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BRIEF REPORT

An assessment of learning rates in habitual prospective memory

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Abstract
Most laboratory research in the field of prospective memory has focused on newly formed (episodic) intentions that are carried out in the experimental context once or only a small number of times. However, many naturalistic prospective memories are carried out many times and these types of (habitual) intentions have been studied much less in the laboratory. In the current study, our aim was to extend prior work examining habitual intentions in laboratory prospective memory paradigms. Participants formed a typical prospective memory intention and then completed an ongoing task in which the intention could be executed up to 63 times. We examined changes in performance across trials in three traditionally important prospective memory metrics: cue detection, task interference, and cue interference. Across repeated performance of the prospective memory task, we observed an increase in cue detection, elimination of task interference, and elimination of cue interference. These results provide key insights into the operation of learning mechanisms in prospective memory paradigms and promote theory development by showing that many of the resource-demanding processes that are theorized to be necessary for successful prospective memory play much less of a role when intentions are repeatedly completed.

Keywords Learning · Automaticity · Habit · Prospective memory

Introduction

Prospective memory (PM) is the ability to plan an intention and remember to execute it in the future. PM is an essential part of daily living and PM failures have direct impacts on health, job performance, and relationships (Phillips et al., 2008). Intentions that need to be performed once/irregularly are referred to as episodic PM (Kvavilashvili & Ellis, 1996), while habitual PM intentions are those that must be executed regularly/routinely (Meacham & Leiman, 1982). Habitual PM tasks have been shown to require less effort over time but little work has explored this concept (Graf, 2012; Graf & Uttl, 2001; Strickland et al., 2022). Contemporary theoretical models of PM provide little insight into the nature of these practice effects—namely, if intentions transition from episodic to habitual, what is the functional form of this transition, and are capacity-consuming processes always required for the fulfillment of habitual PM? The following study evaluates these questions from a learning perspective and provides new empirical data that challenges current theoretical frameworks of PM performance.

A smaller number of published studies have examined habitual PM than episodic PM (Cuttler & Graf, 2009; Einstein et al., 1998; Elvevag et al., 2003; Matter & Meier, 2008; McDaniel et al., 2009; Meier et al., 2014; Vedhara et al., 2004; Zogg et al., 2012). Many of these studies included patient populations, older adults, or focused on medication adherence. One investigation of habitual PM that is relevant to the current study is Meier et al. (2014). They examined how episodic PM intentions shift into habitual intentions by measuring PM behavior and event-related potentials (ERP) across time. Participants engaged in a perceptual discrimination task where they decided whether two sequentially presented colored shapes were the same or different while maintaining a PM intention to respond to a specific color. The analyses divided the dependent measures from the task into two halves. Behaviorally, Meier and colleagues found that PM performance increased from the first to second half, and there were no differences in ongoing task accuracy or reaction times. Physiologically, they also found that the ERP components 450 to 650 milliseconds poststimulus became larger in the second half consistent with a reallocation of processing capacity, facilitation of

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retrieval processes, or a combination of both that differed from the first to second half of the task (Meier et al., 2014).

In our view, a critical advancement from this work is that it suggests that all PM intentions begin as episodic intentions, but if they are repeated and the environment provides support for their completion, then the cognitive/neural dynamics adapt to maintain PM performance while using less capacity. This effect is broadly consistent with the literature on learning and automaticity (Anderson, 1982; Logan, 1988; Newell & Rosenbloom, 1981). The current experiment aimed to replicate and extend the behavioral findings of Meier et al.'s (2014) study by examining change profiles across seven blocks of performance instead of the first versus second half. This extension allows for more precision in modeling change profiles in performance across time and speaks to theories of PM that suggest that capacity-consuming processes are required for successful PM.

Both episodic and habitual paradigms have PM cues embedded in unrelated ongoing tasks to mimic real-world situations (i.e., carrying out PM intentions in the midst of other activities). Ongoing task performance provides important information about the allocation of cognitive resources between the ongoing and PM task (Smith, 2003). Specifically, Smith (2003) was the first to show that when participants are engaged in an ongoing activity and have a PM intention, there is a cost (slowing) to ongoing-task reaction times (Ball et al., 2018; Bowden et al., 2017; Loft et al., 2011; Smith, 2010; Smith & Bayen, 2004) likely due to cognitive resources being devoted to the PM task. Costs, also called task interference, are estimated by analyzing ongoing task reaction time on trials where PM cues do not occur (Brewer, 2015; Hicks et al., 2005; Loft et al., 2008). Importantly, task interference may be reduced when elements of the PM task become habitual but this prediction has yielded little empirical support in the literature.

Another form of cost occurs on the specific trials in which participants successfully respond to PM cues, called cue interference. Cue interference is a slowing of reaction times on PM cue trials relative to control trials during the ongoing task (Marsh et al., 2002). This interference that occurs when a PM cue is encountered is theorized to reflect the operation of a microstructure of cognitive processes that are required for successful PM (intention detection, intention retrieval, context verification, and coordinating the ongoing and PM components of the task; Marsh et al., 2002). For the current experiment, we hypothesized that cue interference would decrease across blocks since the participant will be learning how to better coordinate between executing the ongoing task response once they encounter a PM cue.

Current study

The current study assessed changes in PM metrics across repeated PM trials to estimate learning and automatization of PM task components by fitting power functions to task interference and cue interference profiles across blocks of trials. Critically, when participants first encounter a PM cue in this study we believe that the experience is closely aligned with research in episodic PM and maps onto theories suggesting that capacity-consuming processes are required for successful PM (i.e., we will find significant costs early on in the task). However, in this study, participants ultimately encountered 63 PM cues and by the end of the study, many components of the task may reflect habit-based responding and no longer require capacity-consuming processes (i.e., we will find no significant costs later in the task). This change in the requirements for capacity-consuming processes occurs despite there being no changes to the ongoing task and PM task. We believe that extant theories of PM have a hard time accounting for this pattern of results because most PM theories that describe costs to ongoing activities do not account for intraindividual variability and learning effects. These theories have not been constructed using knowledge from other cognitive traditions like dual-tasking and automaticity that model within-person change across time and performance. It is this latter point that is the most important advancement of this research from our perspective. A growing body of research has started examining intraindividual variability as a critical aspect of cognition and we are trying to incorporate this approach into the study of PM. Examining how PM intentions transition from episodic to habitual can shed light on weak assumptions of existing event-based PM theories and help us better understand how future-oriented behaviors become routine.

Method

Participants

A total of 125 native English-speaking undergraduates were recruited from the participant pool at Arizona State University and compensated with course credit. We chose this sample size based on finding a similar pattern of results to those reported here in a pilot EEG study. All participants were screened for color blindness. One participant was excluded from the no-intention condition due to insufficient ongoing task accuracy, nine participants were excluded from the intention condition due to insufficient performance (below 48% accuracy) on the PM task, and one participant was excluded from the intention condition due to poor ongoing task performance (mean accuracy of 52%), suggesting a misunderstanding of task instructions. This resulted in a total sample size of 114 participants. A 2 (condition: intention vs. no intention) × 7 (block) mixed design was implemented. Fifty-five participants were assigned to the intention condition and

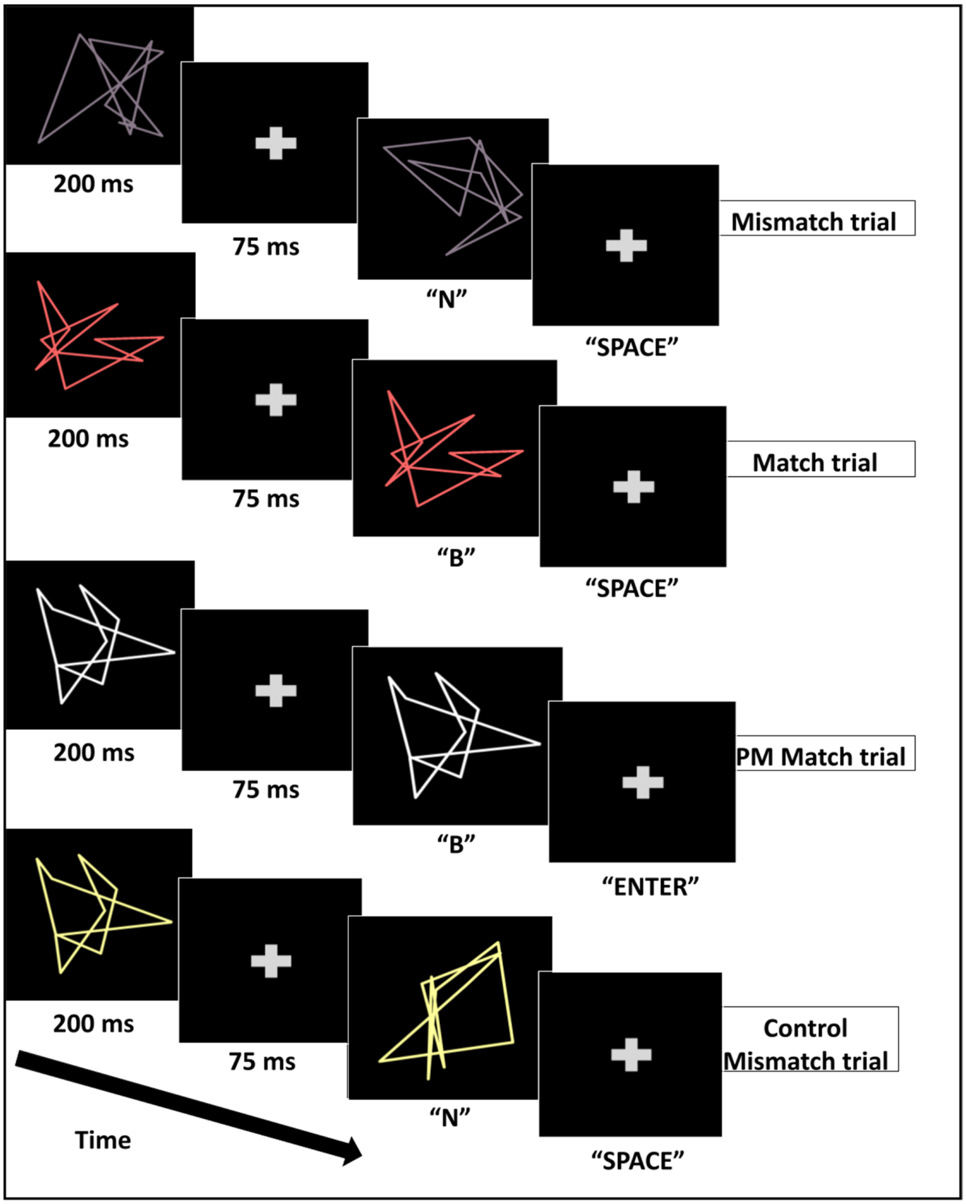

Fig. 1 Example of stimuli appearing on the screen for different trials

59 to the no-intention condition. The study was approved by the Institutional Review Board, and informed written consent was obtained.

Materials

The ongoing task for this study was a perceptual discrimination task of abstract shapes created using MATLAB software (see Meier, 2014, Experiment 2). Each trial consisted of either a matched or mismatched abstract shape pair in one of 19 different colors, including the PM and control conditions. White shapes were used for the PM task and a light-yellow color was used as the control color.[1] The PM stimuli and the control stimuli consisted of exactly the same shapes and differed only by color. For each color, we created five identical and five nonidentical shape pairs. Figure 1 provides an example layout of the task. There were a total of 882 trials, with 756 ongoing trials, 63 PM trials, and 63 control trials.

[1] An unpublished study used the same stimuli but counterbalanced the PM cue being a white shape pair or a yellow (control) shape pair to ensure color did not influence performance. PM performance was found to not be affected by color. Therefore, we kept the PM cue as the white shape for this study.

There were seven blocks in total, each containing 126 trials. All seven blocks had a PM frequency of nine cues per block (7.14%). The first PM target (white shape) appeared on the 14th trial of the first block and all other blocks had the first PM target appearing on the seventh trial. There were six ongoing task trials between each PM or control trial.

Each shape pair appeared as two superimposed images of the same color with an interstimulus gray fixation cross of 75 ms. The first shape appeared for 200 ms, followed by the second shape, which appeared on the screen until the participant made their shape-pair judgment response. Following their judgment response, a gray screen with a fixation cross appeared until the participant pressed the "SPACE" key to advance to the next trial, or if they were in the intention condition and it was a PM cue, the "ENTER" key to advance to the next trial. For the ongoing, PM, and control conditions, match and mismatch trials were randomized.

Procedure

Participants were tested at individual computer stations. There were up to six participants in the room at one time with sessions lasting approximately 45 minutes. Following consent procedures, participants were asked to complete the Prospective and Retrospective Memory Questionnaire. Once completed, participants were introduced to the ongoing task.

Prospective and Retrospective Memory Questionnaire *(PRMQ*; Smith et al., 2000) The PRMQ is a 16-item self-report measure of prospective and retrospective failures in everyday life. This questionnaire was given to all participants for a different purpose so the analysis and interpretation of these results will not be reported in this paper.

Ongoing task instructions The ongoing task for this experiment was a perceptual discrimination task described earlier. The participants were instructed to press the "B" key with their right pointer finger for shape pairs they considered identical and "N" with their right middle finger for shape pairs they considered not identical. To advance to the next set of images, participants were instructed to press the "SPACE" key.

Intention condition Participants in the intention condition were then instructed to continue making shape-pair judgments; however, when a white shape pair appeared on the screen, they were asked to press the "ENTER" key instead of "SPACE" to advance to the next trial. A white shape was then presented on the screen for color reference. They were then shown the instructions again and let the researcher know if they were ready to begin the experiment.

If the participant failed to execute the PM task (i.e. did not press the "ENTER" key), a reminder would appear on screen that read, "Remember to press "ENTER" when you see a white image. Please press the "ENTER" key to continue." Participants were also reminded to press "ENTER" instead of "SPACE" in between each block. This procedure continued for seven blocks.[2]

No-intention condition Participants in the no-intention condition were not aware of the PM intention and were only asked to make shape-pair decisions for all seven blocks.

Results

PM performance across blocks

PM performance is defined as the proportion of correct responses (i.e., "ENTER" key pressed during the intertrial interval) to target cues (white shapes). To evaluate if PM performance improved across blocks, a repeated-measure ANOVA was conducted. Mauchly's test of sphericity indicated that the assumption of sphericity was violated, $\chi^2(20) = 107.19$, $p < .001$, and the Greenhouse–Geisser correction was implemented thereby correcting the degrees of freedom in the following tests. Specifically, PM performance improved across blocks, $F(3.05, 164.54) = 26.64$, $p < .001$, $\eta_p^2 = 0.330$. This improvement was characterized by PM performance being significantly worse in Block 1 in comparison with all other blocks (all ps < .001). Additionally, PM performance in Block 2 was significantly worse in comparison with all blocks, except Block 5 (all ps < .01; see Fig. 2).

Task interference across blocks

Previous research has found cost effects in reaction time (RT) when participants have a PM intention. This effect was replicated in the current study. Mauchly's test of sphericity indicated that the assumption of sphericity was violated, so we report tests using the Greenhouse–Geiser correction, $\chi^2(20) = 262.75$, $p < .001$. We performed a 2 (condition) × 7 (block) mixed-factorial ANOVA on RT across blocks and found that RTs were decreasing across blocks, $F(2.88, 322.43) = 98.79$, $p < .001$, $\eta_p^2 = 0.469$. Additionally, this decrease in RT was more prevalent in those who had an intention versus those who did not, $F(2.88, 322.43) = 10.68$, $p < .001$, $\eta_p^2 = 0.087$.

To better understand this interaction, we conducted post hoc tests and found that there were significant differences in RT between intention and control conditions at Block 1, $F(1, 112)$

[2] Participants in the intention condition had their intention deactivated after the seventh block of trials and then completed an 8th block with no intention. We were interested in commission errors (making a PM response on previous PM targets after being told they were no longer required to make the PM response) but they were infrequent (only N = 4 participants made at least one commission error).

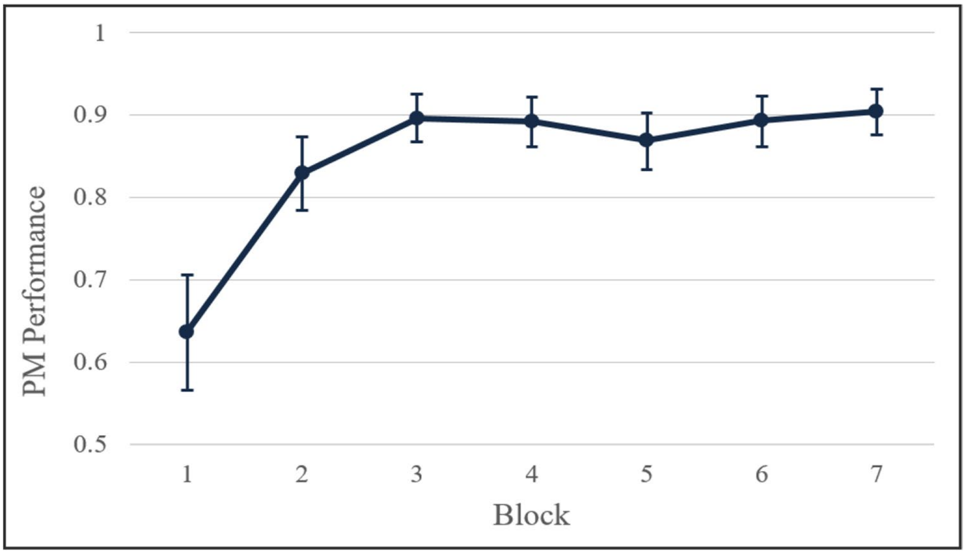

Fig. 2 PM performance across blocks. Error bars represent the 95% confidence intervals

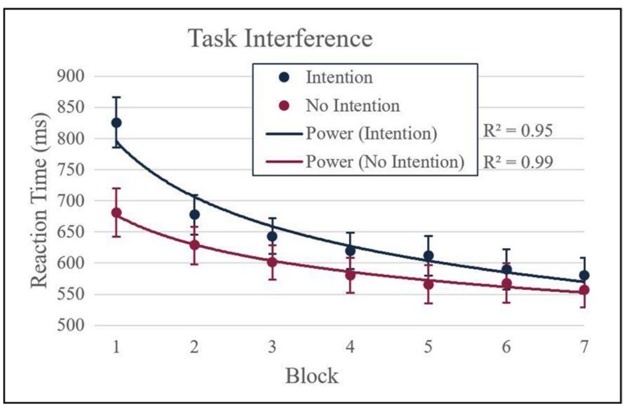

Fig. 3 Task interference with power curve. Error bars represent the 95% confidence intervals

= 26.14, $p < .001$, $\eta_p^2 = .189$, Block 2, $F(1, 112) = 4.83$, $p = .030$, $\eta_p^2 = .041$, Block 3, $F(1, 112) = 4.33$, $p = .040$, $\eta_p^2 = .037$, and Block 5, $F(1, 112) = 4.30$, $p = .040$, $\eta_p^2 = .037$. This finding is unique such that the cost effects were eliminated towards the end of the experiment (Blocks 4, 6, and 7) even though the participants still possessed an active intention (see Fig. 3).[3]

Cue interference

Cue interference is the latency to respond successfully on cue trials. Specifically, we took the participants' mean RT on the PM cue decision trial (saying if the shapes were the same or different for a white shape pair) and subtracted the participants' mean RT on the control decision trials. From this, we are able to see the difference in how long it took each participant to make the ongoing task response on trials that are PM cues relative to control trials. The no intention data points represent the same trials as the intention condition.

Three participants from the intention condition were dropped due to a lack of correct PM responses in Block 1 so the total number of participants in the intention condition was 52. Mauchly's test of sphericity indicated that the assumption of sphericity was violated so all tests reported will be using the Greenhouse–Geisser correction, $\chi^2(20) = 487.64$, $p < .001$. A 2 (condition: intention vs. no intention) × 7 (block) mixed ANOVA was performed to investigate cue interference. Cue interference was found to significantly decrease across blocks, $F(2.03, 221.41) = 17.55$, $p < .001$, $\eta_p^2 = 0.139$, and this decrease was more prevalent for those who had an intention versus those who did not, $F(2.03, 221.41) = 18.066$, $p < .001$, $\eta_p^2 = 0.142$. Follow-up tests revealed significant differences between conditions at all blocks (all $ps < .01$). Importantly, the no-intention condition did not show any interference relative to control trials on the cue trials because they did not have an intention. This means that there is nothing unique about the PM cue trials that lead to the learning effects in the intention condition, other than participants having the intention to respond to the cues. These results are depicted in Fig. 4.

Power functions for task interference

Visual inspection of Fig. 3 shows clear evidence of cost reduction in task interference across bins and a potential difference

[3] Our ongoing task accuracy was at ceiling (91% for those with an intention and 94% for those without an intention) for the entire experiment therefore we do not believe our costs would be due to differences in accuracy. Detailed accuracy results can be found in our supplemental materials.

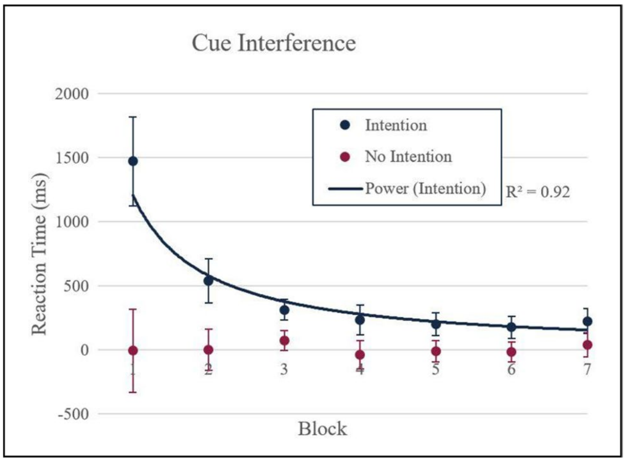

Fig. 4 Cue interference with power function. Data points represent the cue interference scores which is the slowing of reaction times on PM cue trials relative to control trials on the ongoing task. Error bars represent the 95% confidence intervals

Table 1 Power function parameter estimates for task interference

RT = A × Bin^B			
Parameter	Intention	95% CI lower	95% CI Upper
A	802.35	756.23	848.47
B	−0.18	−0.22	−0.13
Parameter	No Intention	95% CI lower	95% CI Upper
A	677.79	665.68	689.89
B	−0.11	−0.12	−0.09

in learning rates between the intention and control conditions. To formally test for this difference, we fit power functions to the average response time data across bins in Fig. 3 separately for each condition (linear-mixed effect model provided qualitatively identical conclusions and is reported in supplemental materials). The intercept and slope (learning rate) parameter estimates along with 95% confidence intervals can be found in Table 1. Two notable features of this analysis warrant discussion here. First, the power functions provided an acceptable fit to the response time data across bins (R^2 intention = .95, R^2 no-intention = .99). Second, the 95% confidence intervals for the learning rates estimated between these two conditions did not overlap. This result supports the hypothesis that one if not more of the underlying mechanisms needed for successful PM performance was also becoming automatic across bins above and beyond making the basic match versus mismatch judgements.

Power functions for cue interference

Figure 4 also shows clear evidence of cost reduction in cue interference across bins. To formally test for this difference, we followed the same procedure described above.

Table 2 Power function parameter estimates for cue interference

RT= A × Bin^B			
Parameter	Intention	95% CI lower	95% CI Upper
A	1,199.91	742.48	1,958.63
B	−1.06	−1.41	−0.71

The intercept and slope (learning rate) parameter estimates along with 95% confidence intervals can be found in Table 2. The power function was fit to the cue interference effect (i.e., the difference in RT) and provided an acceptable fit to the cue interference data across bins (R^2 intention = .92). The control condition was not included in this analysis since cue interference for this group should be at zero as can be visually confirmed in Fig. 4. This result supports the hypothesis that when the participant becomes more familiar with the task and is better able to detect cues, their reaction time is getting quicker and the cue interference is getting smaller.

Discussion

The goal of the current study was to investigate learning rates and evaluate any changes in task interference, cue interference, and PM performance in a habitual PM paradigm. We compared performance in participants with and without PM intentions in the context of the same ongoing task. Previous research on habitual PM found that when participants switch from episodic to habitual PM, there is a reduction in task interference, and PM performance increases. However, there has yet to be an investigation of learning rates of these tasks. As expected, PM performance increased across time in the task. Critically, measures of task interference and cue interference decreased across time in the task and were well fit by a power function similar to other aggregate profiles of changes in behavior with practice (Anderson, 1982; Logan 1988; but see Anderson, 2001; Heathcote et al., 2000).

We replicated prior research finding that participants in the intention condition demonstrated an increase in PM cue detection as the task progressed due to learning (Meier et al., 2014). From these results, it was clear that participants were performing both the ongoing task and the PM task more effectively as the task progressed.[4] Therefore,

[4] We would like to thank a researcher who was curious if our task was similar to a vigilance task and what our results would look like if we did not have a PM intention. Since we found a performance enhancement across time, our results are inconsistent with what a researcher in the vigilance literature might predict. If this followed a more standard vigilance task we would expect to find a performance deterioration across time.

we fit learning curves, specifically power functions, to these data for task interference and cue interference to assess learning rates. We found that there were learning rate differences between costs measured in the intention condition compared with the no-intention condition.

Contrary to Meier et al. (2014), we did find a reduction in cost. When evaluating task interference we found that as the task progressed, there was a reduction in interference for those in the intention condition. Post hoc analysis showed that there were significant differences in RT between the intention and no intention control conditions. These changes are consistent with the power law of practice when analyzing data at the aggregate level. Importantly, we remain agnostic to the true form of learning at the level of each individual and leave this issue for future research in this area (Anderson, 2001; Heathcote et al., 2000). That being said, this study is unique in that cost effects were eliminated towards the end of the experiment even though the participants still had a PM intention that theoretically should have demanded capacity-consuming processes according to current event-based PM theories. However, the instance theory of automatization (Logan, 1988) suggests that with practice, the speed of retrieval will decrease and the amount retrieved (in this case accuracy) will increase which is in line with the findings of this paper. This theory, while not discussed frequently in the PM literature (but see Strickland et al., 2022), suggests that each experience you have with the stimuli stores an "instance" in memory and retrieval probability, as well as speed, increases with the number of stored instances (Logan, 1988; Strickland et al., 2022). The theory also suggests that performance becomes automatic when behavior is no longer based on a general algorithm for performing the task but is instead based on a single-step memory retrieval process (Logan, 1992). Since our participants had 63 encounters with the PM target, as well as 756 encounters with the ongoing task, it is not as surprising to find these effects of learning.

This finding is still unique because theories of event-based PM predict that those in the intention condition should still show some amount of cost during the ongoing task, as they would still need to be actively monitoring for a PM cue. This finding could have been explained if we saw a trade-off in PM performance; however, this was not the case, and PM performance remained at a high level throughout the task. Therefore, although the PM cue demands do not change, there is a decrease in the amount of cost to the ongoing task which is not easily explained by the preparatory attentional and memory processes (PAM) theory (Smith, 2003). The dynamic multiprocess framework (DMPV; Scullin et al., 2013) could suggest that early processes are being used for successful PM completion, but that with repeated completions, a different set of automatic processes are being used. This logic might be consistent with the neural findings from Meier et al. (2014), but the DMPV does not specify how this transition from episodic to habitual PM occurs. That being said, an alternative explanation could be that elements of PM that are related to monitoring, like those specified in the PAM framework, are becoming automatic. Thus, the processes do not change, but they become easier for the system to instantiate, which leads to less ongoing task cost. Therefore, these data highlight new directions for more in-depth theory development and testing.

Regarding cue interference, we were able to fit a power function to costs across bins. This finding supports the idea that as the experiment progresses, the participant becomes more familiar with PM cues and is able to carry out the ongoing task response faster and with less interference. According to Marsh et al. (2002), successful PM performance can be broken down into several cognitive processes including (a) recognition of the cue as relevant to a previously established intention, (b) verification that the cue and its surrounding context meet all of the requirements for responding, (c) retrieval of the correct response action, and (d) coordination of executing both the prospective and ongoing-task responses (Marsh et al., 2003; Marsh et al., 2002). These subprocesses are referred to as the microstructure of PM. Our findings could thus be explained by some, if not all, of learning these microstructures. However, which of these processes is being learned is currently unknown; we only know that learning is occurring due to the reduction in cue interference over time.

While previous research has shown that we are able to replicate findings of cost in both a naturalistic (Smith et al., 2017) and laboratory setting (Smith, 2003), we acknowledge that the paradigm used in this study is not the most accurate representation for real-world habitual PM tasks. Future studies could attempt to remedy this by using one of the more naturalistic paradigms across several days. That being said, this issue, which is often brought up in the field of PM, does not seem to affect the ecological validity of these findings. Additionally, in most PM research, participants are only given a few cues (4–8) and in the current study, they were given many cues (63). Importantly, the cue density was consistent between these two different types of PM research. One important caveat to the current results is that we chose to not randomize (or pseudorandomize) cue position during the task. This fixed cue order could have been a source of information that participants implicitly or even explicitly used to help them automatize the PM responding in the task. An interesting line of future research in habitual PM will be to examine how fixed versus random cue positions influences learning and automatization.

While the area of habitual PM research is still growing, this work challenges current thinking about the nature of PM-specific processes and their requirement for successful performance in episodic PM tasks. This study is important because it shows that during a habitual PM task, individuals are not only learning how to perform the PM intention more effectively, but they are also finding ways to reduce the amount of costs that are associated with having a PM intention (i.e., task and cue interference). We hope that this study will be the first stepping stone to investigating how performance changes as episodic PM tasks become habitual PM tasks along with a better specification of the underlying cognitive processes that may be changing during this process.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13423-022-02214-w.

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Open practices statement The experiment reported in this study was not preregistered. All experimental procedures, code, and data can be accessed online (https://osf.io/9ew86/).