observations of airline pilots (Loukopoulos et al., 2003), accident reports (Dismukes, Berman, & Loukopoulos, 2007), and diary studies of everyday tasks (Holbrook & Dismukes, 2005), we suggest that three features of interrupted tasks may account for much of the considerable vulnerability individuals have to forgetting to resume interrupted tasks until the consequences become all too apparent.

Our first hypothesis is that interruptions create *implicit*, but not necessarily explicit intentions. Interruptions are often abrupt and salient, quickly diverting attention. Thus, when interrupted, individuals may not have time or may be too distracted to encode an explicit intention to resume the interrupted task. In this situation the intention to resume the interrupted task is implicit in the original goal that originally caused the individual to undertake the task. But if no explicit intention is encoded at the time of interruption, what enables individuals to resume the interrupted task on the occasions in which they do

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succeed? It seems likely that in real-world situations individuals eventually encounter some cue that reminds them of the status of the interrupted task, which triggers retrieval of the original goal of performing the task. (See Kvavilashvili & Fisher, 2007, for discussion of the role of happenstance cues in everyday remembering.) But obviously this is a haphazard process. If this hypothesis is correct, individuals are more likely to remember to resume interrupted tasks when they form an explicit intention that links the intended action (resuming the interrupted task) in memory to specific cues likely to be encountered at the appropriate time.

Even when individuals do think at the time of interruption about the need to resume the interrupted task later, this thought may be fleeting because of the demands of the interruption. The individual may recognize the need to resume later but may not encode a specific plan or identify the conditions for resumption. Consistent with this perspective, reducing encoding by dividing attention has been shown to impair prospective memory performance (Einstein, et al., 1997; McGann, Ellis, & Milne, 2002). Also consistent with this perspective are naturalistic studies showing that prospective memory performance improves when participants are encouraged to form explicit implementation plans in which they identify specific times and circumstances for performing a deferred intention (Gollwitzer & Brandstätter, 1997).

Our first hypothesis suggests that resumption of interrupted tasks should improve if participants are given a short pause before engaging the interrupting task. However, it is not *a priori* certain that this would actually improve resumption of interrupted tasks in realistic conditions. In the divided attention studies cited above, participants were forced to divide attention during encoding. But it may be that when individuals are interrupted they pause at least momentarily and long enough to encode an adequate intention to resume the interrupted task. Thus it is important to design an experimental paradigm that interrupts participants abruptly, as often occurs in real-world situations, but allows them to pause before engaging the interrupting task *if they choose to do so*. The abrupt nature of real-world interruptions differs from most prospective memory paradigms in which participants are given specific prospective memory instructions and ample time to encode the target that will signal the time to perform the prospective memory task.

Two prospective memory studies have examined the effects of breaks during the retention interval, with conflicting results (Finstad et al., 2006; Hicks et al., 2000). However, these breaks were administered either during retention interval tasks or during the ongoing task, rather than during encoding under circumstances that may quickly divert attention from elaborating an intention to resume the task that is being interrupted.

Our first hypothesis also suggests that resumption of interrupted tasks should improve if participants are explicitly reminded before engaging an interrupting task of the need to resume the interrupted task. Prospective memory has been shown to improve when participants receive reminders during the retention interval while performing an ongoing task (Guynn, McDaniel, & Einstein, 1998), however the effects of reminders during participant-initiated encoding of intentions has not been studied, and reminders have not been studied at all in the context of remembering to resume interrupted tasks. Contrary to our prediction, encoding reminders might not improve resumption of interrupted tasks if participants adequately encode an intention to resume on their own. Thus it is desirable to compare the effect of encoding reminders with both a no-reminder condition and with a pause condition that allows participants ample time to encode.

Our second hypothesis is that new ongoing tasks that follow immediately after an interruption ends lead individuals further away from remembering to return to the

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interrupted task. The end of an interruption in real-world situations is often followed immediately by other task demands (Holbrook & Dismukes, 2005; Loukopoulos et al., 2003) that may not allow the individual sufficient time to fully process and interpret environmental conditions signifying that the interruption is over and that the associated intention should be retrieved. For example, in the airline accident described previously, the crew was interrupted while performing the pre-takeoff checklist by a radio call and, after responding to the radio call, still other unexpected task demands arose.

In some cases, source activation from environmental cues associated with new task demands may support retrieval of the goals associated with these task demands preferentially over retrieval of the goal to resume the interrupted task. Thus resumption of interrupted tasks may improve with a delay between the end of the interrupted task and the beginning of new task demands. Arguably, this delay would provide a short period in which retrieval of the intention to return to the interrupted task would not have to compete with retrieval of goals for other tasks. This prediction is consistent with studies showing that dividing attention at retrieval impairs prospective memory performance (Einstein et al., 1997; Einstein, McDaniel, Smith, & Shaw, 1998; McDaniel, Robinson-Riegler, & Einstein, 1998), apparently by increasing demands on the central executive (Marsh & Hicks, 1998). However, similar to the issue with encoding pauses, forced divided attention during retrieval does not really capture the situation in which individuals continue to a new ongoing task if they do not remember that an interrupted task has not been completed.

Our third hypothesis is that the flow of ongoing tasks following an interruption often does not distinctively mark the transition from the interrupting task to the next ongoing task that is presented. The condition for resuming the interrupted task is framed intrinsically as the end of the interrupting task. But if an individual is simply responding to a series of task demands as they arise, he or she may not frame the current situation as the end of the interrupting task and the beginning of a new ongoing task. McDaniel et al. (2004a) argue that interrupting the ongoing task with a different task in the delayed-execute paradigm substantially impairs remembering to execute the delayed intention in part because the offset of the interruption is less specific than the target cues used in most prospective memory paradigms.

This argument is also relevant to situations in which the prospective memory task is to remember to resume the interrupted task. The end of an interruption is defined conceptually and must be inferred from multiple aspects of the situation, rather than by a single perceptual cue. This suggests that explicitly delineating the end of the interruption as such should help individuals remember to resume interrupted tasks. Delineating the end of the interruption by explicitly labelling it as such would both make it distinctive and perhaps serve as a reminder cue. In typical prospective memory paradigms, performance has been shown to improve when distinctive cues are used, such as having a target word appear in all capital letters among lower case words for the ongoing task (Brandimonte & Passolunghi, 1994; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). Some forms of reminder cues, but not others, have been shown to improve prospective memory performance in typical prospective memory paradigms (Guynn et al., 1998).

A major challenge for our research was to design a paradigm that would capture critical aspects of real-world interruptions and allow us to systematically explore the three potential sources of variance described above. We needed to interrupt participants in a setting in which they would intend to resume the interrupted task without expecting to be prompted. The interruption should be abrupt but participants should be able to control whether they immediately engage the interrupting task or first pause and, perhaps, encode

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an explicit intention to resume the interrupted task. We also needed new task demands to arise after the end of interruptions in a way that seemed natural and which would not unduly call attention to the fact that the interruption was over. Finally, we needed repeated measures of participants' performance, which is often difficult in naturalistic studies (but see Rendell & Craik, 2000, for an exception).

We settled upon a design that has naturalistic aspects but allows repeated measures. Participants are required to answer a series of questions resembling the scholastic aptitude test (SAT), arranged in blocks, and are instructed that when blocks are occasionally interrupted they should return to the interrupted block after completing the interrupting block but before continuing to next block. We found that in the baseline condition participants frequently forgot to resume the interrupted task as they continued the series of ongoing tasks after the interruption was over. This, plus the effects of several manipulations on performance, supports our argument that interruptions can be viewed as prospective memory tasks.

We made three specific predictions based on our analysis of potential sources of variance: (1) Resumption of a task that is abruptly interrupted will be increased by providing a prompt, or perhaps simply an opportunity, to encode or elaborate an explicit intention to resume the interrupted task. (2) Resumption of interrupted tasks will be improved by decreasing competing demands for attention during the window of opportunity for returning to the interrupted task. (3) Resumption of interrupted tasks will be improved by making the offset of the interrupting task distinctive in relation to the end of other blocks of ongoing tasks.

The first two predictions were tested in Experiment 1 and the third prediction in Experiment 2.

EXPERIMENT 1

The procedure for Experiment 1 is depicted in Figure 1. The experiment included four conditions, conducted between participants. In the *baseline condition* participants answered questions presented on a computer in a series of blocks; the types of question changed between each block. A 'Loading next section' screen appeared for 2.5 seconds at

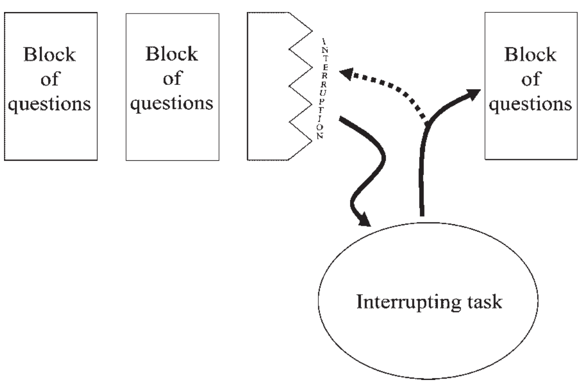

Figure 1. Baseline Condition. A task consists of a block of questions. Sometimes a task is interrupted by another task. At the end of the interrupting task, the computer carries on with the next task. Participants have the option of forcing the computer to resume the interrupted task

DOI: 10.1002/acp

the end of each block. Occasionally participants were abruptly interrupted in the course of one block by another block of a different type. At the end of the interruption participants had an opportunity to return to the interrupted block by pressing a key. Participants were instructed that after completing an interruption they should always return to the interrupted block before proceeding; however they were not given a prompt to do so at the end of the interruption.

To address the first hypothesis, that the sudden intrusion of an interruption discourages adequate encoding of an intention to resume the interrupted task, we used an *encoding reminder* condition in which the interruption began with a four second text message: 'Please remember to return to the block that was just interrupted'. In order to identify whether any improvement in performance is due to the explicit reminder or the four second delay, we also included an *encoding pause* manipulation in which participants saw only a blank screen for four seconds at the beginning of the interruption.

This experiment also included a manipulation to address the second hypothesis, that individuals sometimes forget to resume an interrupted task because interruptions are often quickly followed by other task demands. These task demands draw attention away from the task just interrupted, and weaken the chances that environmental cues will trigger the intention to resume the interrupted task. One might imagine that the 'Loading next section' message that appeared for 2.5 seconds after the end of interrupting blocks (and after all other blocks) would give participants enough time to reflect on whether they should do anything else before starting the block after the interruption. But we suspected that, because this pause was brief and because the message referred to the next section, participants might orient towards preparing for the next section and might not think about the implications of a new block of questions being loaded. (The end of the interrupting block implicitly signals that participants should return to the interrupted block before proceeding to a new block.) To test this hypothesis, we created a *retrieval pause* condition in which the delay after completion of all blocks, including interrupting blocks, was increased to between 8 and12 seconds. (The onset of the interruption occurred without delay, which was also the case in the baseline condition.) During the delay between blocks a countdown clock displayed the remaining time to the next block so it would be obvious to participants that they had plenty of time before new task demands would begin.

Participants

A total of 92 undergraduates were recruited from an introductory psychology course at San Jose State University and were given partial course credit for their participation. Participants were assigned to one of four conditions described below. The baseline condition (22 participants) and the two encoding manipulations (25 and 26) were tested first, and the retrieval pause condition (15 participants) was tested later. The data from four participants were discarded because debriefings revealed they had not understood the task or because the computer malfunctioned during the experiment.

Method

Baseline condition

Each participant answered 220 SAT-style multiple choice questions, which were divided into 20 blocks of 11 questions each. Each block contained only one of the following four

DOI: 10.1002/acp

categories of questions: Math, vocabulary, general knowledge and analogies. The category changed with each block, and questions appeared one at a time. The participant made a choice, pressed the 'Next' button and was given feedback on whether the answer was right or wrong. Then the next question in the block appeared. The questions were self-paced, but if a participant took more than 17 seconds over any question, a message appeared asking him or her to answer the question as soon as possible. At the end of the eleventh question in a block, the message 'Loading next section' appeared for 2.5 seconds. Then the next block of questions started. On average participants took 100 seconds to complete a block of questions.

Blocks 3, 7, 12, 16 and 18 were interrupted, during questions 5, 3, 7, 5 and 9, respectively. The interruption always occurred 2 seconds after a question had appeared, giving the participant enough time to start reading the question but not enough time to answer it. The interrupting task was also a block of 11 questions, but of a different category than the interrupted block. The interruption was marked by a change in the colour of the background screen, and the sudden replacement of the ongoing task by the interrupting task. This was distinct from the start of a regular block because the 'Loading next section' screen did not appear, and the question had not been answered. At the end of the interruption, the 'loading next section' screen appeared for 2.5 seconds, and then the participant was automatically taken to the next block in the sequence unless he or she remembered to return to the interrupted block by pressing the back-arrow key at the end of the interrupting block. The window of opportunity for returning to the interrupted block was the time between the end of the interruption and the beginning of the new block, plus the entire duration of the new block. If the participant pressed the back-arrow key during this window, he or she could finish answering the questions in the interrupted block. After completion of the interrupted block the display automatically advanced to the next block in the sequence.

If the participant pressed the back-arrow key at any time outside the window of opportunity, an alert appeared on the screen that stated 'You were not interrupted! Or you missed the chance to resume an unfinished section' and the display reverted to the beginning of the previous block, so that the participant had to advance through questions already answered. We felt this was sufficient incentive to keep the participants from pressing the back-arrow key at every opportunity. Not all participants committed a false alarm, and on average one false alarm occurred per participant.

Encoding reminder condition

The procedure for this condition was the same as that for the baseline condition, but with one addition: When a block of questions was interrupted, the interruption did not begin immediately. Instead, a screen appeared for 4 seconds with the words 'Please remember to return to the block that was just interrupted'. The message remained on the screen for 4 seconds and then the interrupting block started.

Encoding pause condition

The procedure for this condition was the same as that for the encoding reminder manipulation, except that no text appeared; the participants received a blank screen for 4 seconds. This condition served as a control to the encoding reminder condition, testing whether the reminder or just the pause associated with the reminder is responsible for any effect on resumption of interrupted blocks that might occur.

DOI: 10.1002/acp

Table 1. Description of the four between-subject conditions in Experiment 1

Condition	Lag before interruption	Lag after interruption
Baseline	None	2.5 seconds
Encoding reminder	4 seconds with reminder	2.5 seconds
Encoding pause	4 seconds blank screen	2.5 seconds
Retrieval pause	None	8–12 seconds

Retrieval pause condition

For all blocks, the period between the end of each block of questions and the beginning of the next block was increased from 2.5 seconds to 10 seconds on average (range: 8–12 seconds) and a countdown timer was presented on the screen to indicate time remaining before the next block. (The countdown timer was included to ensure that participants realized the amount of time remaining). During this 10-second period the 'Loading next section' screen appeared.

Table 1 provides a summary of the four different conditions in this experiment.

Procedure

Participants were given printed instructions stating that they should answer the questions as accurately and quickly as possible, and that if a block of questions was interrupted, they should complete the interrupting block and then press the back-arrow key to return to the interrupted block. Participants were asked to repeat back the instructions, and they were taken through a practice run containing five blocks of two questions each. They were shown how a block would be interrupted, and they practiced returning to it by pressing the back-arrow key at the appropriate time. The practice trials matched the condition to which the subject was assigned, so the practice for the retrieval pause condition contained the 8–12 second pause between blocks, while the practice for the encoding conditions had the same pause lasting 2.5 seconds. In the same spirit, the encoding practice trials had a 4-second pause before the start of an interruption (with the relevant presence or absence of text on the screen depending on the condition), while the retrieval pause practice trials did not have that pause. After the practice blocks, they were given unrelated questionnaires to fill out for 5 minutes and then began the experiment. At the end of the experiment, participants were asked debriefing questions to gauge their understanding of the instructions and to probe how they remembered to press the back-arrow key.

Results and discussion

Type I error (α) for all analyses was set to .05. Participants were scored as successfully resuming the interrupted task if they pressed the back-arrow key during the window of opportunity that lasted from the end of the interruption until the end of the block following the interruption. 49% of resumptions (across all conditions) occurred during the following block, however all of these late, but valid, resumptions occurred during the first question of the block. (Excluding these late resumptions did not appreciably change results in either experiment.) Figure 2 shows the mean proportion of interruption trials successfully resumed in each condition. In the baseline condition participants resumed the interrupted task only about half the time, indicating that it was challenging to remember to return to the interrupted task without prompting, even though the interruptions lasted less than

DOI: 10.1002/acp

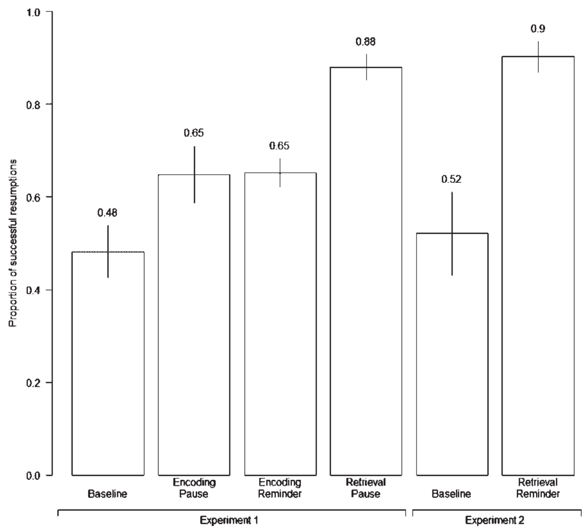

Figure 2. Mean resumption rate in all conditions in Experiments 1 and 2. Single standard errors are shown. The number at the top of each bar indicates the mean resumption rate

2 minutes. From a mean proportion of correct resumption of .48 in the baseline condition, the encoding pause manipulation increased performance to .65 and the encoding reminder also improved performance to .65. The retrieval pause improved performance to .88.The between-subjects factor of condition was significant, $F(3,84) = 9.15, p < .001$, in a one-way ANOVA with the score as the dependent variable. Bonferroni *post hoc* comparisons with the baseline condition showed that all three experimental conditions were significantly different from the baseline condition. The large increase in resuming interrupted blocks in the retrieval pause condition cannot be attributed to any differences in distinctiveness between the interrupted and non-interrupted blocks. Neither can it be attributed to any differences between the practice and test trials, since the practice also had the same 8–12 second pause between blocks.

These results support our hypothesis that individuals may not adequately encode an explicit intention to resume an interrupted task. Interestingly, the encoding reminder did not improve performance beyond that achieved with only an encoding pause, suggesting that encoding was hampered mainly by the abruptness with which the interruption occurred. These results also support our hypothesis that the onset of new task demands after the end of an interruption may interfere with retrieval of an intention (explicit or implicit) to resume the interrupted task.

EXPERIMENT 2

This experiment, conducted within participants, addressed our third hypothesis, that individuals are vulnerable to forgetting to resume interrupted tasks because the flow of ongoing tasks following an interruption often does not distinctively mark the transition from the interrupting task to the next ongoing task that is presented. As before, participants were interrupted on five blocks; two of these blocks were interrupted in the same way the baseline condition of Experiment 1 was interrupted. On the other three interruptions the

DOI: 10.1002/acp

'Loading next section' screen that appeared after the interruption also included the message 'End of interruption'. This manipulation makes the end of interrupting blocks distinctive in relation to the end of other blocks and explicitly delineates when the interruption is over. It may also serve as an indirect reminder of the need to complete interrupted blocks.

Participants

Twenty-six undergraduates were recruited from an introductory psychology course at San Jose State University and were given partial course credit for their participation. The data from two participants were discarded because the computer malfunctioned during the experiment.

Method

The method was identical to the baseline condition of Experiment 1, except that at the end of interruptions 1, 3 and 5, an additional message stating 'End of interruption' appeared under the 'Loading next section' message. This manipulation allowed a within-participant comparison with baseline condition trials.

Results and discussion

For each participant, two scores were calculated: The proportion of successful resumptions on baseline condition trials and the proportion of successful resumptions on trials with the 'End of interruption' message. This message improved performance from .52 (proportion correct) in the baseline condition to .90, which was significant by a two sample, Welch modified, *t*-test, $t(28.9) = 4.1$, $p < .001$. (See Figure 2: 'End of interruption' trials are labelled Retrieval Reminder.) Consistent with our hypothesis, these data show that distinctively delineating the end of an interruption helps participants remember to resume the interrupted task. This manipulation may also have served as an indirect reminder, as discussed in the next section.

GENERAL DISCUSSION

Participants in the baseline condition in both experiments frequently failed to resume the interrupted task, despite a clear understanding of the instructions. In post-experiment debriefings participants indicated that they understood how and when to resume interrupted blocks but simply did not think of the interrupted task when the opportunity to resume occurred. Conceivably, participants might have failed to recognize the interruptions as such when they occurred, interpreting the interrupting block to simply be a part of the interrupted block. The responses on the debriefing questionnaire do not support this interpretation. Also, the change in the colour of the display background and the abrupt switch in category of questions at the moment participants were reading an interrupted block question further argue against it. Thus the failures to resume clearly seem to be failures to remember to act on intentions when the opportunity arose, mimicking frustrating experiences with interruptions in everyday life.

The high proportion of resumption failures in the baseline conditions underscores the considerable vulnerability of individuals when interrupted and not prompted to resume the

DOI: 10.1002/acp

interrupted task. Although it may seem surprising that participants, in all conditions, sometimes forgot to resume a task that had been interrupted less than 2 minutes before, this result is consistent with previous studies showing that participants who retrieve an intention sometimes forget to execute that intention if they must defer execution for even a few seconds (Einstein et al., 2000; McDaniel, Einstein, Stout, & Morgan, 2003).

Both encoding and retrieval manipulations significantly increased the proportion of resumptions of interrupted blocks. The first encoding manipulation—presenting a message, 'Remember to return to the block that was just interrupted'—presumably prompted participants to encode an explicit intention to resume the interrupted task. However, this manipulation also provided a 4-second delay between the beginning of the interruption and the time at which the participant was presented the demands of the interrupting task, and so this manipulation may also have worked by allowing participants more time for encoding an intention. We explored this possibility with a second encoding manipulation in which participants received a 4 second blank screen, which produced a quantitative improvement in resumption performance identical to that seen with the explicit encoding reminder message. Of course we do not know that participants used the period with the blank screen to initiate or to elaborate encoding, but the fact that the explicit prompt and the unfilled lag before beginning the interrupted task had such similar effects suggests this may be the case. It is interesting that the explicit prompt did not provide any further advantage over the 4-second period free of competing demands. This suggests that impaired encoding in the baseline condition resulted primarily from the abrupt onset of new task demands, which is characteristic of many real-world interruptions.

One might argue that the two encoding manipulations simply called participants' attention to the fact of being interrupted, but that is the very point we are making: Interruptions divert attention so abruptly to new task demands that individuals do not adequately process the implications of this diversion and fail to adequately encode an intention to resume the interrupted task when a specific opportunity arises.

The results of the two encoding manipulations are consistent with previous studies showing reduction in prospective memory performance when attention is divided at encoding, presumably reducing the extent or specificity of encoding (Einstein et al., 1997). These results support our hypothesis that individuals sometimes fail to resume interrupted tasks in part because the abrupt onset of interruptions prevents them from adequately encoding an explicit intention to resume the interrupted when the opportunity arises. Our results are also consistent with Altmann and Trafton's (2002) prediction that interrupted tasks should be resumed more promptly if individuals use the lag between the onset of an interruption and beginning the interrupting task to encode links between the goal of resuming the interrupted task and environmental cues that may be encountered when the interruption ends.

The retrieval pause manipulation that increased the length of the 'Loading next section' screen from 2.5 seconds between blocks in the baseline condition to 8–12 seconds and added a countdown timer, improved resumption performance to .88. This large improvement in performance may have occurred because, when participants were freed of competing task demands for substantially more than 2.5 seconds, they had an opportunity to more fully interpret the situation and also may have queried memory for any tasks that they should be performing. These results are consistent with our hypothesis that when interruptions are followed by a series of other task demands, as is often the case in real-world situations, individuals are led down a 'garden path' diverting their attention further and further from the interrupted task. This interpretation is consistent with previous

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studies, using conventional prospective memory paradigms, showing that dividing attention at retrieval reduces performance unless the target cue is highly salient (Einstein et al., 1997; Einstein et al., 2000; McDaniel et al., 1998; McGann et al., 2002). Still other studies have shown that older participants, with diminished working memory capacity, perform worse on prospective memory tests than younger participants, if target cues are not salient (Einstein & McDaniel, 1990; Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995; Johansson, Andersson, & Rönneberg, 2000; Kliegel, McDaniel, & Einstein, 2000; Logie, Maylor, Della Sala, & Smith, 2004; West & Craik, 1999).

Two previous prospective memory studies have included pauses without task demands among their manipulations. Hicks et al. (2000) found that pauses during the retention interval improved prospective memory performance. In contrast, Finstad et al. (2006) found that pauses during ongoing tasks impaired prospective memory performance. However, neither of these studies used pauses in a way to increase the opportunity for initial encoding of a prospective memory intention or to reduce competing demands for attention at the moment when retrieval of the intention was required. These of course were the purposes of our encoding pause manipulation and our retrieval pause manipulation.

Providing the text message 'End of interruption' in the second experiment also increased performance dramatically. This manipulation explicitly delineated the end of the interrupting block and made this block distinctive in relation to other blocks. If participants were simply responding to the series of ongoing task demands they may not have monitored for the end of the interrupting block and may not have conceptually framed the transition from the interrupting block to the next block as 'the end of the interruption'. McDaniel et al. (2004a) suggested that the offset of an interruption in the delayed-execute paradigm is less specific than the target cues typically used in conventional prospective memory paradigms. In our paradigm, the 'End of interruption' manipulation made the target event much more specific than in the baseline condition. In other prospective memory paradigms, making the target cue highly distinctive has been shown to increase task performance (Brandimonte & Passolunghi, 1994; Einstein et al., 2000). Our results show that distinctiveness also improves prospective memory performance when the deferred intention is to resume an interrupted task.

The combination of distinctiveness and the occurrence of the specific phrase 'End of interruption' may have prompted participants to conduct a search of memory for the significance of the phrase and thus retrieve the deferred intention to resume the interrupted task. This possibility is consistent with the *discrepancy-attribution* hypothesis of McDaniel, Guynn, Einstein, and Breneiser (2004b), who suggested that noticing a discrepancy in the expected processing of an ongoing task may elicit a sense of significance about the target event, which in turn stimulates allocation of attention to determine why the event seems significant—in this case because the event is associated in memory with a deferred intention.

The 'End of interruption' manipulation may also have served as a reminder cue. Guynn et al. (1998) found that providing repeated reminders of a particular form while performing an ongoing task improved prospective memory performance. (These reminders were given during the retention interval for the prospective task rather than at encoding or retrieval.) The most effective reminders referred to both the target events and the intended action (e.g. 'Remember the three words you studied and remember what you should do if you see any of those words'). Reminders that referred only to the intended activity were less effective, and reminders that referred only to the target events were not effective.

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If our 'End of interruption' message functioned as a reminder, our results diverge from those of Guynn et al. because our message referred only to the target event. However, the prospective memory literature on the effects of reminder cues is inconsistent. Sharps and Price-Sharps (1996) found an external visual cue (not an explicit verbal reminder of the type used by Guynn et al.) helped older adults remember to perform everyday intentions, but Vortac, Edwards, and Manning (1995) found that a continuous external visual cue did not improve prospective memory performance in a simulated air traffic control task. McDaniel et al. (2004a), using the delayed-execute paradigm, found that the impairment of prospective memory performance caused by interrupting the ongoing task could be reversed by providing a simple visual cue—a blue dot in the corner of the display screen. These divergent findings suggest that the effectiveness of reminders strongly depends on the specific character of the prospective memory task as well as the nature of the reminder.

Our study does not allow us to determine the relative contributions of distinctiveness and reminding in our retrieval cue condition. Indeed, distinctiveness and reminding may be closely intertwined, as implied by the distinctiveness-attribution hypothesis. Further study will be required to explore what specific aspects of target cues prompt retrieval of intentions to resume interrupted tasks.

Comparing the magnitude of the effects of the two encoding manipulations on resumption performance with the magnitude of the effects of the two retrieval manipulations suggests that more improvement in resumption of interrupted tasks can be obtained by providing effective retrieval cues than by improving encoding—at least in our paradigm. One must of course be cautious in extrapolating results from any one laboratory paradigm to diverse real-world situations. Interruptions have been studied fairly extensively in the human–computer interaction literature, but the paradigms used focus on impaired quality of ongoing performance rather than on failure of resume interrupted tasks. In these paradigms the interrupted task remains apparent on the computer screen along with the interrupting task, so participants do not fail to resume the interrupted task. These studies have reported increased error rates (Speier et al., 1999), slower performance (Bailey, Konstan, & Carlis, 2001; Czerwinski, Cutrell, & Horwitz, 2000), impaired memory for the status of the interrupted task (Edwards & Gronlund, 1998), and increase in anxiety and perceived task difficulty (Adamczyk & Bailey, 2004) when interrupted tasks are resumed. Our study demonstrates that when the status of the interrupted task is not manifest, individuals are quite vulnerable to failing altogether to remember to resume the interrupted task.

Interruptions have been used as manipulations in at least two prospective memory paradigms (Einstein et al., 2003; Mäntylä & Sgaramella, 1997; McDaniel et. al., 2004a). However, prior to our study, remembering to resume an interrupted task has not been used as the prospective task. We argue that the need to remember to resume an interrupted task constitutes a special case of prospective memory. Interruptions share the general features of all prospective memory tasks: A delay between the time an intention is formed and the opportunity to execute the intention, and the lack of an external agent that explicitly prompts the individual to attempt to retrieve the stored intention. However, prospective memory tasks created by interruptions have special features that have not been well studied, in part because of the constraints of most existing laboratory paradigms. Those features are: (1) An abrupt intrusion that quickly diverts attention from the foreground task, (2) occurrence of new task demands as soon as an interruption ends and (3) a window of opportunity for resuming the interrupted task—the end of the interruption—that is defined only at a conceptual level by the confluence of diverse cues, rather than by the onset of a specific cue, such as a particular word.

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These three features are not unique to interruptions; they sometimes occur in diverse real-world prospective memory tasks. For example, in writing this discussion section we several times formed intentions to add material later in the section when we found a place in which the material would fit logically. The conditions for executing the intention, encountering a point of logical fit, are defined abstractly rather than in terms of a distinct perceptual cue. Perhaps for this reason we forgot to add this new material until reviewing our notes after completing the section.

To explore those special features we designed a laboratory paradigm that is arguably naturalistic (at least for our college student participants!), captures critical aspects of many everyday and workplace situations, and allows multiple observations for each participant. This new paradigm shares some features with the delayed-execute paradigm, and both paradigms differ from typical prospective memory paradigms in important respects. McDaniel et al. (2004a) point out that, in typical paradigms, participants are given prospective memory instructions with ample time to encode the target item and associated intended action. In both the delayed-execute paradigm and our interruption paradigm, participants must, while engaged in an ongoing task, encode an intention in the specific instance at hand to perform an action that must be deferred. In both our paradigm and the delayed-execute paradigm, the condition for executing the deferred action is defined situationally—completion of an ongoing task—rather than by presentation of a single perceptual cue.

Early studies of prospective memory were mostly naturalistic, and even though they pointed to intriguing issues, they did not allow systematic exploration of underlying cognitive processes (Brandimonte, Einstein, & McDaniel, 1996). Development of laboratory paradigms in recent years has greatly accelerated our understanding of prospective memory, yet it is crucial to recognize that prospective memory situations in everyday and workplace situations are quite diverse. There is great value in identifying the inherent characteristics of these diverse situations that may affect performance and in designing an array of laboratory paradigms to capture these characteristics.

In our study, the substantial error rate in the baseline condition and the large effects of our manipulations suggest that this paradigm is a useful tool for studying interruptions as a form of prospective memory task. Our manipulations affected performance in ways that are consistent with the results of some, but not all, studies using more typical prospective memory paradigms. The inconsistencies occurred in areas in which previous studies gave conflicting results. The divergent findings on some dimensions may well result from differences in the paradigms used, which underscores the fact that no one prospective memory paradigm is likely to capture all aspects of real-world situations.

The improvements in performance provided by the manipulations in our study suggest practical ways to help individuals remember to resume interrupted tasks: (1) Pausing at the beginning of an interruption to encode an intention and forming an explicit plan to resume the interrupted task, (2) creating salient, distinctive cues likely to be encountered and processed at the end of the interruption and (3) pausing whenever changing tasks to review whether all previous tasks have been completed.

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