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The Role of Interruptions and Contextual Associations in Delayed-Execute Prospective Memory

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Summary: We conducted three experiments to examine the dynamics of a delayed-execute prospective memory task involving task interruptions. In the delayed-execute paradigm, participants must delay a response until some future condition is met. After an intention was formed to a salient cue, an interruption reduced prospective memory relative to a no-interruption condition. Prospective memory for cues encountered during an interrupting task was worse than for cues occurring before an interruption, but the location of the cue in either the ongoing task or the interruption did not affect prospective memory. Importantly, reinstating the prevailing context after the interruption alleviated the negative influence of the interruption. Providing participants with information about the future context for making the delayed-execute response also alleviated some of these deficits presumably because participants could encode more specific features of the performance context. These results highlight the potential importance of contextual associations and reminders in completing everyday intentions successfully.

A routine day for an administrative assistant, pilot, or nurse involves performing several complex tasks separately, switching between those tasks, and at times performing them simultaneously. Performing multiple tasks interchangeably typically requires more cognitive effort than either performing them separately or switching between them. Multitasking performance correlates positively with perceived multitasking ability, but those perceptions are inflated (Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). Although many individuals either consider themselves multitaskers or at very least believe they can perform multiple tasks concurrently fairly well, 'supertaskers', or those individuals with exceptional multitasking ability to perform certain tasks simultaneously without showing deficits, represent less than 5% of the population (Strayer, Watson, & Drews, 2011).

The fact that many individuals overestimate their cognitive functioning for these tasks highlights the importance of investigating how individuals formulate goals and future intentions throughout a busy day while switching between various activities. In most instances, following a daily plan to manage one's schedule allows an individual to anticipate when one task will be completed and the next task will begin. In other instances, however, task changes may be either unpredictable or involuntary and thus represent unplanned interruptions during a primary task that may impair performance. Indeed, research on both task switching and interruptions have revealed negative effects on prospective memory (Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003; Finstad, Bink, McDaniel, & Einstein, 2006; Kliegel, Mackinlay, and Jäger (2008); McDaniel, Einstein, Graham, & Rall, 2004; McDaniel, Einstein, Stout, & Morgan (2003); McNerney & West, 2007; West, Scolaro, & Bailey, 2011). Understanding how, and when, future intentions go uncompleted can inform us about how to circumvent failures of either encoding or retrieval. The goal of this set of experiments is to understand the fate of fulfilling delayed intentions that we formulate in the context of interruptions that occur so frequently in our workplace environments.

The ability to fulfill future intentions is referred to commonly as prospective memory. Despite the fact that prospective memory is crucial to performing real-world tasks, and its failures can cause many errors and serious accidents in work place settings (Gawande, Studdert, Orav, Brennan, & Zinner, 2003; Grundgeiger, Sanderson, Venkatesh, & MacDougall, 2010; Liu, Grundgeiger, Sanderson, Jenkins, & Leane, 2009), relatively little is known about how people fulfill their intentions successfully during everyday interruptions. The laboratory paradigm that has come to dominate research in this area attempts to simulate those real-world situations in which a person is cognitively engaged in an activity and an environmental event, or cue, appears during the task that is part of a previously encoded intention (i.e., event-based prospective memory). Many versions of experimental tasks engage participants in an ongoing activity that requires participants to press a key on the computer keyboard when they encounter a cue in that ongoing activity (e.g., Einstein, Holland, McDaniel, & Guynn, 1992; Ellis & Milne, 1996; Maylor, 1996, 1998; Rummel, Einstein, & Rampey, 2012).

This traditional event-based paradigm, however, does lack some features that are a representative of real-world prospective memory tasks, and therefore, simple modifications to the paradigm allow ways to better simulate those situations. For example, Einstein, McDaniel, and their colleagues noted that the standard event-based prospective memory task does not capture those instances in which a person wants to complete an intention, but is temporarily prevented from doing so (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). For instance, seeing a coworker may trigger the intention to deliver a message, but if that coworker is engaged in conversation, fulfilling the intention may require one to wait and

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hold onto the intention until an appropriate moment arises. Even if one could maintain the intention in working memory over such short delays, the effect of real-world delays may be worsened by interruptions from unexpected events (e.g., getting an important work-related phone call). Einstein et al. (2003) have shown that interruptions like these dramatically disrupt intention completion in various contexts and even for intentions that are being maintained over very short delays (see also Dismukes, Berman, & Loukopoulos, 2007; Shum, Cahill, Hohaus, O'Gorman, & Chan, 2013).

The most common method used to study delay and interruption effects on laboratory prospective memory performance is the delayed-execute paradigm (e.g., Einstein et al., 2000). In this paradigm, participants cycle through various ongoing activities, which simulated multitasking contexts quite well because tasks are repeated, interleaved, and allow opportunities for interruptions at various locations of a task. Prospective-memory cues used in this paradigm are typically salient such as the onset of a red computer screen or an uppercase word against all lower case words; high salience ensures that virtually everyone will notice cues and will reencode the initial intention to respond after a delay. The design of the delayed-execute paradigm prevents participants from responding to the cue immediately, as they would in standard event-based tasks, because responses must occur following and not during a task. When participants see a cue and *retrieve* the general intention they formed at the beginning of the experiment, they must instead *formulate* a delayed intention to wait until the current ongoing activity changes and provides an opportunity to respond.[1] In essence, the delayed-execute paradigm represents a unique combination of both event-based (e.g., salient cue that signals the retrieval of the delayed intention) and activity-based (i.e., memory to fulfill the intention after completing another task) prospective memory. See Brewer et al. (2011) for a comparison of these intentions.

Because the earlier studies on the negative effect of interruptions on delayed prospective memory, some research has manipulated aspects of the interruptions in an effort to understand how they affect performance. McDaniel et al. (2004) replicated the task-interruption effect reported by Einstein et al. (2003) and verified that the duration of retention interval from cue occurrence to task change does not change performance in younger adults. Moreover, the duration of the interruption did not seem to impair performance. Such performance following interruptions might be a favorable representation of typical everyday behavior especially because Dodhia and Dismukes (2009) found that participants frequently fail to return to interrupted tasks spontaneously. Because previous research using the delayed-execute paradigm reinstated the interrupted task and this spontaneous reinstatement represents only a subset of our daily activities, we wanted to investigate the effect of contextual reinstatement on delayed/interrupted intentions. In addition to contextual reinstatement effects, we also extended the extant findings by examining the timing of the interruption in relation to the occurrence of the salient cue. More specifically, we included conditions where the prospective memory cue (which signals the *formulation* of the delayed intention) occurs in the interrupting task itself. This could very easily occur with our everyday intentions (e.g., hearing your coworker's name while engaged in an interrupting phone call). Ultimately, understanding how intentions are completed relative to interruptions is the goal of the present research.

An answer to this empirical question depends on what theoretical mechanisms operate over the interval from cue onset to task change. Einstein et al. (2003) favor the idea that an intention comes to mind periodically rather than being maintained actively through rehearsal. Because intentions likely undergo decreased activation from moment to moment, reinstating the context of the ongoing task in which the cue occurred may promote retrieval, which may be crucial for prospective memory success. Evidence supporting this perspective includes research demonstrating that event-based prospective memory performance is better when an intention is linked to a particular context and a cue occurs in that context (Nowinski & Dismukes, 2005) or when the intention to respond during a window of time occurs during an expected context (for time-based prospective memory; Cook, Marsh, & Hicks, 2005). If intentions are, or can become, associated with contexts, then resuming the ongoing activity after the interruption may partially reinstate the intention when the cue appeared in that same activity before the interruption. In other words, resuming the ongoing task may trigger remembering of the intention because the prospective memory cue shares that same task context. Anecdotally, this is likely why, upon forgetting an intention, one may return to a previous location once occupied while the intention was encoded (e.g., the room in which one formed the intention to give the coworker a message). Thus, although research shows that interruptions generally have deleterious effects on prospective memory, the associative reminding that occurs because of the shared task context between the ongoing task and the newly formed intention may ameliorate that negative effect when the original task context (e.g., the room) is reinstated upon returning to the ongoing task.

A cue that occurs during an interrupting task may also result in an association between the intention and the interrupting task itself, which terminates when the ongoing task resumes after the interruption. In this case, there may be no association, or a very weak one, between the intention and ongoing task. Consequently, the deleterious effect of remembering to fulfill an intention at the task change may be greater when the intention is part of an interruption than when the intention was *formed* as part of the ongoing task before the interruption. In this case, returning to the ongoing task would not serve as well as a reminder because the association between intention and the ongoing task would be nonexistent or weaker than when the intention is *formed* in the ongoing task itself. In other words, the inherent nature of interruptions may obviate benefits

[1] To avoid confusion in terminology for the remainder of the manuscript, we wanted to clarify our use of certain terms. In past work using the delayed-execute paradigm (e.g., Einstein, McDaniel, Williford, Pagan, & Dismukes (2003); McDaniel, Einstein, Graham, & Rall, 2004), the term *retrieval* is used to describe the instance when the participant encounters a salient cue and retrieves the general intention that they are to respond when the task changes. The authors also refer to the fact that salient cue signals the *formation* of a specific intention over a delay given the current task context. Although the use of these two terms is not necessarily synonymous, they both describe the point in time during the ongoing task when the participant encounters the salient cue and initiates the delayed intention. Thus, when we use variations of the word *form* in the current discussion, we are *not* referring to the initial encoding of the general intention that occurs before the onset of the task.

resulting from contextual reinstatement, because in real life, they are returned to rarely, unless perhaps they need to be completed again.

Other findings from the prospective memory literature are consistent with such a prediction about the activation of intentions. For example, the intention-superiority effect represents the finding that memories about intentions may reside with an above-baseline level of activation and may be revived into working memory more quickly than non-activated intention-related stimuli (Goschke & Kuhl, 1993; Marsh, Cook, Meeks, Clark-Foos, & Hicks, 2007; Marsh, Hicks, & Bink, 1998). However, Marsh et al. (1998) discovered that intention completion leads to inhibition of intention-related stimuli. The task switching literature on backward inhibition in particular supports the prediction that the abandoned interruption will be inhibited in service of performing a new task (Mayr & Keele, 2000). To the extent that completed tasks are indeed inhibited, completion of the interrupting task in which a cue occurred may also inhibit the intention to respond because it is associated with the interrupting task. More generally, the same predictions could be made by appealing to the fact that the production rule associated with the interrupting task would have to be suppressed upon resumption of the ongoing task (Anderson, 1983; Rogers & Monsell, 1995). We test our predictions in Experiment 1.

EXPERIMENT 1

The purpose of Experiment 1 was three-fold, which we addressed with a mixed design, plus a control condition. First, we wanted to replicate the basic interruption effect with our stimulus materials and procedures. Therefore, we tested a control condition that received no-interruption and compared it to two interruption conditions. Second, our primary purpose of the experiment was to compare performance when the cue occurred *before* the interruption (as in previous work) versus *during* the interrupting task itself. For the interruption conditions, we manipulated within-subjects the presence of cues relative to the interruption; four of the eight cues presented occurred before the interruption and four occurred during the interruption. This placement of the cue within the interruption is a novel manipulation within the delayed-execute paradigm. Third, we wanted to rule out definitively that temporal location of cues mattered in the delayed-execute paradigm. We used a between-subjects manipulation of temporal location of cues in the ongoing task or the interruption. Half of the participants saw four cues occur *early*, whereas the other half saw four cues occur *late* in the cue context.

If our procedures replicate previous research (Einstein et al., 2003; McDaniel et al., 2004), an interruption that follows a salient cue should decrease the probability of remembering the delayed prospective-memory response. In addition, if the theoretical premises discussed earlier are borne out, then a cue that occurs during an interruption will subsequently generate poorer delayed prospective memory because any associations to the interrupting context do not benefit from reinstatement as they would for the ongoing task or they are lost (and/or inhibited) when resuming of the ongoing task. Finally, temporal placement of the cue during an interruption should not matter if the results from the previous studies on the delayed-execute paradigm generalize to cues placed in the interruption itself. If temporal location does matter, then the standard laws of retrospective memory would predict better performance when the cue appears late in the interrupting task because less time, or less retroactive interference from subsequent trials, would cause forgetting of the intention.

Method

Participants

Undergraduate students volunteered in exchange for partial credit toward a course research requirement. The experimenter quasi-randomly assigned participants to one of the three between-subjects conditions (control, cue early, and cue late) based on their arrival at the laboratory and tested them individually in sessions that lasted approximately 45 min. In this experiment and those that follow, the number of students tested per condition may vary slightly because multiple experimenters contemporaneously rotated through the three conditions and not all participants reported for their appointments. The 88 participants were distributed as follows: we tested 30 in the control condition, 31 in the condition where the cues occurred early in the interrupting task, and 27 in the condition where the cues occurred late in that task.

Materials and procedure

We used a modified version of the experimental design used by Einstein et al. (2003) and McDaniel et al. (2004). Because of the complexity of the task, we attempt to provide sufficient detail about our materials and methods. Specifically, we developed eight ongoing activities for our experiment: (1) choosing the synonym of a word from among three alternatives; (2) choosing the antonym from among three alternatives; (3) rating the similarity of pairs of words on a 7-point Likert scale; (4) judging which of three lines was longest; (5) rating the pleasantness of words on a 7-point scale; (6) answering trivia questions that had three options; (7) solving simple addition problems; and (8) solving simple subtraction problems. The computer software ordered these eight tasks randomly for a given block of trials, and then reordered them randomly three additional times so that participants experienced each of the eight ongoing activities in four separate blocks. This provided 32 discrete phases of the experiment, with each phase of the ongoing activity lasting 1 min. Within each ongoing activity, participants experienced 12 discrete trials lasting 5 s each. For example, the participant was asked to rate 12 different words for pleasantness before the ongoing activity changed to a different task. Accordingly, we created 48 unique trials for each of the trivia, synonym, antonym, pleasantness, and words pair tasks. The software dynamically chose these items as needed in a random order anew for each participant tested. By contrast, the trials for the addition, subtraction, and line length problems were created online by the computer software and did so anew for each participant as needed for each trial.

Two salient prospective-memory cues appeared in each of the four blocks of the eight unique ongoing activities, which provided a total of eight cues for measuring prospective memory. Numbering the ongoing activities sequentially from 1 to 32, the cues occurred in activities 3, 6, 12, 15, 19, 23, 28, and 31. In order to make the cues salient for the delayed-execute paradigm, they appeared in a salient red print (cf. red screen used by McDaniel et al., 2004). When participants in the interruption conditions were interrupted while performing an ongoing task, the software cleared the computer screen, issued a unique sound, and displayed the message 'Generate Associates with Experimenter', which prompted participants to turn to the experimenter and start generating their first semantic associate to words printed on 4' × 6' index cards presented to them. The computer paced this task for the experimenter with short beeps at a 3-s space so that participants generated 10 different associates for the 30-s interruption. When the interruption occurred, it replaced six ongoing task trials, which would have also lasted 30 s. Participants then returned to the ongoing activity they were performing before the interruption and completed three more trials. After these trials, participants began a new ongoing task, at which time they were supposed to make their prospective memory response. By contrast, these six trials were not replaced by the interrupting task (e.g., generation of semantic associates) for participants in the no-interruption control condition. After completing the ongoing task, they proceeded to the new task immediately. Please see Figure 1 for a basic schematic of this procedure.

We adopted the Einstein et al. (2003) salient red cue methodology so that we could rule out potential differences detecting cues as well as differences in *forming* delayed intentions when the signaling cue appeared either in the ongoing activity or in the interruption. There is evidence that salient cues produce extremely good event-based prospective memory performance (e.g., Einstein et al., 2000; Smith, Hunt, McVay, & McConnell, 2007). Although the interruption differs physically from the other cognitive tasks performed, the use of a salient cue should create an involuntary capture of attention and thus greatly increase the likelihood of spontaneous retrieval of the general intention (see McDaniel & Einstein, 2000 for a summary of this idea). Consequently, *formation* of the more specific delayed intention should be comparably strong in the ongoing and interrupting contexts. However, we do believe that the detection of non-salient or nonfocal cues, retrieval, or subsequent formation of delayed intentions may be impoverished differentially in these task contexts; see Ball, Knight, Dewitt, and Brewer (2013) for similar arguments. After all, the very nature of non-focal cues renders them more susceptible to failures in cue detection and spontaneous retrieval of the intention (Einstein et al., 2005, Experiment 5; Knight et al., 2011; Marsh, Hicks, & Cook, 2006). Our interruption helps maintain ecological validity and simulates the nature of everyday interruptions that employees encounter while working on computer tasks.

In the no-interruption control condition, the salient red cue always occurred on Trial 3 (out of 12 trials) of the ongoing activity. In the interruption conditions, cue location was manipulated within-subjects such that four cues appeared immediately before the interruption and four appeared during it. As a shorthand notation, we will label these the *before* and *during* conditions, respectively. The timing of the cue was manipulated between-subjects such that cue occurred early in both the ongoing task and the interruption or late in both the ongoing task and interruption. Without the control condition, this provided a 2 (cue location: before vs. during interruption) × 2 (temporal location: early vs. late cue) mixed design. In the early condition, the cue appeared on Trial 3 of the ongoing task cue and the third semantic associate card held up by the experimenter during the interruption, whereas in the late condition, the cue appeared on Trial 10 of the ongoing task and the penultimate card of the 10-card interrupting sequence.

Prior to commencing the sequence of ongoing tasks, participants read instructions for all tasks from the computer monitor. Experimenters reiterated the instructions, gave participants a diagram of the task sequence, and further explained the task until participants understood their task clearly, especially for when they encountered a red cue word.

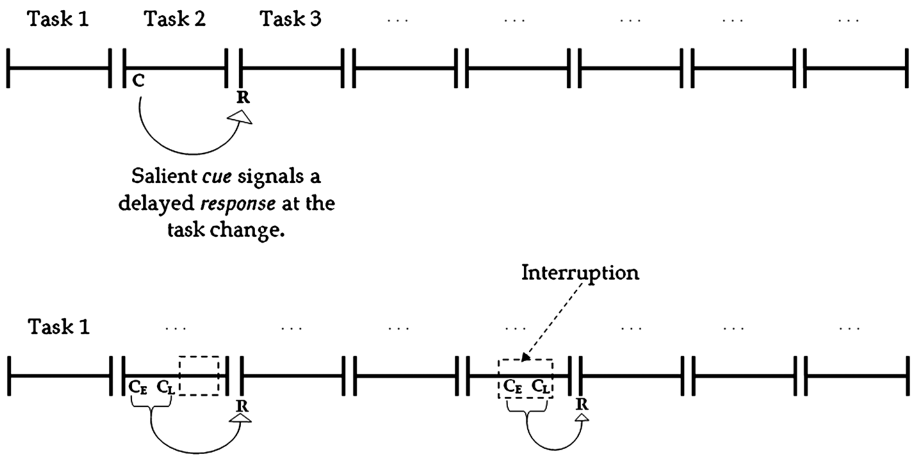

Figure 1. The top panel shows a block of eight ongoing tasks for the no-interruption condition. The salient cue (C) signals participants to formulate the prospective response (R) to be executed when the computerized ongoing task changes. The bottom panel illustrates how the salient cue could appear early (E) or late (L) in the task or the interruption. These locations of the cues in this figure are for illustrative purposes only and do not reflect exact locations in the paradigm

Experimenters explained carefully to participants that they delay their prospective response (the '/' key) until the ongoing task changed. We gave further clarification that the semantic-associate interruption did not count as a task change (although a cue could occur during it, and if so, they should respond at the next ongoing activity task change). Similar to when the cue appeared in the ongoing task, when it appeared in the interruption, participants' prospective responses should be delayed until a change in the ongoing task occurred. Because of the complexity of the experiment, the ongoing task did not commence until the experimenter was convinced that the participant could explain exactly what was asked of them to do using the experimenter's diagram. For additional clarity, the experimenter confirmed by direct questioning that the participant knew what to do if the cue occurred before or during the interrupting task. Immediately before the task began, the experimenter removed the diagram and participants completed a 3-min maze distractor activity.

Results and discussion

Unless otherwise specified with a *p* value, the probability of a Type I error does not exceed the conventional 5%. We summarize the data in the top portion of Table 1 as the proportion of cues that elicited a delayed response within the first two trials after the task change. Late responses were rare and their inclusion as correct does not significantly change the message provided by this stricter scoring. To address whether our materials and procedure replicated previous research showing that interruptions disrupt delayed-execute prospective memory, we compared the control condition to the performance of the other two conditions when the cue occurred before the interruption (columns labeled *before* in Table 1). In order to determine if we could replicate the Einstein et al. (2003) and McDaniel et al. (2004) results, we conducted a planned comparison between the control condition and the two interruption conditions and found worse prospective memory for intentions formed *during* an ongoing task that was later interrupted ($M = 0.69$, $SEM = 0.05$) than not interrupted ($M = 0.86, SEM = 0.05$), $t(86) = 2.15, d = 0.51$. Thus, our materials and procedure are similar to those used in the two previous studies that our current results should generalize.

Table 1. Average delayed-execute prospective memory performance as proportions across the conditions of experiments 1–3

Experiment 1				
Cue occurs early		Cue occurs late		
Before	During	Before	During	Control
0.68	0.43	0.70	0.34	0.86
(0.07)	(0.08)	(0.07)	(0.08)	(0.05)
Experiment 2				
No reinstatement		Reinstatement		
Before	During	Before	During	
0.38	0.28	0.72	0.38	
(0.06)	(0.05)	(0.06)	(0.07)	
Experiment 3				
Cue occurs before		Cue occurs during		
Task	Future task	Task	Future task	
0.61	0.77	0.63	0.58	
(0.07)	(0.05)	(0.06)	(0.05)	

The terms *before* and *during* refer to the placement of the cue relative to the interruption. Standard errors of the mean are in parentheses.

The more important question addressed by the current experiment is whether performance differed when the cue occurred before or during the interrupting task. We excluded the no-interruption control condition and conducted a 2 (cue location: before vs. during interruption) × 2 (temporal location: early vs. late cue) mixed-model Analysis of Variance (ANOVA). A significant main effect of cue location revealed that the delayed intention suffered more when the cue occurred during the interruption than prior to its onset, $F(1, 56) = 25.89, \eta_p^2 = 0.32$. However, there was neither a main effect of temporal cue location (early vs. late), $F(1,56) < 1$, ns, nor an interaction between the two variables, $F(1,56) = 1.01$, ns. The absence of any main effect of temporal cue location (early vs. late) conceptually replicates past work that shows duration manipulations relating to the delay between cue onset and task change, or of the duration of the interrupting task, do not matter in this paradigm. Based on these data, that null effect also seems to generalize to cues appearing in interruptions.

At this juncture, a reasonable explanation for these results is that upon exiting the interrupting task, that context is deactivated, or inhibited, in order to facilitate resuming the ongoing task. That inhibition process appears also to deactivate the intention that was formed during the interrupting task. Of course, this interpretation is predicated on the assumption that intentions can become linked to the context in which they are formed. The next experiment addresses this issue in more detail.

EXPERIMENT 2

Although previous research demonstrated the importance of contextual associations affecting both time-based and event-based prospective memory (Cook et al., 2005; Marsh et al., 2006; Nowinski & Dismukes, 2005), contextual associations have surprisingly not been investigated in the delayed-execute/interruption paradigm. McDaniel et al. (2004) and others always reinstated the same ongoing activity that contained the prospective memory cue and was subsequently interrupted, but their focus was not to examine context or reinstatement effects. We, and others (Einstein et al., 2003; McDaniel et al., 2004), have shown the fragility of maintaining an intention over a delay, especially when one has been interrupted. Given the rich body of literature on retrospective memory showing the benefits of encoding specificity (Thomson & Tulving, 1973), contextual reinstatement of the context in which a cue occurs could alleviate some of the negative effects observed in the presence of interruptions or when intentions are held over a delay without an interruption. Moreover, if contextual associations can influence prospective memory when intentions can be fulfilled immediately upon seeing a cue as in the standard event-based paradigm, reinstatement effects might prove particularly useful when maintaining an intention over a delay and in the presence of an interruption.

Research on intentions in hospital settings also provides some insight about the influence of contextual reminders after interruptions. Liu et al. (2009) examined participants who received blood for a transfusion and needed to validate the blood bag for the patient. When the doctor interrupted participants for a short duration and asked them to perform another task, those who failed to validate the blood for the patient typically did so because they allocated attention away from the transfusion task and to the interrupting task. Remembering to validate the blood bag was better, however, when participants either self-initiated the retrieval of the blood check or returned their attention to the transfusion task, which allowed the blood bag label to cue their memory to validate the blood. Thus, reinstating cognitive processes about the transfusion task served as a useful cue for retrieving the intention for some participants.

Previous studies may have examined the effects of interruptions in best-case scenarios because of the reinstatement of the ongoing task that contained the prospective memory cue. If so, a task change would prevent any contextual reinstatement and potential reminding of an intention formed during the ongoing task. If reinstating the same ongoing activity does indeed influence performance by facilitating memory for the intention, then those few trials that precede the task change must be functionally important to performance in the delayed-execute/interruption paradigm. More specifically, if those trials serve to reinstate the context to which the intention to respond is associated, then their presence may be serving to ameliorate what otherwise would be poorer performance without their reinstatement. We designed Experiment 2 to test this idea by removing the trials of the ongoing task that immediately precede the task change. This modification eliminated the delay between the conclusion of the interrupting task and the critical task change where a response is required. If intentions become associated to the context in which participants *form* them, then the straightforward prediction is that changing tasks directly after the interruption (e.g., no reinstatement of the context) will cause performance to suffer additionally because the environment no longer provides potentially useful retrieval cues. Because the context for intentions *formed* during an interruption is not reinstated (but, likely inhibited), performing the same or a different task after the interruption should not influence prospective memory when cues appeared in the interruption. By contrast, when the ongoing task is not reinstated, the delay between the interruption and the task change is reduced (albeit by only a few trials), which could improve intention completion. Although Experiment 1 would suggest that the duration of the delay would not matter, this set of experiments are to our knowledge the only ones that have examined prospective memory for intentions *formed* during interruptions, so we wanted to test this once again.

Method

Participants

Undergraduates volunteered to participate in exchange for partial credit toward a course research requirement. Each participant was tested individually in sessions that lasted approximately 45 min. For reasons that will become clear when the results are described (i.e., for statistical power), we tested more participants in the no-reinstatement condition than in the reinstatement condition used in Experiment 1 that has these intervening trials just before the task change. We tested 50 participants in the former condition and 36 in the latter condition.

Materials and procedure

The procedural details of this experiment were identical to the condition in Experiment 1 for which a prospective cue appeared *early* in the interrupting task and this was compared within-subjects to when the cue occurred *before* the interrupting task (four cues of each type as in Experiment 1). In order to examine the effects of contextual reinstatement, the computer software removed the three trials following the interrupting task for the no-reinstatement condition. This ensured that the no-reinstatement condition experienced a task change immediately after the interruption ended. This modification removed only 15 s from the ongoing tasks on the eight occasions when the salient cue occurred. Please see Figure 2.

Results and discussion

We summarize the results in the middle section of Table 1. As can be seen from performance in the reinstatement condition (right side of Table 1), this condition replicated Experiment 1 insofar as cues appearing during an interruption again reduced prospective memory relative to cues appearing before the interruption when the ongoing task was reinstated after the interruption. Most importantly, performance was dramatically worse when the ongoing activity was never reinstated (left side of Table 1) after the interruption. In fact, prospective memory for this condition was almost as poor as when the cue occurred during the interruption itself. These impressions were confirmed with a 2 (cue location: before vs. during interruption) × 2 (context: no reinstatement vs. reinstatement) mixed-model ANOVA. The interaction between the two variables was statistically significant, $F(1, 84) = 6.75, \eta_p^2 = .07$ and will be explained after describing the main effects. Replicating Experiment 1, the within-subjects main effect of interruption showed that delayed-execute prospective memory was significantly worse for cues appearing *during* the interruption relative to *before* the interruption and in the ongoing task, $F(1, 84) = 22.10, \eta_p^2 = .21$. The between-subjects main effect of contextual reinstatement also significantly improved prospective memory relative to no reinstatement, $F(1, 84) = 9.90, \eta_p^2 = .11$. This main effect, however, pools over the cue location conditions. Because the interrupting task was never reinstated, a true contextual-reminding effect is isolated specifically to a simple-effects analysis of the *before* conditions that did and did not reinstate the ongoing task context. Notably, the contextual reinstatement reminder after the interruption significantly improved prospective memory relative to changing ongoing tasks after the interruption, $t(84) = 3.91, d = .86$. By contrast, reinstating an interrupted ongoing task did not help intention completion significantly when cues appeared *during* interruptions, $t(84) = 1.22$, ns. Thus, the origin of the interaction is due to a benefit of reinstating the ongoing task when the cue

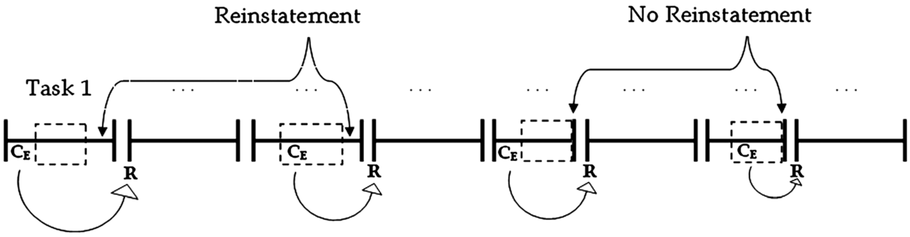

Figure 2. This schematic represents the basic paradigm for Experiments 2 and 3. The salient cue (C) appeared in either the ongoing task or the interruption. Upon seeing the cue, the prospective response (R) is formulated to be executed when the next task begins. The first part half shows how the interrupted ongoing task was reinstated after the interruption, whereas the second half shows how it was not reinstated

occurs in this same task. This reinstatement can serve to remind participants of the intention after a disruptive interruption because the content of the intention contains details about that specific task context. In sum, interruptions hurt prospective memory, and reinstating interrupted tasks can alleviate the damage, but only when the cue occurs in the original context.

Another way to understand the interaction is to examine the effect of interruptions (when cues occur before vs. during them) when the interrupted ongoing task was or was not reinstated after the interruption. As simple-effects analyses, we further compared prospective memory performance for the *before* versus *during* manipulation within each of the reinstatement conditions. The paired-samples comparison revealed that reinstating the context when the cue appeared in the ongoing task after the interruption resulted in significantly better performance compared with switching to the next ongoing task after the interruption, $t(35) = 5.56, d = .93$. When we did not reinstate the ongoing task after the interruption, the comparable paired-samples comparison revealed a nominal performance difference in favor of the cue occurring *before* the interruption compared with *during* the interrupting task, $t(49) = 1.49$, ns. Remember that in the absence of reinstatement, this comparison allows us to test whether prospective memory is worse for a cue before or during the interruption, which we could not test specifically in Experiment 1 because the ongoing task was always reinstated. The larger sample size reflects the fact that we continued to test participants in this condition to see if the numeric difference might be significant with more power. However, even after testing 50 participants, we failed to find a statistically significant effect so we stopped data collection. Thus, the nature of the interaction was due to a reinstatement benefit.

These results are consistent with the hypothesis that the reinstatement trials following the interruption are functionally useful when the cue had appeared in the ongoing task. Those trials may serve as a simple reminder of the intention to respond at the task change because the intention was *formed* within the context of that specific task. In essence, that contextual association is what makes those reinstatement trials so useful. Whether participants are consciously forming such an association between the cue and the context is unclear. Research by Finstad et al. (2006) would suggest this is unlikely unless participants are specifically asked to do so, although the purpose of the next experiment will be to examine that issue in more detail.

Nevertheless, we replicated the very poor performance when intentions are *formed* during an interruption in the reinstatement and the no-reinstatement conditions of this experiment (albeit nominally so when no reinstatement occurred). One could have predicted very high levels of performance in the condition when the ongoing task was not reinstated and the cues occurred in the interruption (i.e., that would have mirrored the control condition of Experiment 1) because nothing intervenes between the interrupting task and the critical task change itself. This outcome, however, did not occur. One hypothesis is that participants may deem the interrupting task as just that, an annoyance that they must deal with before resuming the main part of the experiment. As such, they may execute a rapid inhibition of that task much like the work in the intention-superiority literature. Nonetheless, Experiments 1 and 2 together demonstrate that cues occurring during an interrupting task can become ineffective to prospective memory processes over time.

EXPERIMENT 3

The purpose of Experiment 3 was to explore further the idea that the intention is associated to a particular context. Theoretically, we have assumed that the results from Experiments 1 and 2 are consistent with the idea that the intention to respond is associated to the task in which the cue occurred; it is bound to its context. When the cue appeared before the interrupting task, the intention to press a special key at the task change is associated with the ongoing task, which may or may not resume immediately for a short duration after the interruption. By contrast, when the cue appears during the interrupting task, that particular context is no longer contextually relevant to performing the subsequent ongoing task. The absence of reinstatement would seem to explain, partially anyway, why performance is worse when cues occur in interruptions. Due to the randomized task sequence, one difficulty for participants in the delayed-execute paradigm is predicting the next task they will switch to when the critical task change occurs. Therefore, the intention to respond at the task change can only be associated with a vague notion of the task changing or with termination of the current task. As discussed earlier, some recent reports argue that being able to associate the fulfillment of an intention with a future context (as opposed to the current context) actually improves performance when that context is correct, but has a deleterious effect when that expectation is incorrect (Cook et al., 2005; Nowinski & Dismukes, 2005).

If this theoretical assertion is true, then telling participants exactly which ongoing task they will change to may enable them to anticipate and to plan for it (for a similar explanation, see Brewer et al., 2011). For example, if the salient red cue word is the word ‘subtraction,’ participants can form the more specific intention to respond when the task changes to the subtraction task. We hypothesized that this additional elaboration could ameliorate the interruption effect just as contextual reinstatement ameliorated the deleterious effect of an interruption in Experiments 1 and 2. Theoretically, this manipulation of providing the future context is very similar to establishing an implementation intention (Gollwitzer, 1999; Gollwitzer & Schaal, 1998; Rummel et al., 2012). Performance is poorer for standard intentions such as planning to take vitamins everyday as compared with implementation intentions in which the context and behavior is planned in much more detail (e.g., planning to take one’s vitamins everyday at the breakfast table just before clearing the dishes). Of particular importance to our research question, Rummel et al. demonstrated that implementation intentions improve prospective memory performance due to the spontaneous retrieval of the intention. For an intention that gets interrupted and requires a delayed response, knowing the nature of the future task change could allow participants to formulate a more specific intention that could be retrieved more spontaneously upon changing tasks, which could help protect participants from the negative effects of interruptions in their environment.

Although Dodhia and Dismukes (2009) did not study implementation intentions like Rummel et al., 2012, our manipulation is also similar to thinking about returning to an interrupted task. In their Experiment 1, they point out that forgetting to return to an interrupted task might result from distractions or task demands that follow an interruption. Participants in an encoding-reminder condition saw a 4-s explicit reminder to return to the ongoing task before the interruption began, whereas those in an encoding-pause condition experienced the same 4-s pause, but without an explicit reminder. They showed that an opportunity to remind oneself to return to the interrupted task during a delay before the interruption occurred, either explicitly or self-initiated reminding, increased the likelihood of returning to the ongoing task.

Our motivation is somewhat similar to Dodhia and Dismukes (2009, Exp. 1), so we should explain how our manipulations are both similar to and different from their work. Whereas they focused on understanding how interruptions in our daily lives can create opportunities for us to form an intention to return to the interrupted task, our general focus for all our experiments was on forming intentions to respond at a future task change. For this experiment in particular, we wanted to examine whether knowledge about the future task change could improve prospective memory for responding at the task change similar to how they found reminding participants to return to the ongoing task improved memory for doing so. Although the properties of the intentions differ between our study and theirs, the general principle of reminding should operate similarly in this new experimental context. If thinking about returning to an ongoing task increases the likelihood of returning to that task, we believe that knowledge about the future context that will occur after an interruption should also serve to remind participants about the intention when commencing a new ongoing task.

Although our predictions are straightforward, knowing that future task might not improve prospective memory. Knowledge about the future task might set in motion an endogenous preparation for that new task, which could cause backward inhibition of the interruption and its contents (the *during* condition) and perhaps the contents from the interrupted task (the *before* condition). Because backward inhibition should not be as strong when the future task is not predictable (Hübner, Dreisbach, Haider, & Kluwe, 2003), not knowing the future context might lead to better prospective memory.

In this final experiment, we manipulated context association by issuing half of the prospective cues with no knowledge of the particular future task (just as in Experiments 1 and 2) and the other half by providing the name of the task that would occur at the task change. In order to obtain a more sensitive measure of the effect of future context, we manipulated this knowledge within-subjects and manipulated whether the cue occurred before versus during the interrupting task between-subjects. Whether making a specific association to the future context differentially ameliorates performance in a delayed-execute paradigm when the cue appears before versus during the interruption is unclear. One might predict that it could improve performance more when the cues occurred during the interruption because this is where performance is worst and perhaps most likely to benefit from an association or spontaneous retrieval. Alternatively, depending on the cognitive processes that cause worse performance when the cue occurs in the interrupting task (e.g., inhibition), no improvement may be found or the association might have a negative influence. If found, this result may provide evidence that the interruption and its contents, which include the intention, are inhibited and/or that spontaneous retrieval may not occur for intentions that are formed as part of an interrupting task. This final manipulation should lead to some additional theoretical insights as to what causes the very poor performance that we have repeatedly observed when the cues appear in interrupting tasks. In this experiment, we wanted to examine whether encoding information about the upcoming task improves the completion of delayed/interrupted intentions in the absence of the deleterious non-reinstatement effects found in Experiment 2. Thus, we reinstated the ongoing context for all participants as was done in the Einstein and McDaniel studies.

Method

Participants

Undergraduates volunteered in exchange for partial credit toward a course requirement. As in Experiment 1, experimenters quasi-randomly assigned participants to the two between-subjects conditions. Due to a calculation error and for two participants with outlying performance on the synonym task, final sample sizes resulted in only 30 participants who encountered all eight cues before the interruption and 36 who encountered all eight cues during the interruption.

Materials and procedure

The procedure was identical to the conditions in Experiment 1 that received an interruption, except in the following three respects. First, because location of the cue in the interrupting task had no effect in Experiment 1, we presented the cue early in the interruption because its location was temporally closer when the cue occurred before the interruption. Second, in Experiments 1 and 2, the salient red cue was a word on the computer screen or the word from which participants generated their associate response in the interrupting task. In this experiment, we added an additional red word to the computer screen or to the index card, depending on the condition. When no knowledge of the future context was provided, the cue word was 'task' printed in red either at the bottom of the screen or on the index card. When a future context was provided, the red word named the specific task that would occur at the task change (for example, antonym, line length, etc. depending on randomization). We informed participants of the differences between these two types of cues, but explained specifically that they should respond identically at the critical task change. Importantly, we did not give any implementation intention instructions like Einstein et al. (2003) attempted; and thus, any differences between the two kinds of cues are due to spontaneous cognitive processing of knowing (or not) what the task change will be and encoding that context as part of the intention. Third, and finally, we manipulated whether the cue appeared before versus during the interruption as a between-subjects variable and the specificity of the future context as a within-subjects variable.[2]

Results and discussion

We report results at the bottom of Table 1. The left-hand columns summarize performance when the cues occurred prior to the interruption and the right-hand ones summarize when they occurred in the interrupting task. The 2 (cue location: before vs. during interruption) × 2 (association: task vs. future task) mixed-model ANOVA revealed a statistically significant interaction between the two variables, $F(1, 64){=}6.05, \eta_p^2{=}.09$, but neither main effect was statistically significant; larger of the two, $F(1{,}64) = 1.70, ns$. The interaction arose because associating an intention with a specific future task facilitated performance when the cue occurred in the ongoing activity, $t(29) = 2.57, d{=}.48$, but not when the cue occurred during the interruption, $t(35) < 1$. Providing the specific context about a future task may act like an implementation intention and help prospective memory for cues outside of the interruption. However, the same association does not seem to benefit intentions formed during an interruption. Of course, the reader will notice that performance for cues that occurred during the interrupting task is much better than in Experiments 1 and 2. Because providing a specific context versus not was a within-subjects manipulation in this experiment, that manipulation may have changed fundamentally how participants approached the task.

One way to explain this pattern of results is that participants formed associations that are more specific even in the absence of knowing the exact context that would constitute the task change. Perhaps the outcome in this experiment is a function of introducing participants to the notion that contextual associations can be used to improve prospective memory performance; they might not know this on their own. Alternatively, participants might not attempt to make such associations without some degree of certainty about the ordering of multiple tasks. Previous work showed that an incorrect contextual association hurts prospective memory is a strong demonstration that people who are introduced to using associations tend to rely on them to execute their intended actions (Cook et al., 2005). In those experiments, participants often reported an annoyance when they discovered that experimenters had misinformed them about the context they would be in when they needed to complete a time-based intention. In such instances, predicting an incorrect context is worse than not predicting one at all.

As stated before, knowing the context of the specific task change does not improve performance when the cue occurs during the interruption. Therefore, based on the results from the previous experiment, the locus of the effects found when the cue occurs in the ongoing task may be a combination of both forming more specific associations and being reminded by the reinstatement of the ongoing task as shown in Experiment 2. In other words, we are still somewhat unclear whether the association to the ongoing task or the association to the future critical context, or both, creates the benefit to prospective memory. Although additional empirical work will be needed to resolve these issues, the current experiment is entirely consistent with the message that researchers in this area must begin to critically evaluate the role that associations to current and to future contexts play when an intention is encoded into and/or retrieved from memory.

GENERAL DISCUSSION

Einstein et al. (2000) designed the delayed-execute prospective memory paradigm to study the fate of intentions that participants must maintain over brief intervals. In addition, research suggests that interruptions decrease prospective responding beyond the decrease associated with a delay alone (e.g., Einstein et al., 2003; McDaniel et al., 2004). We show that for younger adults, an interruption in an ongoing activity proves to be quite deleterious to maintaining the intention, thus replicating previous work. Our results, however, do offer some novel insights about the precise effects of interruptions on a delayed prospective memory. One empirical contribution of the present study is that, generally speaking, cues appearing in an interruption degrade intention completion for younger adults even further (Experiments 1

[2] The reader may have noticed that participants have less time to formulate an intention for cue appears during the interruption rather than before it because the ongoing task trials are paced at 5 s, whereas the interrupting task is paced at 3 s. We do not believe that this issue significantly impacts the data for two reasons. First, there was much more information to process in the ongoing task when the cue occurred before the interruption; during the interrupting task, there was only one word to process in order to generate a single semantic associate. Second, Einstein et al. (2003) increased encoding time from 2 s to 6 s (i.e., a three-fold increase) when they gave their participants implementation instructions to imagine the task change and this manipulation did not affect performance. We believe that the type of cognitive processing that occurs when the cue is received influences performance rather than the duration of cue presentation as mentioned earlier in the context of the results from Experiment 1.

and 2). Another novel contribution is that reinstating the context of the interrupted task can improve remembering over these short delays (Experiment 2). Finally, forming specific associations to future contexts (and being accurate when doing so) may under some conditions ameliorate the difficulties people have maintaining intentions over short delays (Experiment 3).

The theoretical contribution of the present experiments highlights two aspects of intention completion that previous work using the delayed-execute paradigm (and the associated research using interruptions) has left unaddressed. Both aspects concern the natural contextual associations that may be formed during intention encoding, namely, the association of the intention to the prevailing context and the association of the intention to the future context of intention completion. Concerning the former, previous instantiations of the use of interruptions in the delayed-execute paradigm had participants return to the task in which the cue to form the intention appeared. The very large effect of removing those reinstatement trials in Experiment 2 demonstrates that the prevailing context in which an intention is formed becomes associated with that intention. Performance suffers markedly without that contextual reinstatement. We know of very little empirical work that highlights the fact that the circumstances surrounding intention completion affects its probability of completion (but see McDaniel, Robinson-Riegler, & Einstein, 1998). Therefore, scientists interested in prospective memory should consider carefully how an association to the context in which an intention is formed affects performance.

If contextual associations of intention formation affect performance as we believe the data from this study demonstrate, one must wonder about the fate of intentions that are refreshed in new contexts. If one forms an intention in a particular context and refreshes it in a new context, do those new contexts become associated with the intention in a way that may actually reduce the likelihood of fulfilling them? Do all of these contextual associations improve or decrease the probability of actual intention fulfillment? Can an intention become decontextualized to the point of being free from an association to any context (e.g., Conway, Gardiner, Perfect, Anderson, & Cohen, 1997)? Are these effects localized to only short-term maintenance of intentions as studied here or do they generalize to longer-term intentions as well? Regardless of the ultimate answers to these interrelated Gedanken experiments, the important point is that associations to the prevailing context at intention formation is currently a poorly understood phenomenon in the prospective memory literature. Consequently, the present results highlight the fact that this may represent a fruitful avenue of theoretical inquiry.

The other contextual association that is important to prospective memory is the future context one expects to be in at the time intention completion is anticipated or required. As noted in the introduction, this contextual association has been recognized as influencing intention completion (Cook et al., 2005; Nowinski & Dismukes, 2005). Earlier we argued that one locus of the poor performance when the cue occurs in the interrupting task is the deactivation of the components of the interrupting task and inadvertently along with the intention itself. Having participants specifically form an association to the task requiring the prospective response improved performance when the cue occurred prior to the interruption. Although it did not improve performance when the cue occurred during the interruption, general performance in that condition was equated to the level of when the cue occurred prior to the interrupting task. As such, we observed an overall benefit to having participants form specific associations that removed the deficit that came from having the cue appear during the interrupting task. This finding is important to consider when dealing with interruptions in our daily lives.

Interruptions have become a staple of our jobs or lifestyles and eliminating them is likely an exercise in futility. Interruptions and multitasking, for example, are pervasive in emergency rooms and other workplace settings and can often result in serious accidents (Chisholm, Collison, Nelson, & Cordell, 2000; Gawande et al., 2003). Disruptions in cognitive processing can often result in failures to return appropriately to the interrupted task (Dodhia & Dismukes, 2009). Even when performing habitual tasks that contain multiple steps, disruptions tend to increase the risk of omitting steps (Loukopoulos, Dismukes, & Barshi, 2009). Dodhia and Dismukes argue that these failures may be due to new attentional demands that prevent encoding a sort of restore point for the interrupted task or because we do not pause for a moment to check the status of the interrupted task. Previous research on delayed-execute prospective memory and interruptions has examined performance under conditions that return participants to the interrupted task (Einstein et al., 2003). Such an experimental task, however, might reflect a best-case scenario associated with interruptions at the cost of ecological validity. Given the complexity of daily activities, we advocate investigating intentions in a variety of contexts, including when interrupted task are resumed automatically, resumed more effortfully, or are skipped. As Dodhia and Dismukes point out, because the environment may not typically return people to interrupted tasks (only 48% of participants did so after the interruption in their experiment, but see Law, Logie, Pearson, Moretti, and Dimarco (2004) for higher return rates in a multitasking environment), understanding the differences between these conditions would be useful. They showed that providing either an explicit reminder at the beginning of the interruption, or a sufficient pause of 8 to 12 s after the interruption, were the best ways to increase the likelihood of returning to the task. These reminders can be very useful given the fact that participants tend not to think about intentions during breaks (Finstad et al., 2006; but see Hicks, Marsh, & Russell, 2000 and Sellen, Louie, Harris, & Wilkins, 1997). Thus, consciously recalling an action that one last executed before the interruption may be a necessary step to temper the severely detrimental effects of interruptions.

Failing to return to the interrupted task is consistent with what happened in our no-reinstatement condition, which resulted in worse performance compared with reinstating the interrupted context. Our manipulation of reinstatement was automatic because the experimental paradigm resumed the interrupted task for participants without requiring them to think strategically about restoring their activity after the interruption. We do not yet understand how reinstating the interrupted context on one's own compares with having the environment do so automatically for delayed intentions at future task changes. Self-initiating a return to the interrupted context may serve to reactivate the intention to a greater degree than would an environmental reminder, but one's ability to engage in a self-initiated reinstatement will likely depend on task demands and working-memory capacity. We expect that those with greater working-memory capacities will likely benefit from both types of reinstatement, whereas others may only benefit from those provided automatically by the environment. Although Ball et al. (2013) found those with higher working-memory capacity performed better with interruptions, empirical questions regarding contextual reinstatement are up for further scrutiny in the laboratory. Nevertheless, nature may offer up a variety of environments that may not be as kind as those experienced in the laboratory may, so we should consider ways to protect ourselves from the harmful effects of interruptions.

Dismukes and colleagues (Dismukes, 2012; Dodhia & Dismukes, 2009) offer some advice to improve various forms of prospective memory. They recommend avoiding multiple tasks when one is very important, forming implementation intentions, linking intentions to habitual tasks, using external memory aids, and establishing cross-checking devices. Such recommendations are seen in some real-world situations where checklists are used to track completed and uncompleted tasks in the emergency room and in the cockpit (Gawande, 2010). When encountering interruptions, they suggest pausing at the interruption and encoding an explicit intention to resume the interrupted task after the interruption. Our results are very consistent with their recommendations. Forming an intention to return to an interrupted task would be very useful not only to return to that task, but also to remember previously stored intentions to complete at a task change. Using cross-checking devices that log our actions before dealing with an interruption would certainly help reinstate the interrupted task, which we have shown ameliorates the negative effect of interruptions in Experiments 1 and 2. In addition to the suggestions by Dodhia and Dismukes, data from our Experiment 3 suggest that linking intentions to a future context be added to the list, yet our previous research suggests that some discretion would be helpful because predicting the incorrect future context could be both harmful to intention completion and an annoyance (Cook et al., 2005). Finally, our work also suggests not trying to form intentions during an interruption. If doing so were unavoidable, elaborating on the intention by writing it down and creating an external memory aid would likely prove very useful.

We designed the current set of experiments to investigate memory for delayed intentions that are formed before and during interruptions rather than to disambiguate between either a contextual-association account or an inhibition account. Perhaps the effects of interruptions are influenced by both mechanisms. Experiment 2, in particular, shows that associations can reduce the negative effect of an interruption. By contrast, worse prospective memory for intentions *formed* during an interruption may support an inhibition account unless intentions are not fully *formulated* during interruptions.

Although we focused on prospective memory accuracy in the present study, future research could examine how interruptions affect the speed of responding to trials during either the ongoing task or the intention. In a multitasking paradigm, Law et al. (2004) found that their interruptions produced timing costs on tasks rather than accuracy deficits (See also Speier, Valacich, & Vessey, 1999). Although we found profound negative effects of interruptions in terms of accuracy consistently in our experiments, interruptions that may not produce accuracy deficits might reveal response-time deficits. Examining response times could also help to understand if the effect of interruptions on prospective memory results, at least in part, from inhibition processes. Consistent with an inhibition account, memory for ongoing task stimuli is negatively affected by maintaining either an event-based or a time-based intention (Cook, Marsh, Clark-Foos, & Meeks, 2007). For some measures of prospective memory (viz., task interference, cue interference), response times to stimuli or cues have been used to provide a more sensitive measure of the costs of holding an intention in memory (Marsh et al., 2006; Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Smith, 2003). The same may be true when examining how interruptions affect prospective memory. If backward inhibition influences delayed-execute performance, the first trial or two following a task reinstatement after an interruption should be slower than trials before the interruption. Those same trials should potentially be faster than the first trials in the switch task, especially if participants believe that they need to return to the abandoned ongoing task after the interruption (Hübner et al., 2003) because backward inhibition of an abandoned task seems to be due an endogenous preparation for the new task (Mayr & Keele, 2000). Little, if any, endogenous preparation would be made for unpredictable task switches. Such a pattern in response times would be consistent with our data showing worse performance in the no-reinstatement conditions because our participants believed that they would need to return to the interrupted task. From a reminder perspective, however, if reinstating the ongoing task serves as a reminder about the intention *formed* earlier, the reminder might interfere with performing the reinstated task and slow down responding in a way similar to the slowing on event-based cue trials (Marsh et al., 2003). Although teasing apart these mechanisms might require cleverly designed experiments, examining this microstructure of interruptions would be important for understanding why or how interruptions hurt prospective memory and how context can attenuate that damage.

In closing, we have proposed an associative-reminder mechanism to explain better prospective memory for cues that occur in reinstated contexts over those that occur during interruptions. We also proposed an inhibitory mechanism to explain worse performance for intentions formed during interruptions relative to those formed before interruptions. One or both of these mechanisms may influence our results and we admit that our current data do not disambiguate between those mechanisms. Nevertheless, we believe that our data highlight an important concern about the fate of intentions formulated before and during interruptions and how to prevent memory failures associated with interruptions. Given the fact that interruptions of various types represent a frequent occurrence during a typical day for most people, additional research could help understand whether the type of interruption may interact with the mechanism of remembering our intentions. Additionally, more work is needed to verify whether these same overarching effects would be found with other types of prospective memory tasks (e.g., more naturalistic tasks and time-based tasks) and whether contextual mechanisms influence those types of delayed-execute intentions more generally or whether the effects are task specific.

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