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Prospective memory: Effects of divided attention on spontaneous retrieval

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Abstract We examined the effects of divided attention on the spontaneous retrieval of a prospective memory intention. Participants performed an ongoing lexical decision task with an embedded prospective memory demand, and also performed a divided-attention task during some segments of lexical decision trials. In all experiments, monitoring was highly discouraged, and we observed no evidence that participants engaged monitoring processes. In Experiment 1, performing a moderately demanding divided-attention task (a digit detection task) did not affect prospective memory performance. In Experiment 2, performing a more challenging divided-attention task (random number generation) impaired prospective memory. Experiment 3 showed that this impairment was eliminated when the prospective memory cue was perceptually salient. Taken together, the results indicate that spontaneous retrieval is not automatic and that challenging divided-attention tasks interfere with spontaneous retrieval and not with the execution of a retrieved intention.

Keywords Spontaneous retrieval · Prospective memory · Divided attention

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Daily life is filled with prospective memory demands, from remembering to take medication to remembering to pick up children from school. Intuitively, it seems that we are especially likely to forget to carry out prospective memory intentions when we are busy (McDaniel & Einstein, 2007). For example, we might forget to take medication when we are thinking about an upcoming presentation, or we might forget to pick up our kids when we are engaged in conversation with a neighbor. Consistent with this intuition, laboratory research has clearly demonstrated that increasing the attentional demands of the ongoing task interferes with prospective memory (Einstein, Smith, McDaniel, & Shaw, 1997; Marsh, Hancock, & Hicks, 2002; Marsh & Hicks, 1998; McDaniel & Scullin, 2010; McNerney & West, 2007; West, Scolaro, & Bailey, 2011).

An important theoretical question is what prospective memory processes are compromised by making the ongoing task more attentionally demanding by dividing attention. Prospective memory tasks can be accomplished via monitoring processes, in which people expend attentional resources to keep the intention activated while performing ongoing activities (Burgess, Quayle, & Frith, 2001) or to search the environment for the prospective memory cue (Smith, 2003). Regardless of the exact process, monitoring is thought to require capacity and to be a proactive process that needs to occur *before* processing of the target event in order to recognize it as a signal for an action. For example, a driver traveling in a new city might attend to the street signs while searching for an upcoming turn. Because of the complete agreement that such monitoring processes require working memory and/or attentional resources (Burgess et al., 2001; Einstein & McDaniel, 2005; McDaniel & Einstein, 2000; Smith, 2003; Smith & Bayen, 2005; Smith, Hunt, McVay, & McConnell, 2007), it is clear that an attentionally demanding divided-attention task should interfere with monitoring. Consistent with this expectation, previous research has demonstrated that divided attention impairs monitoring during vigilance tasks (Parasuraman & Davies, 1977). In the field of prospective memory, Marsh and Hicks (1998) demonstrated that divided-attention tasks that demand attentional resources (e.g., a random number generation task) disrupt prospective memory performance (see also McDaniel & Scullin, 2010). Noting that all of Marsh and Hicks's executive tasks required planning and monitoring, the authors suggested that these tasks interfered with an effortful search for the prospective memory cues.

Recent research has shown that prospective memory retrieval can also occur via spontaneous retrieval processes, in which a cue that has been associated with an intended action triggers retrieval of that intention in the absence of monitoring (Einstein et al., 2005; Harrison & Einstein, 2010; Scullin, Einstein, & McDaniel, 2009; Scullin, McDaniel, Shelton, & Lee, 2010). McDaniel and Einstein have proposed several spontaneous retrieval processes (McDaniel & Einstein, 2007; McDaniel, Guynn, Einstein, & Breneiser, 2004), including a reflexive associative process in which processing of the cue leads to reflexive retrieval of the intended action, and a discrepancy plus search process in which the processing fluency of the cue is discrepant relative to other items in that context and this leads to a controlled search of memory for the source of the discrepancy (i.e., a search for the significance of that item). Note that the term spontaneous retrieval does not imply *automatic retrieval*, because it is possible that not all components of these processes are automatic (Einstein & McDaniel, 2010). In other words, these proposed retrieval processes are spontaneously initiated by the occurrence of the prospective memory cue (rather than by monitoring), but some resources may still be required to deliver the associated action to consciousness.

Currently, it is unknown whether dividing attention impairs spontaneous retrieval. Previous research examining the effects of dividing attention on prospective memory performance (e.g., Einstein et al., 1997; Marsh & Hicks, 1998; McDaniel & Scullin, 2010) did not measure costs, or compromised speed or accuracy on the ongoing task as a result of having a prospective memory intention. Because spontaneous retrieval can only be inferred when retrieval occurs in the absence of ongoing task costs (Einstein & McDaniel, 2010), it is unclear whether lower prospective memory performance for the divided-attention conditions in these experiments was due to impairment to monitoring or spontaneous retrieval or both. In the present research, we strongly discouraged monitoring in an effort to localize the effects of divided attention on spontaneous retrieval processes. To the extent that we were successful, we could begin to evaluate the resource requirements of spontaneous retrieval processes.

One possibility is that spontaneous retrieval is a completely automatic process. The reflexive associative process described above is based on Moscovitch's (1994) view that the hippocampal system is an associative memory system that automatically retrieves memories when relevant cues are processed. From this view, dividing attention should not interfere with spontaneous retrieval as long as the cues are fully processed. Some support for this hypothesis comes from the finding that older adults, who are assumed to have reduced working memory and attentional resources (Braver & West, 2008) show intact spontaneous retrieval processes when a task involves a single, fully processed prospective memory cue (Einstein & McDaniel, 1990; Mullet et al., in press; Scullin, Bugg, McDaniel, & Einstein, 2011). Similarly, patients with frontal lesions, who typically have difficulty forming and implementing plans, benefit from instructional manipulations (e.g., implementation intentions) that increase their reliance on spontaneous retrieval (Lengfelder & Gollwitzer, 2001).

Other research suggests that dividing attention may interfere with spontaneous retrieval. McDaniel and Scullin (2010) found that divided attention impaired prospective memory performance, even under conditions that encouraged automatized retrieval (i.e., the use of implementation intentions). These experiments, however, included no measure of costs (i.e., no control group that did not perform a prospective memory task), and thus dividing attention may have interfered with the quality of the participants' monitoring, and not with spontaneous retrieval.

Dividing attention could compromise spontaneous retrieval in several ways. One possibility is that dividing attention interferes with full processing of potential target events. Following the encoding specificity principle (Tulving & Thomson, 1973), we assume that spontaneous retrieval is more likely when the features of the target cue that are processed at retrieval match those that were thought about at encoding. When our attention is divided, we may perform only a shallow analysis of the objects in our environment, and this may not lead to enough processing (or the right kind of processing) to allow retrieval of an associated intention.

Demanding ongoing activities may also prevent a prospective memory intention from entering into conscious awareness. There may be a threshold for allowing off-task, cue-driven thoughts into awareness, and that threshold may vary depending on other demands placed on their attentional resources (McDaniel & Einstein, 2008). The idea is that individuals may allow many cue-driven thoughts into awareness when they are in a diffuse attentional state, but the threshold may be higher for allowing these thoughts into mind when attention is focused. Such a filtering mechanism would generally be adaptive in the sense of allowing people to maintain their focus of attention by not being continually interrupted by the retrieval of thoughts associated with meaningful cues in their environment. In the context of involuntary autobiographical memories, Conway and Pleydell-Pearce (2000) proposed that cues in the environment can potentially give rise to the activation and retrieval of memories but that an executive control system can suppress retrieval of these memories before they reach conscious awareness. They further proposed that this suppression mechanism is more active when people are in a focused state of attention. Empirical support for this claim has come from the finding that participants report fewer involuntary autobiographical memories when they are in a focused attentional state (Ball, 2007; Kvavilashvili & Mandler, 2004). In other words, involuntary autobiographical memories tend not to pop into mind when people are busily engaged in another task. Along the same lines, Schlagman, Kliegel, Schulz, and Kvavilashvili (2009) found that older adults reported fewer involuntary autobiographical memories than younger adults. They suggested that older adults find everyday life more attentionally demanding and, thus, involuntary autobiographical memories are less likely to pop into awareness. In terms of prospective memory, it may be that the processing of a focal cue triggers activation of the associated intention, but that the intention is less likely to reach conscious awareness when one's ongoing activities are highly demanding.

Another possibility is that dividing attention interferes with spontaneous retrieval by hindering a controlled search of memory following the noticing of a prospective memory cue. As we mentioned previously, one way in which spontaneous retrieval could occur is through a discrepancy plus search process (Breneiser & McDaniel, 2006; McDaniel et al., 2004). After experiencing a sense of discrepancy, dividing attention could interfere with initiating and/or following through on a controlled search to determine the source of the discrepancy.

Still another possibility is that dividing attention interferes with the execution and *not* the retrieval of a prospective memory intention. Spontaneous retrieval could be automatic, but successful performance of an intended action additionally requires that individuals select the retrieved intention, inhibit their ongoing activities, and execute the action. Given that retrieved thoughts are held in focal awareness only briefly without further rehearsal (about 2 s; Baddeley, 1986), it may be that dividing attention interferes with the ability to carry out these processes before the retrieved intention is lost from focal awareness (cf. Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003).

The goals of the present research were to examine the extent to which dividing attention interferes with spontaneous retrieval and to begin to assess these theoretical views. In order to demonstrate spontaneous retrieval, prospective memory retrieval must be shown in the absence of monitoring (Einstein & McDaniel, 2010; Harrison & Einstein, 2010). Thus, in this research, we took advantage of recent advances in the understanding of ongoing task methodology (i.e., instructional and task manipulations) to create conditions that heavily discouraged monitoring. Specifically, we used a single, focal prospective memory target event (A. Cohen & Gollwitzer, 2008; Einstein et al., 2005), emphasized the importance of the ongoing task (Einstein et al., 2005; Harrison & Einstein, 2010), presented only a few prospective memory targets at widely spaced intervals (McDaniel & Scullin, 2010), and led participants to believe that they were unlikely to see any prospective memory targets (i.e., participants were told that only 5 % of all participants would receive prospective memory targets). So that we would be able to evaluate whether participants were monitoring for the prospective memory targets, we asked them to perform both a lexical decision block with an embedded prospective memory task and a control block of the lexical decision task alone. Because monitoring is a capacity-consuming process, it produces measurable costs (i.e., decreased accuracy or slower response times on the ongoing task) during the prospective memory block as compared to the control block (Marsh, Hicks, Cook, & Pallos, 2003; Smith, 2003; Smith et al., 2007). Effect sizes for costs with a single target event are typically in the medium to large range (η_p^2 = .05 to .20; Smith et al., 2007). If we detected no evidence of costs in a situation with high power to detect them, this would indicate that we were successful in eliminating monitoring and examining spontaneous retrieval.

Again, our goal was to assess the extent to which spontaneous retrieval is automatic by assessing the effects of a divided-attention task on prospective memory performance. In Experiment 1, we divided participants' attention using a digit detection task. In Experiment 2, we switched to a more demanding random number generation task. In Experiment 3, we manipulated the salience of the prospective memory cue, with the goal of determining whether dividing attention interfered with noticing that cue or with execution of the retrieved intention.

Experiment 1

In Experiment 1, we divided participants' attention using a digit detection task. Previous research has shown that this task decreases both retrospective memory (Craik, 1982; Jacoby, 1991) and prospective memory performance (Einstein et al., 1997). Einstein et al. (1997) did not measure costs to the ongoing task, and therefore it cannot be determined whether the digit detection task in their experiment interfered with monitoring, spontaneous retrieval processes, or both. In the present experiment, we used conditions that discouraged monitoring and we measured ongoing task costs. If monitoring was eliminated and divided attention reduced prospective memory performance, we could conclude that spontaneous retrieval requires attentional resources. On the other hand, if no evidence of monitoring emerged and divided attention did not affect prospective memory performance, this would suggest that spontaneous retrieval is automatic.

Method

Participants and design The participants were 56 Furman University undergraduates who received either $10 or course credit. The design was a 2 × 2 within-subjects factorial with the variables of block (prospective memory, control) and attention (divided, nondivided).

Materials Participants were tested using E-Prime 2.0 software. A pool of 79 words and 80 nonwords were selected from Balota et al.'s (2007) norms to be the nontarget items in the lexical decision task. Half of the words and half of the nonwords were randomly assigned to List 1 and the other half were assigned to List 2. Words from the two lists were matched on length (*M* = 6.55 letters), frequency (*M* = 10.77 log frequency based off the Hyperspace Analogue to Language norms; Lund & Burgess, 1996), and mean response time in a lexical decision task (*M* = 671.43 ms). Nonwords were matched on length (*M* = 6.04 letters) and mean response time (*M* = 681.43 ms). The order of the lists and the order of the prospective memory and control blocks were counterbalanced. The prospective memory target was the word *level* for half of the participants and *issue* for the other half (log frequency ratings of 11.78 and 11.68, respectively).

Each block of the lexical decision task consisted of 320 trials and was divided into four quarters of 80 trials each. Half of the participants performed the digit detection task on Trials 1–80 and 161–240 (Quarters 1 and 3). The other half performed the digit detection task on Trials 81–160 and 241–320 (Quarters 2 and 4). The prospective memory target appeared on Trials 75, 155, 235, and 315 (twice when attention was divided and when it was not), and the matched control word appeared on the same trials in the control block.

Procedure First, participants read instructions for the lexical decision task. They were told that they would see strings of letters appear one at a time on the computer monitor and that they should press the key labeled *Yes* (the "5" key on the number pad) if a particular letter string formed a word and the key labeled *No* (the "6" key) if it did not. Every lexical decision trial consisted of a 500-ms fixation, the presentation of the letter string—which lasted until participants responded—and a 500-ms intertrial interval. The lexical decision task was referred to as the "speed task" throughout the experiment, in order to discourage monitoring. After reading the instructions, participants completed 10 practice trials and received speed and accuracy feedback. The purpose of this feedback was to emphasize the importance of quick and accurate performance on the lexical decision task.

After the practice trials, participants received instructions for the digit detection task. They were told that during some segments of the "speed task," they would hear digits (0–9) spoken at a rate of one digit every 2 s. The participants were instructed that they would only hear the digits on half of the trials in each block. They were told to press the key labeled *Odd* (the "R" key) whenever they heard two consecutive odd digits (Scullin, McDaniel, & Einstein, 2010). After receiving the instructions for the digit detection task, participants performed 20 practice trials of the lexical decision task with the digit detection task.

At this point, half of the participants (those who were completing the prospective memory block first) received instructions for the prospective memory task. We discouraged monitoring by referring to the prospective memory task as a "secondary task" and by telling participants that the target only occurred for 5 % of participants. Specifically, participants were instructed,

> While performing both the SPEED and ODD DIGIT tasks, we have an additional interest (but only a secondary interest) in your ability to remember to perform an action in the future. Specifically, the word "*level*" may appear, and once you see "*level*" we want you to press the "Q" key. You may press it as soon as "*level*" is presented or right afterwards. However, the word "*level*" only appears for 5 % of participants in this study and, therefore, it is highly unlikely that you will see it.

(The target word was *issue* in the counterbalanced condition.) Participants were required to press the "Q" key to continue.

Regardless of whether they completed the prospective memory or control block first, all participants then received these instructions:

> PLEASE KEEP IN MIND THAT YOUR MOST IMPORTANT GOAL IS TO PERFORM THE SPEED AND ODD DIGIT TASKS AS QUICKLY AND ACCURATELY AS POSSIBLE. IT IS IMPERATIVE THAT YOU GIVE THESE TASKS YOUR FULL ATTENTION. At this time, please call the experimenter over and repeat your instructions to him.

After participants repeated the instructions, the experimenter pressed a hidden key to allow them to continue. Next, participants completed the Mill Hill Vocabulary Scale (Raven, Raven, & Court, 1998), which took approximately 5 min.

After performing the first lexical decision block, participants who had completed the control block first received the prospective memory instructions. Participants who had completed the prospective memory block first were told that they no longer had to remember to press the "Q" key if they saw the prospective memory cue. After reading the instructions, participants explained them to the experimenter. The experimenter pressed a hidden key and participants completed the Shipley (1946) Vocabulary Scale before beginning the second block of lexical decision trials. After completing the second block, the participants were thanked and debriefed.

Results

An alpha level of .05 was used for all statistical tests. Cohen's d or η^2 are used to estimate effect size.

Ongoing task performance To determine whether participants were monitoring for the prospective memory targets, we examined whether there were costs on the lexical decision task in the prospective memory block, as compared to the control block. Data from the last five trials of each quarter (prospective memory target, two words, and two nonwords) were eliminated from analyses of ongoing task performance so that, if a participant made the prospective memory response a few trials late, this would not affect their ongoing task performance. The same procedure was used in Experiments 2 and 3.

First, we calculated the proportions of correct responses for the lexical decision task (accuracy data for all three experiments are reported in Table 1). We included these data in a 2 × 2 within-subjects analysis of variance (ANOVA) with the variables of block (prospective memory, control) and attention (divided, nondivided). We found a main effect of attention, indicating less accurate performance on the lexical decision task when participants were under divided attention (M = .95) as compared to nondivided attention (M = .96), $F(1,55) = 19.86$, $MSE = .00$, $p < .001$, $\eta^2 = .13$. Importantly, neither the main effect of block nor the interaction were significant (Fs < 1), thereby indicating that the presence of a prospective memory task did not affect accuracy on the lexical decision task.

Next, we calculated the average response times for correct word trials on the lexical decision task (Harrison & Einstein, 2010; Smith, 2003; Smith et al., 2007). The average response times were subjected to a 2 × 2 ANOVA like the one for the accuracy data. The mean response times for all three experiments are presented in Table 1. As expected, the ANOVA revealed a main effect of attention, indicating that participants were about 104 ms slower under divided attention (M = 644.40 ms) than under nondivided attention (M = 540.03 ms), $F(1,55) = 102.62$, $MSE = 5{,}944.87$, $p < .01$, $\eta^2 = .65$.

The main effect of block was not significant, indicating that participants were no slower on the ongoing task during the prospective memory block (i.e., no evidence emerged that participants were monitoring), $F(1,55) = 2.95$, $MSE = 3{,}504.98$, $\eta^2 = .05$, and the interaction was not significant, $F < 1$, indicating that the effect of divided attention on response times did not vary across the prospective memory and control blocks. Previous research by Smith et al. (2007) has shown medium to large-sized effects when participants monitor for a single salient target cue. The power to detect a medium-sized effect ($\eta^2 \approx .06$; J. Cohen, 1988) for the main effect of prospective memory condition was .96, and .99 for the interaction.

Digit detection task performance Performance on the digit detection task was assessed by tabulating the number of times participants responded to this task per divided-attention segment. To determine whether the digit detection task incurred a cost when participants had a prospective memory demand, we conducted a paired-samples t test comparing the number of times participants responded to the divided-attention task for the control and prospective memory blocks. Performance was not significantly different for the control (M = 21.33) and prospective memory (M = 20.58) blocks, $t(55) = 1.22$, $p = .23$. The power to detect a medium-sized effect was .96.

Prospective memory performance Prospective memory responses were scored as correct if participants pressed the "Q" key between the onset of the target and the offset of the second lexical decision trial after the target. Prospective memory performance was not affected by divided attention (60 % in the divided-attention condition and 65 % in the nondivided

Table 1 Lexical decision performance (standard deviations are in parentheses)

Experiment			Accuracy		Response Times	
			Divided	Nondivided	Divided	Nondivided
Exp. 1		PM	.95 (.03)	.96 (.03)	651.64 (109.75)	546.39 (59.59)
		Control	.95 (.03)	.96 (.03)	637.17 (136.36)	533.67 (64.51)
Exp. 2	(All 4 quarters)	PM	.92 (.05)	.96 (.03)	1,062.52 (521.24)	617.06 (157.30)
		Control	.92 (.06)	.96 (.03)	1,103.29 (580.11)	578.16 (75.33)
	(Last half)	PM	.92 (.05)	.96 (.03)	1,051.95 (549.44)	589.99 (81.18)
		Control	.92 (.06)	.96 (.03)	1,047.01 (544.00)	578.16 (80.08)
Exp. 3	Salient	PM	.93 (.05)	.96 (.03)	1,072.43 (409.68)	559.42 (46.27)
		Control	.93 (.04)	.96 (.03)	1,083.82 (436.95)	562.14 (62.21)
	Nonsalient	PM	.95 (.04)	.97 (.03)	1,283.94 (576.79)	624.50 (114.70)
		Control	.94 (.04)	.97 (.02)	1,280.79 (510.53)	613.14 (118.16)

condition), $t(55) = 1.03$, $p = .31$, $d = 0.14$. The experiment had high power (.96) to detect a medium-sized effect.

Discussion

This experiment represents the first attempt to examine the effects of divided attention on the spontaneous retrieval of a prospective memory intention under conditions that heavily discouraged monitoring. Importantly, lexical decision accuracy and response times as well as digit detections indicated that we were successful in eliminating monitoring, and thus we were able to evaluate whether divided attention affects spontaneous retrieval. Prospective memory performance was not significantly different under divided versus nondivided attention. This result suggests that spontaneous retrieval may be an automatic process that is not dependent on the availability of attentional resources. Although this finding contradicts the results of several previous prospective memory studies (e.g., Einstein et al., 1997; Marsh & Hicks, 1998; McDaniel & Scullin, 2010), it may be that the divided-attention task in those studies interfered with monitoring processes and not spontaneous retrieval processes.

Spontaneous retrieval may be automatic, but another possibility is that the digit detection task in this experiment was not demanding enough to interfere with spontaneous retrieval. This possibility seems reasonable considering that the divided-attention task of McDaniel and Scullin (2010), a random number generation task, slowed ongoing task responding by more than 1,000 ms, as compared to the 104-ms slowing in our experiment. Thus, before concluding that spontaneous retrieval is automatic, we thought it important to test for the effects of divided attention using a more effortful random number generation task.

Experiment 2

The purpose of Experiment 2 was to again test the effects of divided attention on spontaneous retrieval, but this time using a more demanding random number generation task. The random number generation task includes several processes: holding the set size of numbers, task instructions, and one's own concept of randomness in long-term memory, transferring this information to working memory in order to complete the task, monitoring the output to ensure randomness, and switching production strategies if needed (Jahanshahi, Saleem, Ho, Dimberger, & Fuller, 2006). Because this task places high demands on executive resources (Baddeley, 1986), it is often used to divide attention (Marsh & Hicks, 1998; McDaniel & Scullin, 2010). If spontaneous retrieval is completely automatic, then the results of Experiment 2 should mirror those of Experiment 1. On the other hand, if spontaneous retrieval is not fully automatic, then this more demanding divided-attention task should impair prospective memory performance.

Method

Participants and design Participants were 56 Furman University students who received $10 as compensation, and all participants were tested individually. The design of the experiment was a 2 × 2 within-subjects factorial in which block (prospective memory, control) and attention (divided, nondivided) were the within-subjects variables.

Procedure Experiment 2 was identical to Experiment 1 except that participants performed the random number generation task during the divided-attention segments of the lexical decision task. Participants were told that, during some segments of lexical decision trials, a metronome would play at a rate of one beat per second. Participants were instructed to say a random number (0–9) out loud along with every beat of the metronome. Participants were told that the random number generation task would only occur during half of the trials and that they only needed to perform this task when they heard the metronome. They were also told that this task was intended to be challenging, and they should focus on doing their best and avoid feeling discouraged if they found the task to be very difficult. Participants practiced the random number generation task for 30 s, after which they practiced the lexical decision task. They then performed 20 practice trials of the lexical decision task, while also performing the random number generation task.

Participants then completed the prospective memory and control blocks of the lexical decision task (as in Exp. 1, the order of these blocks was counterbalanced). These blocks were divided into four quarters each and participants performed the random number generation task on either the odd or the even quarters. Responses to the random number generation task were recorded with an external audio recorder.

Results

Ongoing task performance First, we examined whether participants were monitoring in the prospective memory block. To examine accuracy on the lexical decision task, we conducted a 2 × 2 ANOVA with the variables of block (prospective memory, control) and attention (divided, nondivided). The means are presented in Table 1. As in Experiment 1, this analysis revealed a main effect of divided attention, indicating that participants were less accurate on the lexical decision task under divided attention ($M = .92$) relative to nondivided attention ($M = .96$), $F(1,55) = 47.39$, $MSE = .002$, $p < .001$, $\eta^2 = .34$. Also consistent with Experiment 1, the main effect of block and the interaction between block and divided attention were not significant (Fs < 1). Thus, lexical decision accuracy did not vary across the prospective memory and control blocks, and this was the case regardless of divided-attention condition.

Next, we subjected the mean word response times for correct word trials to a 2 × 2 ANOVA with the same independent variables. Mirroring Experiment 1, the main effect of divided attention was significant, indicating that participants were slower on the lexical decision task under divided attention (M = 1,082.90) than under nondivided attention (M = 598.61), $F(1,55) = 49.64$, $MSE = 265{,}704.53$, $p < .001$, $\eta^2 = .44$. Also consistent with Experiment 1, the main effect of block was not significant ($F < 1$). Unlike Experiment 1, however, the interaction between block and attention was significant, $F(1,55) = 4.83$, $MSE = 18{,}386.58$, $p = .03$, $\eta^2 = .003$. We conducted analyses of simple main effects to determine the cause of this interaction. These analyses revealed that, under divided attention, response times during the prospective memory block (M = 1,062.52) were not statistically different from those in the control block (M = 1,103.29), $t(55) = 1.19$, $p = .24$, $d = 0.16$. Under nondivided attention, however, response times during the prospective memory block (M = 617.06) were significantly slower than those in the control block (M = 578.16), $t(55) = -2.07$, $p = .04$, $d = 0.32$, suggesting that participants were engaging resources to monitor for the prospective memory cues.

Because previous research suggests that monitoring wanes over the course of an ongoing task (Loft, Kearney, & Remington, 2008; Scullin et al., 2010a), and because we can only infer spontaneous retrieval under conditions of no monitoring, we examined whether costs of performing a prospective memory task would emerge in the last two quarters of each block of lexical decision task trials. These means are presented in Table 1. Using the same ANOVA as before, we again found a significant effect of divided attention, $F(1,55) = 50.21$, $MSE = 247{,}534.09$, $p < .001$, $\eta^2 = .45$, and no significant effect of block ($F < 1$). Critically, and unlike when all quarters of the lexical decision task were included, the interaction between block and divided attention was not significant ($F < 1$). That is, when we examined only the second half of the prospective memory and control blocks, we saw no evidence that participants were monitoring for the prospective memory targets, despite having good power to detect a medium-sized main effect of block (.96) and a medium-sized Block × Attention interaction (.99).

Random number generation task performance We used three measures of randomness to determine whether the random number generation task would incur costs from the participants' having to perform the prospective memory task (Towse & Neil, 1998). We examined redundancy, which is a measure of the equality of participants' responses (whether participants sampled each of the numbers the same amount or if they favored a few numbers); the random number generation score, which is a measure of the randomness in the sequence of numbers that the participants gave; and the turning point index, which is another measure of sequence regularity. Because monitoring was absent only in the second half of the prospective memory block, we conducted our random number generation task analyses only on performance during the second half of each block. Random number generation performance, as indicated by all three dependent measures, was not significantly different during the prospective memory block than during the control block (Fs < 1, ps > .65).[1] We had good power (.96) to detect a medium-sized effect in these analyses.

Prospective memory performance Prospective memory accuracy was scored in the same way as in the previous experiment. First, we examined prospective memory performance throughout the entire experiment. Participants were more likely to complete their prospective memory intention when their attention was not divided (M = 53 %) than when it was divided (M = 37 %), $t(55) = -2.96$, $p = .004$, $d = 0.40$. However, evidence of monitoring did emerge in the first half of the prospective memory block, so it was unclear whether this effect was due to the random number generation task disrupting monitoring or to spontaneous retrieval. Because we were interested in the effects of divided attention on spontaneous retrieval, we analyzed the prospective memory accuracy for the last half of the prospective memory block (i.e., one prospective memory target under divided attention and one under nondivided attention). Prospective memory performance was still significantly higher under nondivided attention (M = 54 %) than under divided attention (M = 34 %), $t(55) = 2.66$, $p = .01$, $d = 0.28$.

Discussion

Because we found no evidence of monitoring in the second half of the prospective memory block, we can infer that participants were relying on spontaneous retrieval. Critically, performing a highly demanding divided-attention task (McDaniel & Scullin, 2010) impaired prospective memory performance. Thus, the differences in prospective memory performance across the divided and nondivided segments of the lexical decision task demonstrate that a demanding divided-attention task interferes with spontaneous retrieval of a prospective memory intention.

From these data, we cannot make any theoretical claims about what aspect of spontaneous retrieval is affected by

[1] The results were the same when all four quarters of the lexical decision task were included in the analyses, all ts < 1.83, ps > .07.

divided attention. In Experiment 3, we sought to replicate the finding of impaired spontaneous retrieval with a concurrent random number generation task under conditions of no monitoring, with the additional goal of discerning whether divided attention affects the retrieval versus execution of a prospective memory intention.

Experiment 3

In Experiment 3, we manipulated the perceptual salience of the prospective memory cue in order to determine whether divided attention interferes with retrieval of the intention into awareness or with executing a retrieved intention (i.e., postretrieval processes). Assuming that the intention associated with highly salient cues is consciously retrieved, even under conditions of high demands (cf. Einstein, McDaniel, Manzi, Cochran, & Baker, 2000), finding similar disruptive effects of dividing attention with salient and nonsalient cues would suggest that dividing attention interferes with processes occurring after conscious retrieval, such as scheduling and executing the action during the retrieved intention's brief existence in focal awareness (McDaniel & Scullin, 2010). On the other hand, finding that divided attention affects prospective memory retrieval with a nonsalient cue but not with a salient cue would suggest that demanding ongoing activities interfere with the retrieval of the intention into conscious awareness.

A second goal of Experiment 3 was to replicate the finding that performing a concurrent random number generation task impairs spontaneous retrieval when the prospective memory cue is not perceptually salient. Given that some evidence for monitoring emerged in the first half of the prospective memory block in Experiment 2, we thought it important to again test for the effects of dividing attention under conditions that discouraged monitoring.

Method

Participants and design The participants were 64 Furman University students who received $10 as compensation. The design was a 2 × 2 × 2 mixed factorial design in which salience of the prospective memory cue (salient, nonsalient) was the between-subjects variable and block (prospective memory, control) and attention (divided, nondivided) were the within-subjects variables. A group of 32 participants was assigned to each of the between-subjects conditions.

Procedure The procedure for Experiment 3 was identical to that of Experiment 2, except that half of the participants received a prospective memory cue that was perceptually salient. For these participants, the prospective memory cue appeared in bold, capitalized, red font (all other items appeared in nonbold, lowercase, white font). The remaining half of the participants received a prospective memory cue that was not perceptually salient, just as in Experiment 2.

Results

Ongoing task performance As in Experiments 1 and 2, to determine whether participants were monitoring, we first examined accuracy and response times on the lexical decision task. To examine accuracy, we conducted a 2 × 2 × 2 ANOVA with the between-subjects variable of salience of the prospective memory cue (salient, nonsalient) and the within-subjects variables of block (prospective memory, control) and attention (divided, nondivided). The means are presented in Table 1. As in Experiments 1 and 2, the main effect of attention was significant, indicating that participants were less accurate on the lexical decision task when their attention was divided (M = .94) than when it was not divided (M = .97), $F(1,62)$ = 41.70, MSE = .001, p < .001, η^2 = .29. No other main effects or interactions were significant (ps > .08). Thus, no evidence was apparent that receiving a prospective memory task produced costs in lexical decision task accuracy.

Next, we examined the mean response times for correct word trials in the lexical decision task. The response times were subjected to a 2 × 2 × 2 ANOVA like the one for the accuracy data. These means are presented in Table 1. The main effect of divided attention was significant, indicating that participants were slower to respond to word trials when their attention was divided (M = 1,180.24 ms) than when it was not divided (M = 589.80 ms), $F(1,62)$ = 122.67, MSE = 181,888.13, p < .001, η^2 = .59. None of the other main effects or interactions were significant (Fs < 1.88, ps > .17). Thus, we found no evidence that participants were monitoring for the prospective memory cues. The analysis had high power (.99) to detect a medium-sized effect for the main effect of block.

Random number generation task performance We conducted three 2 × 2 repeated measures ANOVAs with the between-subjects variable of salience of the prospective memory cue (salient, nonsalient) and the within-subjects variable of block (prospective memory, control) for the same three measures of randomness that we used for Experiment 2. For all three measures, neither the main effect of block (Fs < 1.75, ps > .19), the main effect of salience (Fs < 1, ps > .75), nor the two-way interaction (Fs < 2.6, ps > .15) were significant. Importantly, no evidence emerged that participants' performance during the random number generation task was any less random during the prospective memory block, relative to the control block.

Prospective memory performance Prospective memory performance was subjected to a 2 × 2 repeated measures ANOVA with the between-subjects variable of salience of the prospective memory cue (salient, nonsalient) and the within-subjects variable of block (prospective memory, control). A main effect of salience was apparent, indicating that participants were more likely to execute the prospective memory response when the prospective memory cue was salient ($M = .91$) than when it was not salient ($M = .46$), $F(1,62) = 53.04$, $MSE = 0.124$, $p < .001$, $\eta^2 = .46$. The main effect of divided attention was not significant ($F < 1$). Critically, we observed a significant interaction between salience and divided attention, demonstrating that divided attention did not impair performance for participants who received salient targets (95 % for divided attention and 87 % for nondivided attention) but did impair performance for participants who received nonsalient targets (39 % for divided attention and 53 % for nondivided attention), $F(1,62) = 6.19$ $MSE = 0.06$, $p = .02$, $\eta^2 = .09$.

Discussion

Replicating Experiment 2, Experiment 3 showed that a highly demanding divided-attention task (random number generation) impaired spontaneous retrieval with a nonsalient, focal prospective memory cue. When the same cue was perceptually salient, however, prospective memory performance was high and did not suffer under divided attention. These results suggest that divided attention, with nonsalient target cues, interferes with retrieval of the intention into awareness. Once participants have retrieved the intention, however, as appears to be the case with the perceptually salient cue, divided attention does not affect their ability to schedule and execute the prospective memory response.

Additional analyses

As has been developed throughout this article, a critical requirement for inferring spontaneous retrieval is that retrieval must be demonstrated in the absence of monitoring. This requirement was met in each of the individual experiments; despite high power to detect a medium-sized effect (the typical effect size reported for monitoring for a single target event; Smith et al., 2007), we found no evidence of monitoring. It is still possible, however, that participants were engaging in some low-level monitoring that would only be detectable with very high statistical power. To maximize power for testing this possibility, we analyzed the data from all 176 participants in all three experiments (omitting the first two quarters of Exp. 2). Specifically, we conducted a 4 × 2 × 2 mixed ANOVA on lexical decision task response times with the between-subjects variable of group (Exp. 1, Exp. 2, Exp. 3 Nonsalient, Exp. 3 Salient), and the within-subjects variables of block (prospective memory, control) and attention (divided, nondivided).

We found a main effect of attention, with participants responding less quickly on the lexical decision task when their attention was divided ($M = 1{,}013.59$ ms) than when it was not divided ($M = 574.51$ ms), $F(1,172) = 214.22$, $MSE = 146{,}618.64$, $p < .01$, $d = 2.24$, $\eta^2 = .49$, and a main effect of group, $F(1,3) = 18.95$ $MSE = 211{,}045.07$, $p < .01$, $\eta^2 = .25$. Both of these effects were qualified by a Group × Attention interaction, $F(3, 172) = 17.82$, $MSE = 146{,}618.64$, $p < .01$, $\eta^2 = .12$, indicating that the response time cost to the lexical decision task from dividing attention was greater in Experiment 2 and in Experiment 3 nonsalient and salient (471.08, 663.54, and 517.35 ms, respectively) than in Experiment 1 (104.37 ms), which confirms that the divided-attention task (digit detection) was less demanding in Experiment 1. Most importantly, neither the main effect of block nor any interactions with block approached significance (Fs < 1.23, ps > .27). These results indicate that, even with very high power (.99) to detect a small-sized effect ($\eta^2 \approx .01$; Cohen, 1988) of block and very high power (.97) to detect a small-sized interaction between block and attention, no evidence of monitoring (or changes in monitoring) emerged in our experiments.

Although no evidence for monitoring was apparent at the group level, it may be possible that some participants were monitoring and that the decrease in prospective memory performance under divided attention in Experiments 2 and 3 was due entirely to reduced monitoring in the divided-attention segments for those participants. To examine this possibility, we conducted an individual difference analysis in which we identified those participants who were most and least likely to be monitoring. We analyzed only the data from Experiment 2 (omitting data from the first two quarters) and the Experiment 3 nonsalient condition because these two groups of participants received identical tasks and only these two groups showed an effect of divided attention on prospective memory performance. For this individual difference analysis, participants were separated into two categories on the basis of whether they showed any response time cost to the prospective memory block. To adjust for counterbalancing order, we first calculated the average practice effect for each group by subtracting the average response times in the participants' first block of the lexical decision task by the average response times in the second block. This was only done for participants' response times in the quarters when they did not have to perform the divided-attention task. The average practice effect for each group was added to the participants' average response time in the second block of trials to correct for the practice effect of performing an additional block of lexical decision trials (Einstein et al., 2005). Participants who performed the lexical decision task more slowly during the prospective memory block were considered those who were most likely to be monitoring and those who did not were considered to be the least likely to be monitoring.

Across our two groups (Exp. 2 and Exp. 3 nonsalient), 54 participants showed a nominal cost to the lexical decision task (M_{Cost} = 54.36 ms) and 34 participants did not (M_{Cost} = −38.75 ms). The proportion of participants showing a cost and not showing a cost did not differ, $\chi^2(1) = 0.56$, $p = .46$. To examine whether monitoring led to better prospective memory and could account for the effect of dividing attention on prospective memory performance, we conducted a 2 × 2 mixed ANOVA that included the between-subjects variable of cost (cost, no cost) and the within-subjects variable of attention (divided, nondivided). We found a main effect of attention, indicating that participants successfully executed the prospective intention more often when their attention was not divided (M = 52 %) than when it was divided (M = 38 %), $F(1,86) = 6.56$, $MSE = 0.12$, $p = .01$, $\eta^2 = .07$. Prospective memory performance was not statistically different for participants who showed a cost (M = 45 %) than for those who did not (M = 45 %), $F < 1$, and, critically, the decrements to prospective memory performance from dividing attention did not differ for those who showed a cost and those who did not, $F < 1$. Thus, no evidence emerged that the divided-attention effects on prospective memory were driven by the participants who were most likely to have been monitoring.[2]

General discussion

Previous research has demonstrated that divided-attention tasks impair prospective memory (e.g., Einstein et al., 1997; Marsh & Hicks, 1998; McDaniel & Scullin, 2010); however, none of these studies provided a clear index of monitoring, and thus it was not possible to determine whether divided attention interfered with monitoring processes or spontaneous retrieval or both. The goal of the present research was to extend previous work by isolating the effects of divided attention on spontaneous retrieval processes. To do this, we attempted to eliminate monitoring by emphasizing the importance of the ongoing task and presenting only a few widely spaced focal prospective memory cues (Einstein et al., 2005; Harrison & Einstein, 2010). Importantly, despite high statistical power, we found no evidence of monitoring in Experiments 1 and 3 or in the second half of the prospective memory block in Experiment 2. Our combined analysis also speaks to our success in eliminating monitoring. Combining the data from all three experiments provided excellent power to detect even a small-sized effect; still, we observed no evidence of monitoring. Thus, consistent with past research (e.g., Harrison & Einstein, 2010; Scullin et al., 2009; Scullin et al., 2010a), our results support the existence of spontaneous retrieval (i.e., that retrieval can occur in the absence of monitoring), and importantly they provide the first clear test of the resource requirements of spontaneous retrieval processes.

Our results indicate that the effects of divided attention on spontaneous retrieval processes depend on the nature of the divided-attention task and the salience of the prospective memory target cue. In Experiment 1, performing a moderately demanding divided-attention task (a digit detection task) did not impair prospective memory performance with a nonsalient cue. In Experiments 2 and 3, however, a highly demanding divided-attention task (random number generation) disrupted prospective memory with a nonsalient cue. Consistent with the conclusions of McDaniel and Scullin (2010), our results indicate that spontaneous retrieval processes are not fully automatic (Einstein & McDaniel, 2010).

Our results also provide leverage on the prospective memory processes that are not disrupted by a demanding divided-attention task. The results of Experiment 3 indicate that once an intention is consciously retrieved, divided attention does not interfere with the scheduling and execution of the intended action. The near ceiling prospective memory performance with a highly salient cue in both the nondivided and divided-attention conditions indicates that the significance of the prospective memory target was noticed even under divided attention and that dividing attention does not disrupt postretrieval processes that are necessary for carrying out intended actions (i.e., inhibiting the ongoing task demands and organizing an action; Ellis, 1996). It is important to note that the divided-attention task did not disrupt postretrieval processes under the present performance conditions, in which participants could perform the action immediately after retrieving the intention. In other research, when actions must be briefly deferred (as is the case when one retrieves the intention to take medication in the bathroom but then must hold onto the intention until one gets to the kitchen in which the medication is kept), divided attention has been shown to interfere with postretrieval processes such as maintaining the intention and/or scheduling and executing the response (Einstein et al., 2003; McDaniel, Einstein, Stout, & Morgan, 2003).

The finding that a highly demanding divided-attention task impaired prospective memory performance with a nonsalient cue is consistent with several possible explanations. One is that dividing attention may interfere with full processing of the target cue, which could compromise associative retrieval processes (Moscovitch, 1994). Indeed, the lowered accuracy on the ongoing task when attention was divided (in all of the experiments, but particularly in Exps. 2 and 3) suggests that dividing attention compromised the quality of processing of items appearing in the lexical decision task. Another possible

[2] The conclusions of this analysis were the same when we conducted regression analyses using monitoring cost to predict prospective memory performance. Monitoring cost did not significantly predict either nondivided prospective memory performance ($\beta = .05$, $p = .68$) or divided prospective memory performance ($\beta = .03$, $p = .80$).

explanation is that we may set a higher threshold for allowing cue-driven thoughts into conscious awareness when we are extremely busy or focused on the tasks at hand (Conway & Pleydell-Pearce, 2000). Following the reflexive associative account of spontaneous retrieval, it may be that processing of the prospective memory cue led to some activation of the associated intention, but the higher threshold for allowing thoughts into awareness may have prevented that intention from coming to mind. It may also be the case that the highly demanding divided-attention task in our experiments interfered with a discrepancy plus search process of spontaneous retrieval. Specifically, divided attention may have disrupted the initial perception of discrepant processing of the prospective memory target and/or a controlled search for the source of that discrepancy. Because we attempted to reduce the discrepancy between the prospective memory targets and nontarget items by presenting the nontarget items multiple times during the lexical decision task (Breneiser & McDaniel, 2006), however, we believe that discrepancy was unlikely to be a major factor in this research. At this point, further research is needed to examine these possibilities.

In finding no evidence that participants were monitoring for prospective memory targets, our results suggest that participants were relying on spontaneous retrieval in both the nondivided- and divided-attention conditions. Nevertheless, it is impossible to conclusively prove that all monitoring was eliminated, and it could be that participants were engaging in undetectable low levels of monitoring and that dividing attention interfered with those processes. But, if that is the case, then monitoring processes are much more subtle and less capacity consuming than previously thought. All theories of monitoring (Burgess et al., 2001; Guynn, 2008; Smith, 2003) assume that monitoring involves controlled processing and exacts measurable costs to the ongoing task. Smith et al. (2007), using task conditions that likely encouraged monitoring, found detectable costs (medium- to large-sized effect; an average cost of 88 ms) when the prospective memory target was a single highly salient item (e.g., the participant's name), and these costs would have been easily detected in our experiments. According to the preparatory attentional and memory processes theory, these costs reflect capacity consuming processes that perform recognition checks for the purpose of determining whether environmental events match the prospective memory target (Smith & Bayen, 2005). Although no theory has yet specified the exact capacity demands of monitoring, if one assumes that functional monitoring was taking place in our experiments, the negligible costs that we observed would seem to argue against certain types of monitoring processes such as a sustained controlled monitoring process that involved checking individual lexical decision items for whether or not they were instances of the target. Instead, one would have to argue for subtler monitoring processes such as the instantiation of a retrieval mode (although see Guynn, 2008, for evidence that a retrieval mode creates costs) or monitoring processes that involve periodic and infrequent activation of the prospective memory intention. Given our high power to detect even small-sized effects in the combined analysis, another implication of this interpretation is that some monitoring processes do not take up capacity and/or that some forms of monitoring may not be measurable with existing behavioral techniques.

Interestingly, with a perceptually salient prospective memory cue, divided attention did not affect prospective memory performance. This result suggests that highly salient cues help ensure the retrieval of the prospective memory intention into awareness even when attention is heavily divided. The finding of spared prospective memory performance with a highly salient cue demonstrates that the use of such cues is highly effective and should especially be considered when busy conditions are anticipated. Note again, however, that participants in the present experiments were able to immediately execute their prospective memory response, and divided attention would undoubtedly impair the ability to maintain an intention over a delay, even with a highly salient cue (Einstein et al., 2000; Einstein et al., 2003; McDaniel et al., 2003). Salient cues may not be the only route to conscious retrieval under divided-attention conditions, however. For example, effective prospective memory encoding processes (such as the use of implementation intentions; Gollwitzer, 1999; McDaniel & Scullin, 2010) may be more likely to lead to activation levels that exceed the threshold for allowing thoughts into awareness under busy conditions.

In summary, the present experiments provide the first clear demonstration that highly demanding divided-attention tasks pose serious threats to carrying out intended actions, not only because they interfere with monitoring processes (Parasuraman & Davies, 1977), but also because they disrupt spontaneous retrieval. The finding that a highly demanding divided-attention task impaired prospective memory performance under conditions of no monitoring indicates that spontaneous retrieval processes are not fully automatic. A well-functioning attentional system enables us to focus resources on currently active goals while suppressing distraction. One consequence of highly demanding ongoing activities is that they make us less sensitive to consciously realizing the significance of prospective memory cues in our environment.

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