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Flexible attention allocation dynamically impacts incidental encoding in prospective memory

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Abstract

Remembering to fulfill an intention at a later time often requires people to monitor the environment for cues that it is time to act. This monitoring involves the strategic allocation of attentional resources, ramping attention up more in some contexts than others. In addition to interfering with ongoing task performance, flexibly shifting attention may affect whether task-irrelevant information is later remembered. In the present investigation, we manipulated contextual expectations in event-related prospective memory (PM) to examine the consequences of flexible attention allocation on incidental memory. Across two experiments, participants completed a color-matching task while monitoring for ill-defined (Experiment 1) or specific (Experiment 2) PM targets. To manipulate contextual expectations, some participants were explicitly told about the trial types in which PM targets could (or not) appear, while others were given less precise or no expectations. Across experiments, participants' color-matching decisions were slower in high-expectation trials, relative to trials when targets were not expected. Additionally, participants had better incidental memory for PM-irrelevant items from high-expectation trials, but only when they received explicit contextual expectations. These results confirm that participants flexibly allocate attention based on explicit trial-by-trial expectations. Furthermore, the present study indicates that greater attention to item identity yields better incidental memory even for PM-irrelevant items, irrespective of processing time.

Keywords Prospective memory · Attention allocation · Incidental encoding

To successfully carry out future intentions, it is often important to monitor the environment for the appropriate context in which to act. For instance, if you intend to take exit 70 while driving on the interstate, you might start monitoring the exit signs as you get close to your exit (e.g., Exit 65–69), but not when you are further away (e.g., Exit 25–29). Maintaining prospective memory (PM) intentions tends to slow down responses, and cause more errors, during ongoing activities (e.g., driving; Hicks et al., 2005; McDaniel & Einstein, 2000; Smith et al., 2007). In this investigation, we examined how the contextual expectations of event-based PM intentions dynamically adjust attention allocation in a trial-by-trial manner, and how these adjustments affect both ongoing task performance and subsequent incidental memory for PM-irrelevant items.

Many views of event-based PM (Guynn, 2003; McDaniel & Einstein, 2000; Scullin et al., 2013; Smith et al., 2007; Smith & Bayen, 2004) assume that interference costs in response times and accuracy reflect a shared limited-capacity pool of attentional resources that gets divided between implementing the PM intention and completing the ongoing task. Importantly, individuals metacognitively assess the relative difficulty of executing the PM intention during ongoing task contexts, allowing them to efficiently divide attention resources between the two by adopting a "global," task-general attention allocation policy (Hicks et al., 2005; Marsh et al., 2005; Marsh, Cook, & Hicks, 2006a). When the PM task is relatively easy, resources can be primarily allocated to completing the ongoing task, minimizing or even eliminating interference costs. However, when the global demands of the PM task increase (e.g., ill-defined targets and/or multiple targets), implementing PM intentions becomes more difficult and resources must be devoted to strategically monitoring the environment for the conditions in which to implement the intention, impairing ongoing task performance (Cohen et al., 2008; Hicks et al., 2005). Interestingly, the *subjective*

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demand of PM tasks also produces interference costs: Objectively easy PM intentions interfere with ongoing task performance when individuals perceive them as either difficult (Lourenço et al., 2015) or important (Loft et al., 2008). Although objective task demands certainly impact ongoing task performance, effects from subjective demands highlight the additional influences of top-down attentional control.

The distribution of attentional resources between PM and ongoing tasks is not immutable, but can be *flexibly* adjusted on a trial-by-trial basis. This allows individuals to adapt as they gain experience completing the task or if the perceived demands of the PM task change (e.g., Lourenço et al., 2015). Flexible attention allocation also allows for more efficient use of resources, such that resources can be devoted to the ongoing task in contexts where PM targets are not expected, but strategically diverted to monitoring during contexts when they are likely to appear (Bowden et al., 2017; Bugg & Ball, 2017; Kuhlmann & Rummel, 2014; Lourenço et al., 2013; Marsh et al., 2006a, b). Smith et al. (2017), for example, examined how expectations influence PM performance by showing participants pictures from around their campus in an ordered (i.e., logical walking order) or random progression. While viewing the photos, participants' ongoing task was to indicate whether each picture contained more than six people, but those in the PM condition were to provide an alternative response to specific campus locations (e.g., student union). Although monitoring for PM targets in the ordered and random conditions produced interference costs (relative to a no-intention control group), the cost was smaller for the ordered condition. As participants in the ordered condition got "closer" to PM target locations, interference costs increased. By contrast, participants in the random condition showed equivalent interference costs for all pictures. These results suggest that participants in the ordered condition strategically divided attention between the PM and ongoing tasks: They devoted more resources to the ongoing task when they knew the PM location was "far away," but increased their PM monitoring when they knew the target location was imminent.

Diverting attentional resources from the ongoing task to the PM task involves shifting focus across various task-relevant features in the environment (e.g., from people to locations in Smith et al., 2017). Since Craik and Lockhart's (1972) seminal work, extensive research has demonstrated that attentional shifts facilitate incidental encoding of newly attended information into long-term memory (for a review, see Castel et al., 2015). Consequently, when attention is shifted to search for PM targets, incidental item encoding may be facilitated by attentively inspecting the item's identity (i.e., determining whether the item is a target). This relation between attention allocation and incidental encoding has often been studied in visual search tasks: As with PM, individuals strategically monitor for specific targets among arrays of other objects, similar to how TSA agents search luggage for illegal items. Research in visual search has shown that, when searches demand greater attention (e.g., due to imprecise or multiple target cues), responses are slower and more error prone. Although such highly demanding search tasks emphasize target detection, research consistently shows that nontarget objects encountered during demanding searches are more likely to be later recognized in surprise memory tests (Guevara Pinto et al., 2020; Guevara Pinto & Papesh, 2019; Hout & Goldinger, 2010, 2012; Thomas & Williams, 2014). Importantly, these findings replicate even when viewing metrics (e.g., number of objects, inspection durations) are equated across difficulty conditions (see Guevara Pinto & Papesh, 2019), suggesting a strong relationship between attention allocation and incidental encoding in other monitoring tasks.

Difficulty-enhanced incidental memory has also been reported in the PM literature. Loft and Humphreys (2012; see also Humphreys et al., 2020) presented participants with a lexical-decision (LD) task and the PM intention to respond to one specific target word (e.g., *peach*; focal condition) or words from a specific category (e.g., *fruits*; nonfocal condition). After the PM phase, participants completed a surprise old/new recognition test for the nontarget items presented during the LD task. Relative to a no-intention control, both PM conditions made slower LD responses, but participants in the nonfocal condition incurred greater costs than those in the focal condition. In the memory test, however, participants in the nonfocal condition recognized more nontarget items than participants in the focal and control conditions, suggesting that the higher attentional demands of nonfocal PM intentions facilitated incidental item encoding.[1] Knight et al. (2011) also examined incidental item encoding during a PM task and found that nontarget items that were similar to PM targets, and thus demanded greater attention to reject as nontargets, were more likely to be remembered.

The present investigation assessed how flexible attention allocation may dynamically impact what is (and is not) incidentally encoded during a PM task, independent of the global attentional demands of the task. If individuals selectively allocate resources to detect PM targets (i.e., scrutinizing items' identities or meanings) in trials where these are expected, then incidental encoding of any item presented on those trials should be facilitated, even if it is not the expected target. Conversely, in trials where PM targets are not expected and attention is focused on the ongoing task, item identification (and consequently item encoding) should be limited. To assess how flexible attention allocation impacts incidental encoding, we adapted a paradigm used by Kuhlmann and Rummel (2014; see also, Smith & Bayen, 2004): During the

[1] `Loft and Humphreys (2012) explained their results as a consequence of semantically matching items to PM cues in the nonfocal condition (e.g., "is chair a *fruit*?"). While this explanation is plausible, we appeal to an attention-driven explanation, and in our experimental design we use a PM task that does not involve semantic categorization.

ongoing task, participants viewed one of three polygons sequentially presented in four different colors, followed by a word. Participants then determined whether the word's font color matched any of the four immediately preceding colors. The PM task required participants to make a different response for any *animal* names, which were only ever presented on trials with a specific shape. Kuhlmann and Rummel used three levels of context instructions to manipulate attention allocation: (1) Explicit instructions specified which polygon would precede PM targets; (2) oblique instructions noted that one polygon, but not which, would precede PM targets; and (3) no-context instructions did not mention the predictive context relationship. Participants who were explicitly instructed about predictive contexts had the highest PM accuracy and only experienced interference costs in trials where they expected to encounter PM targets. These results reveal that contextual cues (e.g., polygons) can be used to flexibly switch attention between the ongoing (i.e., color processing) and PM (i.e., item processing) tasks. This flexible deployment of attention should have consequences for what people incidentally remember about the non-PM items encountered during low- versus high-expectation trials. To examine this hypothesis, we expanded upon Kuhlmann and Rummel's paradigm to include an incidental memory test for non-PM words.

In the present study, participants completed a color-matching task[2] with the PM intention to provide a separate response to any item ending in *-ion* (Experiment 1) or for the items *corn* and *dancer* (Experiment 2). In both experiments, task expectations were manipulated between groups by giving participants different instructions about the polygon that would precede PM targets: Some participants were given explicit expectations, some were given nonspecific expectations, and some were given no expectations (see Experiment 1 Procedure section), allowing to us compare flexible attention allocation, and its consequences for incidental encoding, based on contextual expectations in a graded manner. After the color-matching phase, participants completed a surprise old/new recognition test for the nontarget items encountered throughout the color-matching task. In line with previous research (Kuhlmann & Rummel, 2014), we predicted that participants would shift attention from color processing to identity processing in trials where they expected PM targets to appear, incurring greater interference costs (both in RTs and error rates) during PM-relevant, relative to PM-irrelevant, trials. Additionally, we predicted that incidental learning would benefit from this shift in attention, allowing participants to later recognize more items encountered from PM-relevant trials than items encountered in PM-irrelevant trials. Because we predicted that item encoding would be dependent on the amount of attention allocated, not on the length of encoding time, incidental item recognition should be related to, but not dependent on, interference costs.

Experiment 1

Participants A power analysis ($1 - \beta = .95$; $\alpha = .05$, within–between interaction with 0.5 correlation among repeated measures across conditions, and nonsphericity correction of 1) conducted using G*Power 3.1 (Faul et al., 2007) on the Group × Context effect size reported in Kuhlmann and Rummel (2014; $\eta_p^2 = .40$) suggested a sample size of 12 participants in each experimental group. Two hundred and sixty-five university students[3] participated in exchange for partial course credit ($M_{age} = 19.41$ years, $SD_{age} = 3.19$ years; 146 females). All participants were native English speakers. Participants were randomly assigned to one of four conditions, three of which included PM intentions, but varied the instructions about when to expect PM targets. They received specific instructions ($n = 71$), oblique instructions ($n = 64$), or no instructions ($n = 70$). The fourth condition was a no PM-intention control condition ($n = 60$).

Materials A list of 150 words (average length = 6.2 letters) with mean word frequency of 63.57 (Kuçera & Francis, 1967) was used for nontarget stimuli (see Appendix Table 5 for the full word list). Eight additional words ending in the syllable -*ion* were selected as PM targets (*illusion, lion, onion, action*, *violation, scallion, potion, religion*). No other experimental words ended in *-ion*. All words were presented in 22-point Courier New font, and in red (255, 0, 0), blue (0, 0, 255), lime (0, 255, 0), yellow (255, 255, 0), or magenta (255, 0, 255) font color. The four polygon shapes (triangle, square, pentagon, and hexagon) used in the color-matching task were sized to fit within a 1,280 × 720 pixel rectangle, and were also presented in either red, blue, lime, yellow, or magenta color. All stimuli were presented on 21.5-inch monitors, with 1,920 × 1,080 screen resolution and 60-Hz sampling rates. Experimental procedures were controlled using E-Prime 2.0 (Psychology Software Tools).

Procedure The design was a 2 (trial type: PM relevant, PM irrelevant) × 3 (group: specific instruction, oblique instruction, no instruction) mixed design, with group as the between-subjects variable. All participants completed two phases—a PM phase, followed by a surprise recognition test. During the

[2] The color-matching paradigm was selected because it involves a different processing orientation (i.e., color emphasis) than the PM task (i.e., spelling/identity emphasis). Thus, the difference across experiments is the specificity of the PM targets.

[3] Research assistants completed multiple experimental sessions during the last week of data collection for the semester, when we were close to our sample size goal. We erred on the side of oversampling to avoid cancelling participants who signed up for the study.

PM phase, participants completed the color-matching task schematically outlined in Fig. 1: After pressing space bar to initiate the trial, participants viewed a single polygon sequentially presented in four different colors, followed by a short delay, after which a word appeared in one of the five font colors. As in previous work using the color-matching task (Kuhlmann & Rummel, 2014), each polygon was presented centrally on a black screen for 500 ms, followed by blank 250 ms interstimulus interval (ISI). After all four colors were presented, a 500-ms delay displaying three crosses (+++) appeared at the center of the screen prior the onset of the word. In a randomly determined half of the trials (48 trials), the word appeared in the same color font as one of the polygons, while in the other half, the word appeared in a different color. Participants pressed the "F" key if the font color matched any of the four previous colors, and the "J" key if it did not. Words were presented until participants responded. A 2-second time penalty followed incorrect responses.

After providing written informed consent, participants practiced eight color-matching trials (half color-match, half color-mismatch). After practice, participants read the PM instructions: If a word ending in "*ion*" appeared, they were to abandon the color-matching task and press the "B" key instead. Participants in the specific-instruction condition were shown a specific polygon (e.g., a square) in white, and read that it would always precede PM targets (PM-relevant trials). They also read that targets would never follow any other polygon (PM-irrelevant trials). In this sense, PM-irrelevant trials were always deterministic, meaning that they would never include a PM target. PM-relevant trials, however, were probabilistic, randomly including both nontarget and target items, with PM targets presented in only one third of PM-relevant trials. The identity of the PM-relevant polygon was counterbalanced across participants. Participants in the oblique and no-instruction conditions completed the same practice task as those who received specific instructions, but they received different preexperimental instructions regarding PM targets: Those in the oblique-instruction condition were told that PM targets would only appear following one specific polygon shape, but they were not told the *identity* of the relevant shape. Participants in the no-instruction condition did not receive any instructions regarding the relationship between PM targets and polygon shapes. The control group was only given color-matching instructions, and did not complete the secondary PM task.

After the researcher verbally repeated the instructions, verifying that participants understood the PM intention and its relationship to the polygon shapes (i.e., specific and oblique instructions only), participants solved arithmetic problems for 3 minutes before starting the PM phase. The PM phase consisted of 96 trials (half color match, half color mismatch). For each trial, the polygon was randomly selected, with each shape used equally often (24 trials each), resulting in 24 PM-relevant trials and 72 PM-irrelevant trials. Nontarget words were randomly selected (without replacement) on each trial, with the exception of Trials 12, 24, 36, 48, 60, 72, 84, and 96, which were reserved for PM targets (half color-match trials, half color-mismatch trials). Importantly, across all experimental conditions, PM targets were always preceded by the "relevant" polygon, ensuring that, besides the instruction manipulation, the task was identical for every experimental participant.

After the completion of the PM phase, participants completed a 64-item (half old) surprise old/new recognition test in which old items were drawn from the nontarget words presented in the color-matching task. Half of the old items were sampled from PM-relevant trials, while the other half were sampled from PM-irrelevant trials. New items were randomly sampled from remaining words in Appendix Table 5. Participants pressed the "F" key to indicate that they remembered an item and the "J" key if they did not. Each item was presented individually in white font (255, 255, 255) at the center of the screen until response, with a 500 ms ITI between items. No feedback was given.

After the memory test, participants completed a postexperiment survey to assess whether (1) they remembered the PM intention and its associated target feature (i.e., *-ion*), and (2) they understood the relationship between polygons and PM targets. For participants in the specific-instruction condition, the second question served to assess whether they remembered the PM-relevant polygon. For those in the oblique and no-instruction conditions, it served to determine whether they learned the relationship as the color-matching

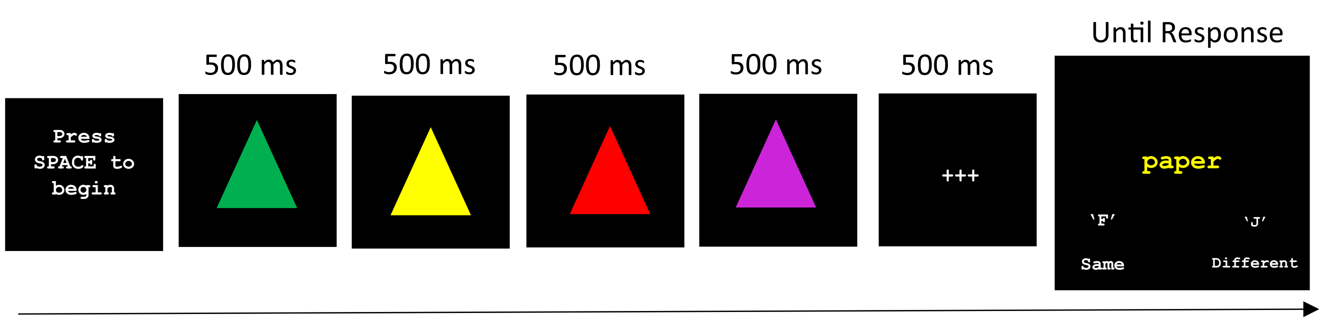

Fig. 1 Trial schematic for the color-matching task. A 250 millisecond ISI was presented between polygon presentations. Color image available for online publication only

task progressed, causing them to change their attention allocation strategy throughout the task. Both questions were open-ended, and participants provided their answers by typing them with the keyboard.

Results

All proportion data were arcsine-square-root transformed prior to analysis to ensure normality. For clarity, we present raw values in text and tables. All descriptive details supporting the analyses appear in Table 1. Alpha level for all analyses was .05, and multiple comparisons were subjected to Bonferroni corrections calculated in JASP (JASP Team, 2020) by multiplying the resulting p value by the number of comparisons made. Post-hoc comparisons described in-text thus reflect Bonferroni corrected p values (p_{Bonf}). Greenhouse–Geisser-corrected degrees of freedom are reported for any contrasts involving sphericity violations. Raw data and analysis files for all experiments are available on OSF (https://osf.io/bkw5g/). Prior to analyses, 12 participants (four specific, three oblique, five no instruction) were excluded for not recalling the PM task in the postexperiment survey and failing to respond to a single PM target during the PM phase.

PM performance Prospective memory performance was analyzed in a one-way between-group analysis of variance (ANOVA) on the proportion of correct PM responses for each experimental condition. Because participants in the specific-instruction condition knew which polygon would always precede PM targets, we expected that they would have a higher proportion of correct PM responses. However, PM performance did not differ across conditions (p > .250). Overall, PM performance was high, with all conditions responding to at least 70% of PM targets (see Table 1).

Color-matching accuracy For each participant in the experimental conditions, the first trial of the experiment and trials following PM targets were removed from analyses to avoid any artificial costs associated with these trials (Boywitt & Rummel, 2012). First, we assessed whether holding a PM intention in mind produced interference to the ongoing task by comparing each condition's color-matching error rate (collapsed across trial type) to that of the control group (no PM intention). A one-way ANOVA on color-matching error rates indicated that holding a PM intention in mind interfered with the ongoing task, $F(3, 250) = 4.34$, $p = .005$, $\eta_p^2 = .049$, as both the oblique and no-instruction conditions made more errors, overall, than the control group, both $p_{\text{Bonf}} < .05$. The Specific Instruction condition, however, did not differ from the control, $p_{\text{Bonf}} = .122$ (see Table 1). The three experimental conditions did not differ from one another.

To determine whether color-matching error rates differed across trial types for each experimental condition, we conducted a 2 (trial type: PM relevant, PM irrelevant) × 3 (instruction: specific, oblique, no instruction) mixed-model ANOVA, with instruction as the between-subjects variable. However, no main effects, or interactions, were observed.

Color-matching RTs Response time (RT) analyses were limited to trials with correct color-matching responses. Similar to the previous analyses, for each participant in the experimental conditions, the first trial of the experiment, and the first trial following PM targets, were removed to avoid any artificial costs. Additionally, prior to data analysis, trials with RT outliers were filtered, with cutoff values defined as 2.5 standard deviations above the individual participant mean (separately for color-match and color-mismatch trials). This resulted in 4.2% and 5% of color-match and color-mismatch trials being dropped from the analyses, respectively. A one-way ANOVA further confirmed that holding a PM intention in mind interfered with the ongoing task, $F(3, 250) = 8.63$ $p < .001$, $\eta_p^2 = .09$, as all three experimental conditions produced slower responses than the control group, all $p_{\text{Bonf}} < .05$ (see Table 1). However, the experimental conditions did not differ from one another.

RTs were then submitted to a 2 (trial type) × 3 (instruction) mixed-model ANOVA to assess whether trial types and/or instructions differentially slowed ongoing task responses. A main effect of trial type was observed, $F(1, 191) = 44.87$ $p <$ .001, $\eta_p^2 = .19$, in which responses were slower during PM-

Table 1 Mean prospective memory and color-matching performance as a function of experimental conditions in Experiment 1

Instruction type	PM accuracy	Error rates			Response times		
		PM irrelevant	PM relevant	Trial difference	PM irrelevant	PM relevant	Trial difference
Specific	.71 (.05)	.089 (.009)	.103 (.014)	.014 (.013)	1,482 (60)	1,728 (61)	246 (30)***
Oblique	.70 (.04)	.101 (.01)	.124 (.013)	.023 (.012)	1,652 (72)	1,715 (71)	63 (29)*
No instruction	.72 (.04)	.096 (.007)	.097 (.011)	.001 (.009)	1,697 (56)	1,711 (54)	14 (23)
Control	n/a	.063 (.005)	n/a	n/a	1,302 (51)	n/a	n/a

Difference scores were computed by subtracting the mean scores of PM-Irrelevant trials from mean scores of PM-relevant trials

Statistical difference between PM-relevant and PM-irrelevant trials is noted by * ($p < .05$) or *** ($p < .001$). Standard errors are displayed in parentheses relevant (M = 1719, SE = 36) than PM-irrelevant trials (M = 1611, SE = 38). However, this effect of trial type should be interpreted within the context of a reliable Trial Type × Instruction interaction was also observed, $F(2, 191) = 17.98$, $p < .001$, $\eta_p^2 = .15$. Post hoc comparisons revealed that the effect of trial type was only reliable for the specific, $p_{\text{Bonf}} < .001$, and oblique instruction conditions, $p_{\text{Bonf}} = .026$ (see Table 1). Response times between trial types did not differ for the no-instruction condition.

To further explore this interaction, we conducted tests of simple effects to compare RTs across conditions during PM-relevant and PM-irrelevant trials separately. There were no differences between conditions for PM-relevant trials ($p > .250$), suggesting that interpretation of the reliable interaction is nuanced: Although participants in the specific-instruction condition knew exactly in which trials PM targets could appear, they did not incur greater interference costs than participants in the oblique or no-instruction conditions. For PM-irrelevant trials, however, a reliable effect of condition emerged, $F(2, 191) = 3.12$, $p = .046$, $\eta_p^2 = .032$, characterized by shorter RTs in the Specific Instruction relative to the no-instruction condition, $p_{\text{Bonf}} = .045$. This suggests that the interaction was driven mostly by facilitation of color-matching responses during PM-irrelevant trials: If participants knew exactly when PM targets would *not* appear, and focusing on spelling was unnecessary, they devoted more attention to completing the ongoing task. The specific and oblique-instruction conditions did not differ from one another, $p > .05$.

Nontarget recognition To assess how item recognition was impacted by holding a PM intention in mind, hit and false alarm rates were used to calculate the signal detection index of discriminability (d').[4] To examine how overall sensitivity varied across conditions, we analyzed d' in a one-way ANOVA, which was reliable, $F(3, 250) = 4.67$, $p = .003$, $\eta_p^2 = .053$. Only the specific-instruction condition yielded higher sensitivity than the control group, $p_{\text{Bonf}} = .002$ (see Table 2). No other comparison was reliable, suggesting that explicit contextual expectations are necessary to facilitate nontarget encoding in a dual-task, relative to single-task, condition.

To evaluate how incidental encoding varies across trial types and conditions, we examined d' in a 2 (trial type) × 3 (instruction) mixed-model ANOVA. A main effect of trial type was observed, $F(1, 191) = 7.69$, $p = .006$, $\eta_p^2 = .039$, but was interpreted within the context of a reliable interaction, $F(2, 191) = 4.38$, $p = .014$, $\eta_p^2 = .04$. Post hoc comparisons revealed that only participants in the specific-instruction condition showed higher discriminability for items from PM-relevant (M = 1.06, SE = .10) than PM-irrelevant trials (M = .79, SE = .07), $p_{\text{Bonf}} < .001$. These results suggest that flexible attention allocation dynamically impacts incidental encoding, facilitating item encoding when attention is directed to assess whether an item is a PM target, and limiting encoding when attention is devoted to processing item features relevant to the ongoing task (e.g., color). To examine whether incidental encoding (and thus subsequent discriminability) was better when participants had expectations about PM targets, we conducted tests of simple effects to compare d' across conditions for items presented in PM-relevant trials and items presented in PM-irrelevant trials separately. However, both tests of simple effects failed to reach significance, both ps > .05, indicating that despite numerical differences in discriminability (see Table 2), incidental encoding was roughly equal across all experimental conditions.

Lastly, to better understand the relation between attention allocation and nontarget recognition, individual correlation analyses were conducted on recognition hit rates and ongoing task performance measures (both error rates and RTs) for each experimental condition. All correlational analyses yielded nonreliable results (all ps > .05), indicating that incidental item recognition was not related to the speed of color-matching decisions (see Appendix Fig. 2 for data scatterplots).

Postexperiment survey At the end of the experiment, we asked participants in the experimental conditions whether they remembered the PM task (e.g., "What were the *special* items and what response were they supposed to receive during the first part of the experiment?"). Twelve participants failed to recall the PM task and were consequentially removed from analyses. We also asked participants if they were aware of the PM-relevant shape (e.g., "What was the relationship between the *special* items and the shapes during the first part of the experiment?"). Of the remaining participants, all but two participants in the specific-instruction condition directly named the PM-relevant shape. The majority of participants (all but seven) in the oblique-instruction condition learned the association between PM targets and the PM-relevant shape.[5] Lastly, three participants in the no-instruction condition noted a relationship between PM targets and polygons, but none of them stated the identity of the PM-relevant shape.

Discussion

Experiment 1 tested whether flexible attention allocation induced by PM expectations differentially impacts how nontargets are incidentally encoded. Participants completed a color-

[4] Note that d' was calculated separately for items presented during PM-relevant and for items presented during PM-irrelevant trials based different hit rates. However, the false-alarm rate used in each calculation was the same for both types of items.

[5] The pattern of results does not change when those participants who did not indicate the correct association between PM targets and the PM-relevant shape are dropped from the analyses.

Table 2 Mean recognition memory performance as a function of experimental conditions in Experiment 1

Instruction type	Discriminability (d')			Hits		False alarms
	PM irrelevant	PM relevant	Trial difference	PM irrelevant	PM relevant	
Specific	.786 (.065)	1.06 (.099)	.274 (.078) ***	.556 (.021)	.636 (.024)	.290 (.061)
Oblique	.760 (.070)	.821 (.083)	.061 (.110)	.593 (.018)	.612 (.021)	.333 (.020)
No instruction	.789 (.068)	.785 (.068)	-.004 (.059)	.588 (.024)	.585 (.025)	.315 (.019)
Control	.532 (.086)	n/a	n/a	.493 (.025)	n/a	.332 (.026)

Difference scores were computed by subtracting the mean scores of PM-Irrelevant trials from mean scores of PM-relevant trials

Statistical difference between PM-relevant and PM-irrelevant trials is noted by * ($p < .05$) or *** ($p < .001$). Standard errors are displayed in parentheses

matching task with a nonfocal PM intention in mind (i.e., monitoring for words ending in *-ion*), and PM expectations were manipulated between-groups by instructing some participants about the type of trial in which PM targets could (or would not) be presented. Relative to a control condition with no PM intention, all PM groups incurred interference costs in color-matching response times. Furthermore, response times differed in trials where participants explicitly expected, or implicitly learned to expect, PM targets to appear (i.e., specific and oblique-instruction conditions, respectively) relative to trials where PM targets were not expected. Meanwhile, participants with no explicit PM expectations (i.e., no-instruction condition) showed no performance difference between PM-relevant and PM-irrelevant trials. Whereas Kuhlmann and Rummel (2014) found that participants with specific instructions engaged in greater strategic monitoring (resulting in larger ongoing task costs) in high-expectation trials, we observed effects in low-expectation trials: Participants with specific instructions reduced monitoring when they did not expect a PM target (resulting in ongoing task *facilitation*). Although the effects operate on different trial types, they are nevertheless consistent in showing that participants flexibly allocated attention between the PM and ongoing tasks depending on PM target expectations. As predicted, this flexible distribution of attentional resources incidentally influenced item encoding: Participants who received specific instructions about when to expect PM targets had enhanced memory for nontargets encountered during PM-relevant, relative to PM-irrelevant, trials. That this was only observed in the specific-instruction condition suggests that participants must have clear expectations for when to monitor for PM targets if they are to shift attention to process the item's spelling. Similarly, clear expectations for when *not* to expect targets facilitates shifting attention to features relevant to the ongoing task (i.e., font color), limiting item processing, and subsequently reducing incidental item encoding. Comparatively, learned expectations (i.e., oblique-instruction condition) may not be enough to cause participants to reduce monitoring in PM-irrelevant trials.

Unexpectedly, there were no differences between PM groups in detection of PM targets. Although participants in the specific-instruction condition knew exactly when PM targets could appear, they did not detect more PM targets than participants in the oblique or no-instruction conditions. PM performance was relatively high (72% for no instruction) compared to other studies using a similar paradigm (53% for the "No Context Information" condition in Kuhlmann & Rummel, 2014). It is possible that this is due to the perceived difficulty of the PM intention used in Experiment 1 (i.e., respond to items ending in *-ion*). The apparent demands of this intention might have caused participants in the no-instruction conditions to engage in more proactive control of attention (Ball & Brewer, 2018; Braver, 2012; Bugg et al., 2013), whereby they continuously monitored for PM targets throughout the color-matching task. This is supported by relatively strong ongoing task interference (approximately 400 ms) coupled with a high degree of PM target detection. This could also explain why there were no differences across experimental conditions in ongoing task performance or simple effects tests of incidental recognition. In fact, the color-matching response times for our experimental conditions in Experiment 1 were, on average, 476 ms slower than those observed by Kuhlmann and Rummel (2014). Perhaps participants' attention was, for the most part, focused on detecting PM targets. To test this possibility, we conducted a second experiment to replicate the findings of Experiment 1 using a seemingly easier nonfocal[6] PM intention (i.e., respond to *corn* or *dancer*). If participants perceived the PM task to be easy, they should be more likely to allocate attention to the ongoing task, reducing interference costs in the color-matching task. Importantly, this may allow for differences across PM conditions to emerge when comparing performance separately for PM-relevant and PM-irrelevant trials, as attention may be selectively allocated to the PM task only when PM targets are expected.

[6] Although responding to specific PM targets is easier than responding to ill-defined targets (e.g., `Hicks et al., 2005), processing in the ongoing (color emphasis) and PM tasks (identity emphasis) does not overlap, making the PM intention nonfocal.

Experiment 2

Participants A new group of two hundred and four university students participated in exchange for partial course credit (M_{age} = 18.72 years, SD_{age} = 1.20 years; 151 females). As in Experiment 1, they were randomly assigned to one of three instruction conditions[7]: The specific-instruction condition (*n* = 68), the oblique-instruction condition (*n* = 69), or the no-instruction condition (*n* = 67).

Materials Nontarget words were identical to Experiment 1. Two additional items were selected to serve as PM targets (*corn* and *dancer*). Target items from Experiment 1 were *not* used in either the color-matching task or the surprise recognition test.

Procedure The procedure was nearly identical to Experiment 1, with a PM Phase (color-matching task) followed by a surprise old/new recognition memory test. Th PM task differed slightly from Experiment 1, such that participants were instructed to make the PM response only when either "corn" or "dancer" appeared. Instructions regarding the association between PM targets and the PM-relevant shape, and all other experimental details, were identical to Experiment 1.

Results

All statistical analyses and reporting choices were identical to Experiment 1. Descriptive details supporting the analyses are found in Tables 3 and 4. Prior to analyses, six participants (three specific, one oblique, two no instruction) were excluded for not recalling the PM task in the postexperiment survey and failing to respond to a single PM target during the PM phase.

PM performance Relative to Experiment 1, PM target detection increased by over 10%, indicating that the PM task was indeed easier when well-defined PM cues were used (see Table 3). Again, however, no reliable difference between Instruction conditions was observed, $p > .250$.

Color-matching accuracy Analyses excluded the first trial of the experiment and the first trials following PM targets. To examine how error rates varied across trial type and conditions, we conducted a 2 (trial type: PM relevant, PM irrelevant) × 3 (instruction: specific, oblique, no instruction) mixed-model ANOVA, with instruction as the between-subjects variable. A main effect of trial type, $F(1, 195) = 13.06$, $p <.001$, $\eta_p^2 = .06$, was interpreted within the context of a reliable interaction, $F(2, 195) = 6.43$, $p =.002$, $\eta_p^2 = .06$. The interaction showed reliable differences between PM-relevant and PM-irrelevant trials for the specific, $p_{\mathrm{Bonf}} = .001$, and oblique-instruction conditions, $p_{\mathrm{Bonf}} = .041$, but not for the no-instruction group, $p_{\mathrm{Bonf}} > .250$ (see Table 3). This indicates that, when participants expected PM targets, attention was shifted from processing the item's color to processing the item's identity, resulting in more color-matching errors relative to trials where targets were not expected.

Color-matching RTs Using the same trimming procedures as Experiment 1, outlier trials were removed prior to analyses for each trial type, resulting in 1.6% and 5.4% of PM-relevant and PM-irrelevant trials dropped, respectively. Analyses were limited to trials with correct color-matching responses (excluding the first trial of the experiment and the first trial following PM targets). A 2 (trial type) × 3 (instruction) mixed-model ANOVA revealed a main effect of trial type, $F(1, 195) = 46.84$, $p < .001$, $\eta_p^2 = .19$, which revealed slower responses during PM-relevant (M = 1583, SE = 33) than PM-irrelevant trials (M = 1506, SE = 32).[8] A reliable interaction, $F(2, 195) = 19.01$, $p < .001$, $\eta_p^2 = .16$, revealed that this effect was exclusively driven by the specific-instruction condition: Trial type differences only emerged for participants in the specific, $p_{\mathrm{Bonf}} < .001$, but not the oblique or no-instruction groups (both $p_{\mathrm{Bonf}} > .05$). This suggests that when participants had explicit knowledge of predictive trial types, they allocated attention to emphasize item color, not item identity, which speeded color-matching responses in trials in which PM targets were not expected. Lastly, we compared color-matching RTs across conditions during PM-relevant and PM-irrelevant trials separately. Unlike Experiment 1, there was no group difference for PM-irrelevant trials ($p > .05$). Similarly, no significant differences were observed for PM-relevant trials, $F(2, 195) = 2.88$, $p = .058$, $\eta_p^2 = .03$, despite the surprisingly short RTs in the oblique-instruction condition (see Table 3). Although participants in the specific-instruction condition knew exactly when PM targets could appear, they did not incur any additional costs on those trials above what they already incurred by holding a PM intention in mind (e.g., oblique and no-instruction conditions). Instead, participants in the specific-instruction condition seem to use their knowledge primarily to withdraw attention during PM-irrelevant trials.

Nontarget recognition To assess how incidental item encoding differed across trial type and instruction conditions, we analyzed d' in a 2 (trial type) × 4 (instruction) mixed-model ANOVA. The effect of trial type, $F(1, 195) = 13.03$, $p < .001$, $\eta_p^2 = .06$, was interpreted within the context of a reliable

[7] Because Experiment 1 established that PM intentions produce interference costs, we did not include a control group in Experiment 2, which was designed to more fully explore attention allocation differences between PM instruction groups.

[8] RT responses in Experiment 2 were 100-ms faster, on average, than those observed in Experiment 1 (see Table 1).

Table 3 Mean prospective memory and color-matching performance as a function of experimental conditions in Experiment 2

Instruction type	PM accuracy	Error rates			Response times		
		PM irrelevant	PM relevant	Trial difference	PM irrelevant	PM relevant	Trial difference
Specific	.83 (.02)	.080 (.007)	.127 (.014)	.047 (.012)***	1,465 (52)	1,644 (53)	179 (25)***
Oblique	.83 (.03)	.093 (.009)	.118 (.013)	.025 (.011)*	1,445 (47)	1,468 (45)	23 (21)
No instruction	.84 (.03)	.093 (.010)	.084 (.013)	−.009 (.011)	1,610 (67)	1,632 (73)	22 (20)

Difference scores were computed by subtracting the mean scores of PM-irrelevant trials from mean scores of PM-relevant trials

Statistical difference between PM-relevant and PM-irrelevant trials is noted by * ($p < .05$) or *** ($p < .001$). Standard errors are displayed in parentheses

interaction, $F(2, 195) = 11.95$, $p < .001$, $\eta_p^2 = .11$. Post hoc comparisons revealed higher discriminability for items encoded during PM-relevant trials relative to those encoded during PM-irrelevant trials for the specific, $p_{\mathrm{Bonf}} < .001$, but not for the oblique and no-instruction conditions, both $p_{\mathrm{Bonf}} < .05$ (see Table 4). This suggests that flexibly allocating attention based on PM expectations impacts incidental learning: Participants had better incidental memory for words encountered in contexts that focused attention on item-processing, relative to contexts that focused attention on extraneous stimuli characteristics (e.g., font color). Importantly, incidental recognition was not related to decision time during the ongoing task. None of the correlational analyses between recognition hits and color-matching RTs yielded statistically reliable results (all ps > .05; see Appendix Fig. 3 for data scatterplots), indicating that item encoding was not impacted by the speed of color-matching decisions.

More importantly, we examined whether incidental encoding was better when participants had expectations about PM targets by comparing d' across conditions for items encoded during PM-relevant and PM-irrelevant trials separately. The results showed a reliable effect of condition for items encoded during PM-relevant trials, $F(2, 195) = 4.61$, $p = .011$, $\eta_p^2 = .05$. Post hoc comparisons indicated that the specific-instruction condition showed enhanced incidental memory ($M = 1.02$, $SE = .07$) relative to the no-instruction condition ($M = .74$, $SE = .07$), $p_{\mathrm{Bonf}} = .008$. No other comparison was reliable (see Table 4). Although ongoing task performance was nearly indistinguishable for participants in the specific and no-instruction conditions (see Table 3), participants in the specific condition remembered more items from PM-relevant trials. This suggests that an explicit shift in attention to item-level processing in preparation for possible PM targets may affects memory *without* affecting ongoing task performance. No effect of condition was observed for items encoded during PM-irrelevant trials.

Postexperiment survey As mentioned, six participants failed to recall the PM task and were removed prior to analyses. All of the remaining participants in the specific-instruction condition correctly named the PM-relevant shape. All but 15 participants in the oblique-instruction condition learned the association between PM targets and the PM-relevant shape. No participants in the no-instruction condition noted a relationship between PM targets and polygons.

Discussion

To explore how trial-by-trial fluctuations in attention impact ongoing processing (and subsequent memory), Experiment 2 adopted an easier PM task to reduce continuous monitoring for PM targets across all trial types (e.g., Bugg et al., 2013; Einstein et al., 2005; Scullin et al., 2013). Despite the easier PM task, participants in the specific-instruction condition strategically monitored their environment to implement the PM

Table 4 Mean recognition memory performance as a function of experimental conditions in Experiment 2

Instruction type	Discriminability (d')			Hits		False alarms
	PM irrelevant	PM relevant	Trial difference	PM irrelevant	PM relevant	
Specific	.660 (.059)	1.02 (.067)	.360 (.062) ***	.516 (.022)	.642 (.021)	.286 (.017)
Oblique	.777 (.057)	.881 (.061)	.104 (.054)	.558 (.021)	.595 (.02)	.290 (.018)
No instruction	.813(.056)	.740 (.067)	−.073 (.059)	.569 (.02)	.550 (.022)	.281 (.016)

Difference scores were computed by subtracting the mean scores of PM-irrelevant trials from mean scores of PM-relevant trials

Statistical difference between PM-relevant and PM-irrelevant trials is noted by * ($p < .05$) or *** ($p < .001$). Standard errors are displayed in parentheses intention, allocating attention to process the item's identity or color based on their expectations. This was evidenced by slower color-matching responses in trials in which PM cues were expected, and faster responses in trials where PM cues would not appear, despite no improvement in PM performance relative to the other PM conditions. Relative to the no-instruction group, they also incidentally remembered more nontarget items from PM-relevant, relative to irrelevant, trials. This effect emerged despite both groups performing nearly identically on PM-relevant ongoing task trials. This suggests that, when participants explicitly expected a PM target to appear in a specific trial, attention shifted from emphasizing color processing to emphasizing identity processing, facilitating memory for non-PM words. More importantly, it also suggests that incidental nontarget memory may index differences in item processing that may not always be reflected in traditional measures of interference costs (e.g., RTs). And while changes in both incidental memory and RTs were caused by fluctuations in attention, with no explicit expectations, attention was likely divided between identity and color emphasis across all trials, which did not produce robust incidental encoding.

Unlike Experiment 1, interference costs emerged in error rates in Experiment 2, despite Experiment 2 adopting a seemingly easier PM task. Error rates went down in every condition across Experiments 1 and 2 except in the specific-instruction PM-relevant condition, which saw a 2% increase in errors. Although this increase may have been driven by the ease of maintaining (and expecting) two specific PM targets, it remains an intriguing question for future research: Why would an easier PM task produce interference costs in error rates?

General discussion

The present study investigated how contextual expectations about prospective memory (PM) target likelihood affect attention allocation, and the consequences of this attentional flexibility on incidental memory for nontarget items. Participants completed a color-matching task (as in Kuhlmann & Rummel, 2014) with the PM intention of responding to ill-defined (Experiment 1) or specific (Experiment 2) PM targets. We manipulated contextual expectations by giving participants specific, oblique, or no instructions about trial contexts in which PM targets could appear. Following the PM phase, their memory for nontarget items was measured in a surprise old/new recognition test. Response time analyses confirm that participants allocated their attention to the ongoing task in trials where they did not expect PM targets to appear. Comparatively, trials where targets were explicitly expected were associated with slower responses and more color-matching errors, as attention was focused on identifying PM targets. The consequence of this attentional focus during high-expectation trials was further revealed by incidental memory performance: Participants recognized more items from trials in which they had expected (but did not encounter) PM targets, relative to trials in which they knew PM targets would not appear.

When maintaining PM intentions, individuals divide their attention between completing their ongoing task and monitoring the environment for cues to implement their intention (Smith et al., 2007). This division of resources initially depends on the relative difficulty or importance of the PM task (e.g., Hicks et al., 2005; Loft et al., 2008; Lourenço et al., 2015), but can be flexibly adjusted in order to meet fluctuating task demands (Kuhlmann & Rummel, 2014; Marsh et al., 2006a, b; Smith et al., 2017). When attention is allocated to the PM task, processing item identity is critical: Individuals need to accept or reject items as PM targets in order to implement the corresponding PM response. Attending to item identity may, however, interfere with ongoing responses if that information is not relevant for completing the ongoing task (e.g., color matching; Einstein et al., 2005). Importantly, expectations about when targets can be encountered allows individuals to strategically divide their attention between implementing PM intentions and completing the ongoing task. This strategic allocation of attentional resources facilitates incidental item encoding when task-irrelevant items are encountered instead of expected PM targets. Conversely, focusing attention on the ongoing task may limit item identity processing, reducing the likelihood that the item will later be recognized.

Across both experiments, we found that expecting, but not encountering, PM targets was associated slower RTs during PM-relevant relative to PM-irrelevant trials, and more nontarget items encountered during PM-relevant trials were remembered. More importantly, these effects depended on participants' explicit knowledge about when PM targets could appear: Participants who received specific instructions about PM-predictive trial types prioritized color processing during PM-irrelevant trials, responding quickly and remembering fewer words. During PM-relevant trials, however, they allocated more attention to identity-specific information (e.g., spelling, meaning), responding more slowly, but remembering more words. In comparison, participants who did not receive instructions about PM-predictive trial types incurred equal costs during PM-relevant and -irrelevant trials, and remembered a similar number of words from those trial types. In Experiment 2, which used an easier PM task, we observed better memory for words encountered in PM-relevant contexts for participants in the specific-instruction condition than those in the no-instruction condition. The lack of RT differences during PM-relevant contexts between the two groups suggests that encoding time did not impact incidental memory. Instead, the processing orientation engaged prior to item onsets facilitated encoding, as participants attended to the item's identity when expecting to encounter a PM target. It also suggests that differences in item processing based on PM expectations may not always be captured in RT costs (possibly due to small RT differences from speeded responses, and/or ceiling effects). Examining incidental memory for nontarget items in addition to interference costs can provide complementary evidence for variations in the quality of item processing based on PM demands.

The present results are consistent with previous work examining incidental memory following PM tasks (e.g., Humphreys et al., 2020; Knight et al., 2011; Loft & Humphreys, 2012). These studies have highlighted the interplay between PM demands and incidental memory, where incidental memory for nontarget items increases with the "global" attention demands of the PM task. Our study, however, is the first to demonstrate the dynamic effect of *flexible* attention allocation on nontarget recognition, where incidental memory differs on a trial-by-trial basis based on expectations of PM task context. These findings are also comparable to those observed visual search tasks, where individuals monitor for target objects among arrays of nontarget objects. As in PM (e.g., Cohen et al., 2008; Hicks et al., 2005), task performance changes when monitoring becomes more challenging: For example, accuracy decreases and response times increase when observers search for multiple potential targets (e.g., Menneer et al., 2007; Menneer et al., 2009) or when the target is vaguely specified (e.g., Malcolm & Henderson, 2009; Schmidt & Zelinsky, 2009). As in the present study, prior visual search research has shown that observers incidentally encode nontarget objects (Guevara Pinto et al., 2020; Hout & Goldinger, 2010, 2012; Thomas & Williams, 2014), particularly when task demands require greater attention to inspect search items. For instance, Guevara Pinto and Papesh (2019) recently found that individuals titrate their attention on a trial-by-trial basis, allocating resources to closely examine each object when they expect target detection to be difficult. This "narrowing" of attention induced by target expectations limited observers' ability to perceive peripheral features in the display, but facilitated incidental object encoding, improving performance in a surprise recognition test. Similarly, when individuals expect a PM target in a specific context, they engage in preparatory attentional processes, focusing closely on identifying the item to correctly implement the PM intention. This limits processing of other perceptual features (e.g., color), resulting in slower and more error-prone responses, but increased memory for incidentally encoded words.

Although the present investigation was not designed to adjudicate between PM theories, the results are consistent with "shared-attention" views of event-based PM (Guynn, 2003; McDaniel & Einstein, 2000; Scullin et al., 2013;Smith et al., 2007 ; Smith & Bayen, 2004). For instance, the preparatory attention and memory process (PAM) model argues that two processes, a preparatory attention process and a retrospective memory process, are responsible for successfully implementing PM intentions (Smith et al., 2007; Smith & Bayen, 2004). According to PAM, a preparatory attention process is responsible for scanning the current environment for opportunities to implement the PM intention, preparing the individual to retrieve that intention. Once an opportunity to implement the intention is encountered, the retrospective memory process discriminates whether the opportunity is indeed appropriate to execute the intention. In the present study, participants discriminated nontarget words from PM targets, and this was facilitated by knowing the PM-relevant shape. Thus, preparatory attention may have been selectively engaged when participants noticed the PM-relevant shape, allowing participants in the specific-instruction condition to readily process the upcoming word, incidentally encoding it into memory. Similarly, when they noticed the PM-irrelevant shape, participants may have prepared to efficiently complete the ongoing task by shifting attention to the item's color, minimizing incidental encoding.

Our results are also generally consistent with those of Kuhlmann and Rummel (2014), who employed a similar color-matching task with nonfocal PM intentions. Unlike Kuhlmann and Rummel, however, we did not observe a benefit of instruction on PM performance: Participants were equally likely to detect PM targets regardless of their expectations about when to expect those targets. Expecting PM targets during PM-relevant trials allowed participants in the specific-instruction condition to better encode upcoming nontarget words. However, they did not detect more PM targets than the no-instruction conditions. While it is possible that these two conditions continuously monitored for targets in Experiment 1 due to the difficulty of the PM intention (i.e., items ending in *-ion*), Experiment 2 employed an easier PM task (reflected in a 10% overall increase in targets detected), but still yielded equal PM accuracy between all three groups. Similarly, our specific-instruction condition did not produce reliably slower color-matching responses than the no-instruction conditions during PM-relevant trials.

The lack of performance differences across PM instruction conditions may be attributable to several elements of the design. For example, we used a random trial-by-trial contextual cue, which often leads to reduced strategic monitoring than block-level designs (e.g., Bugg & Ball, 2017; Lourenço & Maylor, 2014; Smith & Skinner, 2019) as participants may remain in retrieval mode across all trials (Guynn, 2003). The probabilistic nature of PM-relevant trials may also have affected performance. Bugg and Ball (2017) found that the use of contextual cues (e.g., PM-relevant shape) to flexibly allocate attention between ongoing and PM tasks is dependent on the predictive validity of those cues. They had participants complete a lexical decision task using items presented in the upper and lower portions of a computer screen, instructing some of them (specific condition) that PM targets (syllable *tor*) would only appear in word items on the upper location. Other participants (oblique condition), however, were instructed that the target could appear in any location or item type (words and nonwords). When participants in the specific condition perceived the context cues to be deterministic (100% likely), interference costs were exclusively limited to the PM-relevant context relative to the oblique condition. However, when the context cues were perceived as probabilistic (70% likely), then interference costs emerged in PM-irrelevant contexts, with little to no differences between conditions. In the present study, PM-relevant shapes were only followed by PM targets in 33.33% of trials. This relatively low predictability of contextual cues may not have been perceived as useful, prompting participants in the specific-instruction condition to allocate attention to the ongoing task even during PM-relevant trials. In comparison, PM-irrelevant trials were 100% valid, meaning that a PM target never appeared following a PM-irrelevant shape. These trials elicited RT differences between the specific-instruction and no-instruction conditions. This, however, does not explain the higher recognition rates for PM-relevant items from the specific-instruction condition, relative to the no-instruction condition, in Experiment 2.

It is possible that differences in nontarget recognition between PM conditions reflect differences in proactive and reactive modes of cognitive control (Ball & Brewer, 2018; Braver, 2012; Bugg et al., 2013). For instance, the explicit instructions given to the specific-instruction condition may have encouraged a reactive control of attention, in which participants only focus on processing item identity if they spontaneously react to the PM-relevant shape. The no-instruction condition, on the other hand, may have adopted a more proactive control of attention, generally slowing color-matching responses throughout the ongoing task without focusing specifically on item identification. More research is needed to understand the complex relationship between how contextual cues influence the flexible division or control of attention and how these processes impact incidental item encoding.

In contrast to shared-attention views of PM, it has been proposed that interference does not arise from divided attention, but from speeded response competition between the ongoing task responses (e.g., color match vs. color mismatch) and the PM task responses (e.g., PM target vs. not a PM target). According to the Prospective Memory Decision Control (PMDC) framework (Strickland et al., 2018), evidence for both task-response sets accumulates in parallel at the same time once the item is presented, but the accumulation of evidence for the frequently executed ongoing task response is faster than for the infrequent PM response. To mitigate these differences in accumulation rates, individuals exert *proactive* control on both the ongoing task and PM response thresholds to allow time for PM evidence to accumulate (Heathcote et al., 2015; Loft & Remington, 2013; Strickland et al., 2017; but see also, Ball et al., 2020). Specifically, the response threshold for the ongoing task is increased while the threshold for the PM response in decreased. Adjusting both thresholds systematically increases the probability of that a PM response is made before the routine ongoing task response. Additionally, *reactive* control is exerted based on stimulus properties after the presentation of an item. For example, PM-related stimulus characteristics improve processing efficiency for PM-relevant information, but inhibit processing of information relevant to the ongoing task. Reactive control thus speeds up the evidence accumulation for a PM response while simultaneously slowing down the accumulation for an ongoing task response.

The PMDC framework suggests that the enhanced recognition for nontarget items observed in the present study may have been elicited through multiple mechanisms. First, response thresholds for ongoing task responses may have been proactively increased during PM-relevant trials, to allow time for PM evidence to accumulate. Consequently, items presented during PM-relevant trials had longer encoding times, relative to items presented during PM-irrelevant trials. This would, however, imply a direct relationship between encoding time and subsequent item recognition, yet both experiments in the present investigation failed to show any relationship between encoding time and recognition. It is therefore more likely that encoding of PM-relevant items was facilitated by reactive control exerted upon the presentation of PM-relevant shapes. Once the PM-relevant shape was detected, processing of PM-relevant information (item identity) was emphasized, while processing of PM-irrelevant information (item color) was inhibited. Note that the PMDC model differs from shared-capacity theories in that it predicts that reactive control only affects processing facilitation/inhibition during PM-relevant trials and not during PM-irrelevant trials. By contrast, dividing attentional capacity between the ongoing and PM tasks would impact processing in both PM-relevant and irrelevant trials. In Experiment 1, our data show only numerical improvements in recognition of nontarget items encountered during PM-irrelevant trials by the oblique and no-instruction conditions relative to the control group. While this may be indicative that item processing is impacted during non-PM trials when PM-related stimulus characteristics are not detected, we believe that further research is required to understand whether item processing can be influenced by reactive control during PM-irrelevant trials.

Although PM theories may offer interesting explanations for the present findings, it is important to emphasize that this study was not designed to test or discriminate between them. Instead, the focus of our study was to examine whether *flexibly* allocating attention based on PM expectations would result in differential word encoding. Our results suggest that contextual expectations influence incidental encoding, which can be explained by both shared-attention or response-competition models. Further research on this topic, however, may provide insights into how incidental nontarget memory following PM tasks may index processing *quality* at the moment of encoding, yielding an alternate approach to contrast the different models of PM.

In summary, just as drivers can start monitoring for their exit on the interstate, individuals are able to strategically allocate their attention during PM tasks, impacting what is (and is not) incidentally remembered. The present study examined how flexible attention allocation in PM dynamically impacts whether nontarget items are incidentally encoded into memory *irrespective* of changes in processing times. Contextual cues can bias individuals' expectations about PM targets, prompting them to closely inspect items in order to implement intentions when targets are expected, or shifting processing to focus on features relevant to the ongoing task when targets are unlikely. Importantly, when attention is shifted back-and-forth from the ongoing task to detect upcoming PM targets, incidental item encoding is modulated, increasing (or decreasing) what is remembered from the task set.

Appendix 1

Table 5 Nontarget stimuli used in Experiments 1 and 2

ABILITY	DANGER	HOME	MOOSE	SATURN
ACTIVTY	DAUGHTER	HOUR	MORNING	SEDIMENT
AFTERNOON	DEATH	ICE	MOUTH	SHERIFF
ALLIGATOR	DEFENSE	IDEA	NATURE	SHIRT
APPEARANCE	DINNER	IGLOO	NEURON	SHOEMAKER
AREA	DINOSAUR	IRIS	PAGE	SOCCER
ATTITUDE	DIRT	ISLAND	PAINT	SOLDIER
AUTHORITY	DOME	IVORY	PATH	SONG
BALLET	ELECTRICTY	JEWELRY	PEACE	SOURCE
BASIS	EMBRYO	JUSTICE	PERFORMANCE	STONE
BEDROOM	ENEMY	KITCHEN	PHARAOH	STRENGTH
BEETLE	EQUAL	KNOWLEDGE	PIG	SUGAR
BELL	ESKIMO	KOALA	PIMPLE	SUNBURN
BREATH	EVENING	LAUNDRY	POCKET	SUNLIGHT
BULLET	EVENT	LAKE	POLO	TAILOR
CACAO	FACT	LENGTH	POPCORN	TERRITORY
CAMEL	FAN	LOSS	PRISM	THING
CANDY	FLASK	MAIL	PROTON	THROAT
CAPSULE	FLEA	MAYOR	PUDDING	TOASTER
CARNIVAL	GAME	MANNER	PULLEY	TODAY
CASHIER	GEM	MARKET	PUPPET	TRUTH
CENTURY	GLACIER	MATRIX	QUALITY	TUBE
CHALK	GORILLA	MEAL	QUANTUM	TUNDRA
CHAPTER	GUITAR	MEMBER	RADIATOR	UMPIRE
CHEESE	HABITAT	MEMORY	RECIPE	UNIVERSITY
CHICK	HALL	MILE	REHEARSAL	WEALTH
CORTEX	HEAT	MOLE	RETINA	WHEAT
CREDIT	HEIGHT	MOMENT	ROCK	WOOL
CROCODILE	HEIST	MONTH	ROLE	YEAST
CROWD	HISTORY	MONUMENT	ROOF	YOUTH

Appendix 2

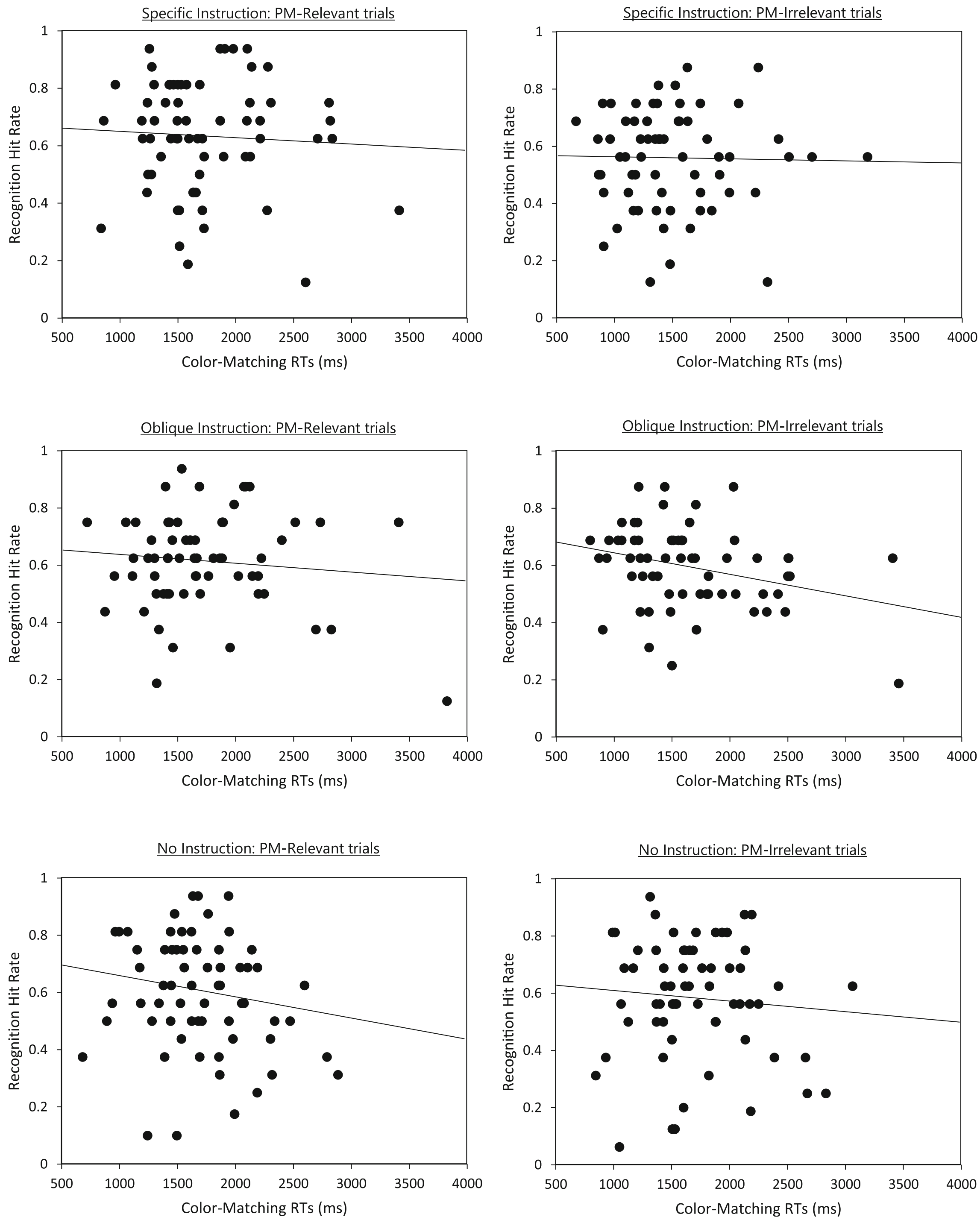

Fig. 2 Scatterplots showing color-matching response times and recognition hit rates for the experimental conditions in Experiment 1, each fitted with its corresponding trend line. Left panels reflect PM-relevant trials, right panels reflect PM-irrelevant trials. Top panels reflect the specific instruction condition, middle panels reflect the oblique instruction condition, and the bottom panel reflects the no-instruction condition

Appendix 3

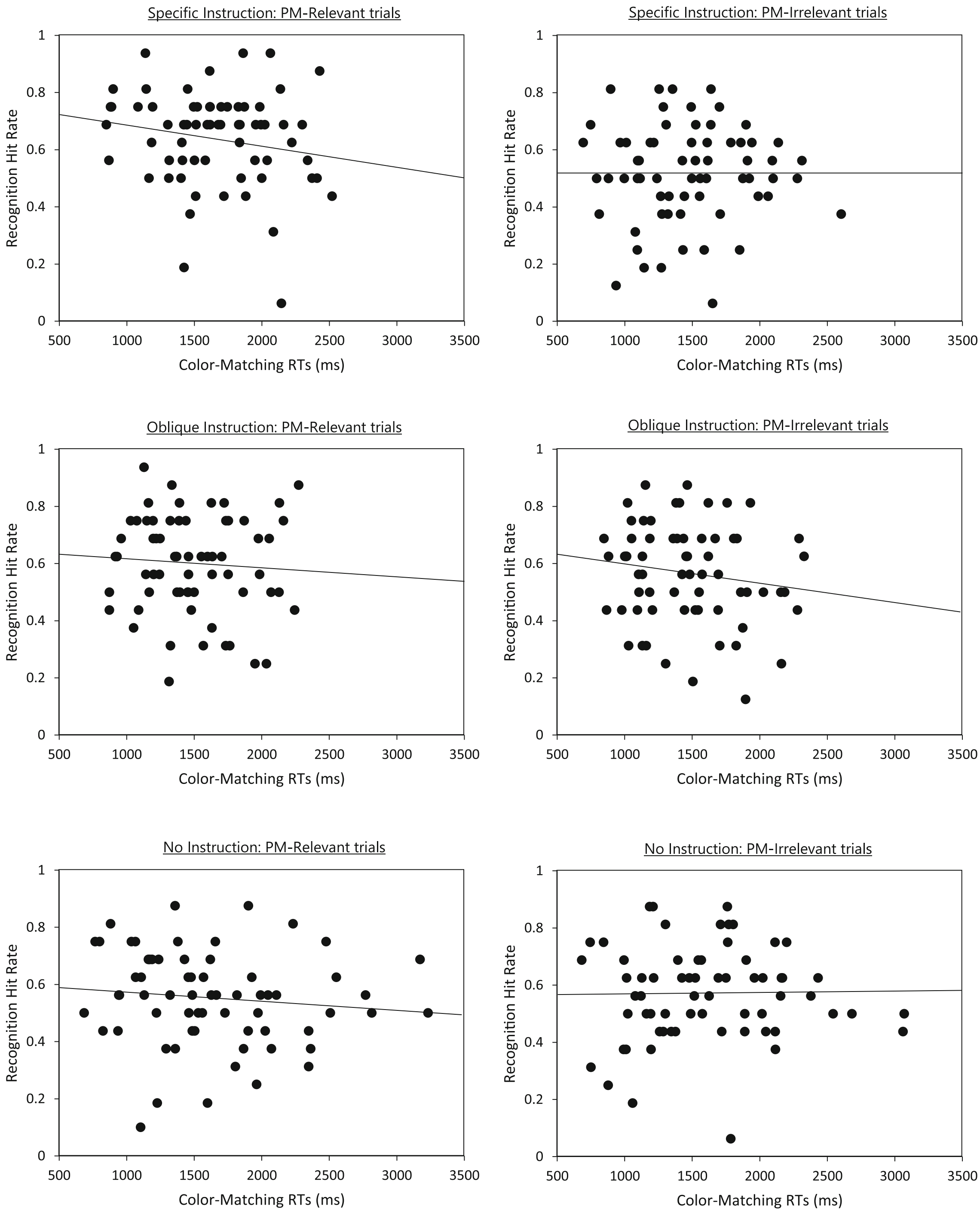

Fig. 3 Scatterplots showing color-matching response times and recognition hit rates for the experimental conditions in Experiment 2, each fitted with its corresponding trend line. Left panels reflect PM-relevant trials, right panels reflect PM-irrelevant trials. Top panels reflect the specific instruction condition, middle panels reflect the oblique instruction condition, and the bottom panel reflects the no-instruction condition

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