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Reminders Eliminate Age-Related Declines in Prospective Memory

B. Hunter Ball[1], Phil Peper[2], and Matthew K. Robison[1]
[1] Department of Psychology, University of Texas at Arlington
[2] Department of Psychology, Arizona State University

Prospective memory (PM)—the process of establishing intentions for future action and remembering to fulfill these intentions at the appropriate time—is necessary for many instrumental activities of daily living and for maintaining functional independence with increased age. Offloading PM demands onto the environment, such as setting a reminder alarm to take medication, offers an easy and effective way to mitigate age-related PM declines. However, a lack of basic knowledge about the cognitive and metacognitive processes that drive offloading decisions presents barriers to successful implementation. The present study addresses these issues by examining age differences in PM for offloaded (i.e., with reminders) and nonoffloaded (i.e., without reminders) intentions under low and high memory demands. With highly specific intentions that can be retrieved via bottom-up processes (Experiment 1), there were no age differences in PM without reminders, and younger and older adults equally benefitted from reminders under high memory load. With nonspecific intentions that require top-down attention for retrieval (Experiment 2), older adults had worse PM under high load without reminders. Critically, this age difference was eliminated with the use of reminders, likely due to increased reminder checking for older adults under high load. These findings suggest that offloading can circumvent cognitive capacity limitations and minimize computational effort to improve intention fulfillment in older adults. The theoretical and applied ramifications of these findings are discussed.

Public Significance Statement
With an increasing aging population showing memory declines, many of which remain untreatable, finding ways to reduce prospective memory failures is critical for healthy aging. The present study suggests that reminders (e.g., to-do list) may provide an easy and effective means to mitigate age-related prospective memory declines.

Keywords: aging, prospective memory, attention, cognitive offloading, metacognition

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Prospective memory (PM) refers to the ability to remember to perform delayed intentions at the appropriate moment in the future, such as remembering to pick up medication from the pharmacy after grocery shopping. PM is critical for maintaining independence with increased age, and PM failures are associated with a variety of health consequences and difficulties in daily activities (Woods et al., 2012). With an increasing aging population showing memory declines, finding ways to reduce PM failures is critical for healthy aging. One way for older adults to manage multiple daily intentions is to offload them using reminders. For example, digital assistants (e.g., Amazon Alexa) can send reminders to complete tasks at the appropriate moment. However, a lack of basic knowledge on the cognitive and metacognitive factors that contribute to reminder usage presents barriers to successfully implementing them to improve everyday PM. The purpose of the present study is to better understand how age influences the decisions to use reminders and the utility of reminders in a controlled laboratory setting.

Aging and Prospective Memory

Considerable research has shown that aging is associated with declines in laboratory PM performance (Kliegel et al., 2008).

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B. Hunter Ball https://orcid.org/0000-0002-9119-7640

Data can be found in the Open Science Framework and can be accessed at https://osf.io/z9avt/?view_only=d85110af6ec841d8804f173e18e7e447 (Ball et al., in press). Portions of the data were presented at the Ball et al. (2022). This work was supported by the National Institute of General Medical Sciences (Grant R16GM146705) awarded to B. Hunter Ball and by the National Institutes of Health.

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Correspondence concerning this article should be addressed to B. Hunter Ball, Department of Psychology, University of Texas at Arlington, 501 Nedderman Drive, Arlington, TX 76019, United States. Email: Hunter.Ball@uta.edu

However, age deficits are more apparent for some tasks than others. In a standard laboratory task,[1] participants form an intention to make a special response (e.g., press the "7" key) upon encountering a set of PM targets embedded in an ongoing task (e.g., lexical decisions). Research suggests that bottom-up processes can trigger PM retrieval when there is a specific PM target (e.g., the word "peach") that overlaps with ongoing task processing (i.e., making word/nonword decisions), whereas PM retrieval requires controlled attention when targets are nonspecific (e.g., any fruit) and do not overlap with ongoing task processing (Lyon, & Hicks, 2023). For example, specific intentions are detected at a much higher rate and produce less cost to ongoing task performance (i.e., slower or less accurate responding on nontarget trials) compared to nonspecific intentions (Anderson et al., 2019; Einstein et al., 2005). Notably, age differences are typically smaller with specific targets compared to nonspecific targets (Kliegel et al., 2008; Mullet et al., 2013; Rendell et al., 2007).

These dissociations in performance have led to the development of the multiprocess framework of PM, which posits that PM retrieval can occur via two processes: spontaneous retrieval and preparatory monitoring (McDaniel & Einstein, 2000). Specific target detection can occur via spontaneous retrieval—a hippocampally mediated process that results in bottom-up retrieval of the intention following discrepant processing associated with the repetition of PM targets from encoding and retrieval (Cona et al., 2016; Gordon et al., 2011). In contrast, nonspecific target detection occurs via preparatory monitoring, which is a frontally mediated process where intention retrieval relies on active maintenance of the intention and search for the PM targets (Brewer et al., 2010; Burgess et al., 2001; McDaniel et al., 2013). Previous research has shown that reactive control (bottom-up) mechanisms associated with spontaneous retrieval generally remain intact with age, whereas proactive control (top-down) mechanisms associated with preparatory monitoring decline with age (Ball et al., 2023; Braver, 2012). As such, older adults fulfill fewer nonspecific intentions because they are less able to proactively allocate limited-capacity monitoring resources to the PM task (Rendell et al., 2007). This suggests that reminders may help by reducing monitoring demands, which should be especially beneficial for older adults. However, the few studies on the topic only partially support this conjecture.

Prospective Memory Offloading

In one of the first laboratory studies of PM, and incidentally, of PM offloading, Einstein and McDaniel (1990) had participants perform a PM task with specific targets similar to that described previously. In the reminder (i.e., offloading) condition, participants were able to develop any external memory aid they wanted from various materials available (pens, article, rubber bands, etc.). Most participants wrote down the PM intention on a piece of paper and taped it to the computer screen. In the no-reminder condition, participants had to maintain the intention internally. The results showed that reminders improved PM performance. Interestingly, however, there were no age differences in performance. While surprising at the time, these null age effects likely reflected the fact that specific target detection could occur via spontaneous retrieval processes that remain intact with age.

Henry et al. (2012) had younger and older adults complete a "virtual week task," which is a computerized board game that simulates activities that occur during a normal day (e.g., shopping, meeting a friend for tea, eating dinner). A variety of attentionally demanding PM intentions were formed upon landing on certain spaces (e.g., "buy pen when shopping later," "take medication after dinner," etc.). Participants completed the task with and without the use of reminders. When reminders were available, participants could check a "to-do" list (self-initiated condition) or would have the to-do list automatically shown to them (experimenter-initiated condition) that displayed information about the PM intentions that needed to be completed. The results showed the anticipated age differences in performance, whereby older adults performed the task less effectively. PM performance was also improved with reminders. However, there was no interaction between age and reminders, meaning that both age groups benefitted equally from reminders (i.e., offloading did not reduce age differences in PM). Notably, younger and older adults checked the to-do list equally as often in the self-initiated condition, suggesting that perhaps older adults were not metacognitively aware of their poorer performance and did not strategically compensate for these declines by checking reminders *more* frequently.

Consistent with the findings from Henry et al. (2012), Scarampi and Gilbert (2021) had younger and older adults perform an "intention offloading task" where they dragged numbered circles to the bottom of the screen in numerical order. At the start of each trial, participants would be given a PM intention to drag one (low load) or three (high load) of the circles to a different location (e.g., drag number 3 at the top of the screen) when encountered in numerical order. In the reminder blocks, as soon as the task started, participants were allowed to drag the PM targets near the edge of the screen where the targets eventually needed to be moved (e.g., the top). In the no-reminder blocks, the PM targets were fixed in place until encountered in numerical order. Prior to starting the task, participants also rated their metacognitive confidence in their ability to complete the task with and without the use of reminders. Previous research with younger adults has shown that individuals that are more *underconfident* in the internal memory abilities (i.e., without reminders) choose to use reminders more frequently when given the option, suggesting that they strategically compensate for their poorer perceived memory ability (for a review, see Gilbert et al., 2023). Scarampi and Gilbert found that younger adults outperformed older adults under high load without reminders, but there were no differences under low load, consistent with the idea that older adults have difficulties with greater attentional demands. However, while reminders helped more under high load, this did not differ as a function of age. Thus, as with Henry et al. (2012), offloading did not reduce age differences in PM performance. Also similar to Henry et al., younger and older adults set reminders equally often under high load, meaning that older adults did not compensate for their poorer internal memory ability under high demands by offloading more frequently when allowed. Interestingly, metacognitive judgments revealed that older (but not younger) adults were *overconfident* in their ability to complete the task without reminders, which may explain why they did not use reminders more frequently. Using a similar procedure, Tsai et al. (2023) also found

[1] We refer to this as the "standard" paradigm, as the general procedure has been widely adopted by researchers in the field to understand the theoretical mechanisms that support PM in laboratory settings. However, while this procedure has high internal validity, it lacks in external validity.

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that older adults used reminders less frequently than is optimal based on their own internal memory abilities.

The extant studies show that while reminders improve performance, they do not eliminate—or even reduce—age differences in performance. These findings run contrary to the assumption that older adults should benefit most from offloading, as reminders should reduce the demands placed on attentionally demanding monitoring processes that decline with age (McDaniel et al., 2013). The results do point to potential errors in older adults' metacognitive monitoring of their internal memory ability (i.e., overconfidence) and/or poor metacognitive control of effectively utilizing reminders (i.e., underreliance on reminders). For clarity, metacognitive monitoring (e.g., performance predictions) refers to assessing the progress of learning while metacognitive control (e.g., decisions to offload) refers to the selecting of strategies to regulate performance (Nelson & Narens, 1990). However, as none of these studies compared age differences in performance using both specific and nonspecific PM tasks that theoretically place different demands on controlled attention processes, it is not entirely clear how reminders may serve to influence performance and when older adults may or may not strategically compensate for poorer internal memory ability.

To better characterize how reminders influence PM retrieval, Peper et al. (2023) had younger adults learn one (low load) or multiple (high load) PM targets that were embedded in an ongoing syllable judgment task (i.e., two or three syllables). In the first experiment, the PM targets (e.g., "peach") and reminders (e.g., "peach") were specific words, and in the second experiment, the PM targets (e.g., any fruit, such as peach) and reminders (e.g., "fruit") were nonspecific categories. In the reminder blocks, the targets were presented at the top of the screen throughout the task. It was found that reminders mitigated the negative influence of memory load on PM performance for both specific and nonspecific PM targets. Participants also reported checking reminders more frequently under high load, suggesting they had some metacognitive awareness of the task difficulty. However, reminders did not influence ongoing task performance. It was argued that checking the specific reminders may improve target recognition by increasing the discrepancy signal when encountering targets during the ongoing task (i.e., it increases the likelihood of spontaneous retrieval), while nonspecific reminders may reduce the demands on memory maintenance by allowing participants to verify whether the current item (e.g., peach) matches the set of targets that would otherwise be held in working memory (i.e., it reduces the need for preparatory monitoring). Given age dissociations in spontaneous versus preparatory processes, this would suggest that reminders should be most beneficial for older adults with nonspecific PM targets.

The Present Study

The present study used a similar methodology as Peper et al. (2023) in which participants learned one (low load) or four (high load) PM targets that they were to respond to during an ongoing syllable judgment task with or without the use of reminders. Experiment 1 used specific targets, and Experiment 2 used nonspecific targets. In the reminder blocks, the learned targets were presented at the top of the screen throughout the task. In the no-reminder blocks, unrelated words were presented at the top of the screen. Following encoding of the PM targets, participants were instructed whether they would have reminders available to them throughout the task. Reminder instructions were provided after encoding, as prior research shows that participants encode information less effortfully when they know reminders will be available (Kelly & Risko, 2019; Peper & Ball, 2024). Figure 1 displays what this looked like to participants across experiments. Two novel extensions from Peper et al. (2023) were that participants predicted how well they would do during each block (metacognitive monitoring) and eye-tracking methodology was used to examine how frequently participants checked reminders (metacognitive control). Eye tracking has only been used in a handful of prior PM studies (e.g., Moyes et al., 2019; Shelton & Christopher, 2016), but has never been employed in an offloading paradigm. One primary advantage is that it offers a real-time indicator of reminder checking[2] rather than having to rely on self-reports of checking at the end of the task, which may be susceptible to bias. We anticipated that all participants would benefit from reminders, but this should be especially pronounced for older adults with nonspecific intentions.

Transparency and Openness

Transparency in Data, Analysis, and Materials

All research reported herein was conducted using appropriate ethical guidelines and was approved by the Institutional Review Board at the University of Texas at Arlington (IRB Protocol 2018-0683: *Controlling Memory and Attention*). We report how we determined our sample size, all data exclusions, all manipulations, and all measures. De-identified data, analytic code, and programs for each experiment are available in the Open Science Framework at https://osf.io/z9avt/?view_only=d85110af6ec841d8804f173e18e7e447.

One additional "Pilot Study" was conducted online via Prolific where participants ($N = 220$; age 18–78) completed a high load (five abstract words that served PM targets) version of the task with or without the use of reminders. In each tertile of the age distribution, there were 74 (age 18–35), 74 (age 36–62), and 72 (age 63–78) participants, respectively. Participants were randomly assigned to a between-subjects reminder ($N = 107$) or no-reminder ($N = 113$) condition. Using age as a continuous variable, this study found no age differences in PM performance with or without reminders, and reminders equally improved performance for younger and older adults. Full task details and results can be found in the Supplemental Material.

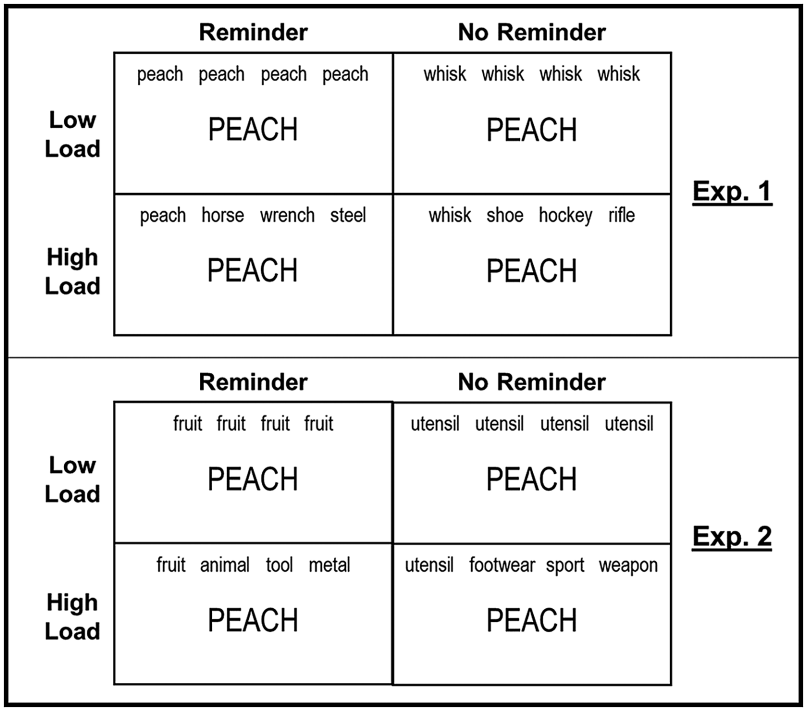
Experiment 1

Experiment 1 examined for the first time, using eye-tracking methodology, whether age differences in PM performance could be mitigated from offloading using a standard PM paradigm. Participants learned one (low load) or four (high load) specific PM targets (e.g., table, shoelace, etc.) and were instructed to make a special keypress (press the "spacebar") any time the words were encountered during the subsequent syllable judgment task. Under low load with specific targets, there should be little utility of using reminders and minimal age differences in performance. Under high load, however, older adults may detect fewer targets without reminders (Ballhausen et al., 2017; Einstein et al., 1992). Assuming older adults are metacognitively well calibrated to their internal

[2] We also assessed task-evoked pupillary responses during the task to index attentional effort. However, for the sake of brevity, the details from these analyses are presented in the Supplemental Materials.

Figure 1

Example of Prospective Memory Targets and Reminders in Experiments 1 and 2



Note. Within each grid, squares on the left and right for each experiment represent the appearance of the PM task for the reminder and no-reminder blocks, respectively. The word in the middle of the visual depiction of the computer screen (i.e., "peach") represents a PM target trial. The words at the top of the screen represent reminders (reminder blocks) or distractors (no-reminder blocks). Distractors were presented in the no-reminder blocks to match for perceptual characteristics of the reminders. Specific targets were used in Experiment 1, meaning that the targets and reminders were identical. Nonspecific targets were used in Experiment 2, meaning the reminders were categories and the targets were category exemplars. In Experiments 1 and 2, the top and bottom squares represent the task appearance for the low and high load blocks, respectively. PM = prospective memory; Exp.1 = Experiment 1; Exp.2 = Experiment 2.

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memory abilities, we anticipated that reminders would reduce, or even eliminate, age-related differences in performance and that this would be associated with greater reminder checking frequency for older adults. However, we also thought it was possible to replicate the results from the Pilot Study in which no age differences in performance emerge, even under high load without reminders (see Supplemental Materials for details).

Method

Power calculations indicated that 66 participants were needed in each experiment to detect a medium-sized interaction effect ($f = .25$) with 80% power and $\alpha = .05$. A minimum sample of 70 participants was chosen (younger adults $n = 35$; older adults $n = 35$) to account for potential exclusionary data. However, as younger adult data collection coincided with the end of the semester, we continued to enroll undergraduate students from the University of Texas at Arlington so they could complete the research credits for a class requirement. Older adults aged 55 and above were recruited from the Dallas–Fort Worth metroplex and were paid $20 for their participation. Data collection started in 2020 and finished in 2022. The entire experiment lasted approximately 1 hr. The original sample consisted of 58 younger and 43 older adults. However, five participants were excluded for failing to understand task instructions, resulting in 57 younger and 39 older adults in the final sample.[3] Older adult participant demographics can be found in Table 1 (M_{age} = 65.31, $SD = 6.36$, Min = 55, Max = 77). Demographic information was not collected for younger adults due to an oversight. The "group differences" column therefore reflects a comparison to the younger adult data in Experiment 2, which is representative of the University of Texas at Arlington psychology participant pool.

Design

A 2 (Offloading: reminder vs. no reminder; *within-subjects*) × 2 (Load: low vs. high; *within-subjects*) × 2 (Age: younger adult vs. older adult; *between-subjects*) mixed-factorial design was implemented.

[3] Excluded participants either failed to make an ongoing task response in the first block ($n = 2$) or in any block ($n = 2$), or made the same ongoing task response ("J" key) across all blocks ($n = 1$).

Table 1
Demographic Information for Experiments 1 and 2

Demographic variable	Older (Exp. 1)	Older (Exp. 2)	Younger (Exp. 2)	Age difference (Exp. 1)[a]	Age difference (Exp. 2)
Mean age (*SD*)	65.31 (6.36)	67.51 (4.05)	20.98 (4.75)	*	*
Years of education (*SD*)	16.72 (1.57)	15.73 (2.18)	12.56 (0.96)	*	*
Mean English speak proficiency (*SD*)	9.46 (0.76)	9.46 (0.65)	9.33 (1.15)	*ns*	*ns*
Mean English understand proficiency (*SD*)	9.41 (0.75)	9.53 (0.56)	9.49 (0.91)	*ns*	*ns*
Mean English read proficiency (*SD*)	9.39 (0.89)	9.44 (0.97)	9.42 (0.96)	*ns*	*ns*
% English as second language	5.1	2.7	27.3	*	*
% Male	18.9	10.8	40.9	*	*
% Female	81.1	89.2	59.1	*ns*	*
% White	81.1	83.8	25.0	*	*
% Black/African American	2.7	13.5	22.7	*	*ns*
% Asian	0.0	0.0	27.3	*	*
% Hispanic or Latino	10.8	2.7	22.7	*ns*	*
% American Indian/Native Alaskan	2.7	0.0	0.0	*ns*	*ns*
% Other	2.8	0.0	2.3	*ns*	*ns*

Note. Values in parentheses reflect the standard deviation of the mean. Exp.1 = Experiment 1; Exp.2 = Experiment 2; *ns* = nonsignificant.
[a] Demographic data were not collected for younger adults in Experiment 1, so the age group difference is relative to the demographic characteristics of the younger adults in Experiment 2.
* $p < .05$.

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Materials

Ongoing task stimuli were selected from the English Lexicon Project (Balota et al., 2007). These consisted of 396 words that were 5–7 letters in length, half of which had one syllable and half of which had two syllables. An additional 10 words were selected as PM targets, 10 were selected for distractors in the no-reminder condition (described below), and 10 words were selected as new items on the postexperimental recognition test. Approximately half of these additional words contained one syllable, and the other half contained two syllables. The stimuli were presented in uppercase white font at the center of the screen on a dark-gray background. Targets in the reminder blocks or distractors in the no-reminder blocks were displayed at the top of the screen in yellow font.

Procedure

The experiment involved participants performing a syllable judgment ongoing task with PM targets embedded. Participants completed demographics questions, practiced the ongoing task, received the intention instructions (and were quizzed), performed four separate PM blocks that were administered in a randomized order (each block included a target learning, distractor, and an ongoing task phase), and completed a postexperimental questionnaire. For the ongoing task, participants judged whether the word stimulus had one or two syllables. Each trial began with a 1 s fixation cross, and stimulus presentation was fixed at 3 s. If an ongoing task response was made prior to the 3 s duration, the stimulus (e.g., "shoe") was backward masked with pound signs (e.g., "####") that matched in character length to the stimulus for the remainder of the 3 s trial.

Practice Block Phase. After reading instructions for the ongoing task, participants completed a 20-trial practice block and received accuracy feedback after each trial. Participants were only allowed to proceed after achieving 75% accuracy or greater on the practice. Afterward, participants performed another practice block (40 trials) without feedback.

PM Instruction Phase. Upon completing the practice phase, participants received instructions for the upcoming PM task. Participants were instructed that, across four separate blocks, they were going to learn a single PM target (low load) or a list of four PM targets (high load) that were to later appear during the syllable judgment task. The PM intention was to make a special response (press the "spacebar") whenever they encountered the PM target(s). They were to press the spacebar *instead* of making their ongoing task response. However, participants were told that the primary objective was still to perform the ongoing task as quickly but as accurately as possible. They were instructed that during the reminder blocks, the studied word (low load) or words (high load) would be presented at the top of the screen, whereas in the no-reminder blocks, an unrelated word (low load) or words (high load) would be presented at the top of the screen. Importantly, they were instructed that they would learn about whether reminders were available *after* the target learning phase.

A brief instructions quiz was then presented to each participant with three questions that asked about the goal of the intention, the PM response, and the purpose of the reminders. Participants had to get every question correct before proceeding. If they answered a question wrong, they had to reread the instructions to ensure proper encoding of the PM task.

Target Learning Phase. At the start of each PM block, participants studied the PM target(s) for 5 s each. Either one (low load) or four (high load) PM targets were presented in the center of the screen, one at a time, and participants were instructed to study the targets for the entire 5 s. One (low load) or four (high load) of the 10 PM targets were randomly assigned to each block, and none of the targets repeated across blocks. After learning the targets(s), participants completed judgments of learning where they made predictions about the proportion of targets they would recognize in the ongoing task. Following judgments of learning, participants

were instructed whether a reminder would or would not be available for the subsequent PM block depending on the condition (reminder vs. no reminder).

Distractor Phase. After each learning phase, participants completed arithmetic problems involving multidigit addition and subtraction for 2 min before the PM block.

Ongoing Task Phase. Before beginning the ongoing task phase, participants received instructions that reiterated only the ongoing task instructions. The ongoing task consisted of 84 trials with word type (one vs. two syllable) randomly presented. PM targets were presented every 20 trials. The single PM target was presented four times in the low load block, whereas each of the four PM targets was presented once in the high load blocks. To match for perceptual characteristics in the reminder and no-reminder blocks, the studied word (reminder) or unrelated (no reminder) targets(s) were presented at the top of the screen in yellow font throughout the task (Figure 1). To match for perceptual characteristics across the low and high load blocks, a single word was listed four times (low load), or four separate words were listed once each (high load).

Postexperimental Questionnaire Phase. After the PM block, participants completed postexperimental questions assessing their retrospective memory for the PM task. They were first asked to freely recall the intention and then given a multiple-choice test to identify the PM intention (i.e., "look for specific words") and the response (i.e., "press spacebar"). Participants were also asked a 5-point Likert scale question about how frequently and how often (1 = *not at all*, 5 = *all the time*) they used the reminders in the reminder blocks.

Eye Tracking

Pupil data was continuously recorded binocularly at 60 Hz using Gazepoint GP3 HD eye trackers (Gazepoint, Inc.). The eye trackers were mounted to the bottom of the computer monitors, and participants freely viewed the screen (i.e., did not have head stabilized in a chinrest). We elected to allow free viewing for participant comfort, as this data was collected under pandemic restrictions that required participants to wear a facemask throughout the experiment. Prior to beginning the task, the researcher verified the eye tracker was accurately reading the participant's eyes with the Gazepoint Control program. We used the pupil diameter averaged across both eyes for all analyses. In instances in which only one eye was tracked, we used the pupil size of that eye. We performed several procedures to ensure clean data. First, we filtered out any measurements that were outside a reasonable range (<2 mm or >8 mm; Mathôt, 2018). Trials in which more than 50% of the data were missing due to blinks or off-screen fixations were excluded from analyses. Any participant who had more than 50% of their data missing for the task was excluded from the reminder checking analyses.

Behavioral Dependent Variables

Target Detection. PM performance was calculated as the proportion of successful PM responses out of four PM target trials in each block. Reliabilities for all measures can be found in the Supplemental Material.

Metacognitive Calibration. Calibration was calculated by subtracting PM performance from the performance predicted by the judgment of learning, whereby scores closer to zero represent better calibration.

Reminder Checking. Reminder checking was assessed by calculating the proportion of trials during each block in which a participant fixated at the upper 85% of the screen where the reminders or distractors were presented for a minimum of 100 ms.

Supplemental Dependent Variables

We also measured ongoing task accuracy, speed, and task-evoked pupillary response during the ongoing task phase for nontarget trials only. However, because this was not of primary interest in the present study, we present these data in the Supplemental Materials.

Results

The primary dependent variables were submitted to a 2 (Offloading: reminder vs. no reminder; *within-subjects*) × 2 (Load: low vs. high; *within-subjects*) × 2 (Age: younger adult vs. older adult; *between-subjects*) mixed-factorial design.

Target Detection (Figure 2A)

Reliabilities for target detection across each of the four block types can be found in the Supplemental Material. Target detection was higher with reminders, *Reminders:* $F(1, 94) = 28.106$, $p < .001$, $\eta_p^2 = .230$, and under low load, *Load:* $F(1, 94) = 43.906$, $p < .001$, $\eta_p^2 = .318$, but did not differ by age (*Age:* $F < 1$). There was an interaction between reminders and load, *Reminders* × *Load:* $F(1, 94) = 28.106$, $p < .001$, $\eta_p^2 = .230$. This interaction indicates that reminders improved performance under high load, $F(1, 95) = 47.085$, $p < .001$, $\eta_p^2 = .331$, but not low load ($F < 1$). There were no other interactions, *Age* × *Reminders:* $F < 1$; *Age* × *Load:* $F < 1$; *Age* × *Reminders* × *Load:* $F(1, 95) = 1.087$, $p = .300$, $\eta_p^2 = .011$. Thus, younger and older adults equally benefitted from reminders under high load.

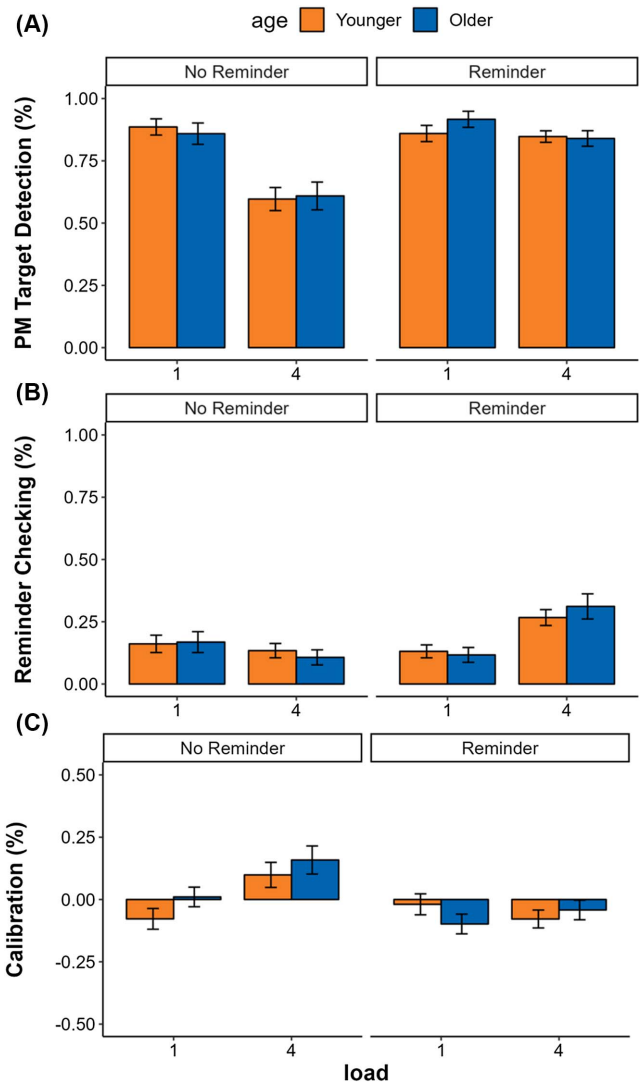
Reminder Checking (Figure 2B)

Fourteen participants missing over half of their pupillary data were excluded from this analysis. Reminder checking was higher with reminders, *Reminders:* $F(1, 78) = 15.450$, $p < .001$, $\eta_p^2 = .165$, and under high load, *Load:* $F(1, 78) = 18.512$, $p < .001$, $\eta_p^2 = .192$, but did not differ by age (*Age:* $F < 1$). There was an interaction between reminders and load, *Reminders* × *Load:* $F(1, 78) = 34.749$, $p < .001$, $\eta_p^2 = .308$. This interaction reflects that participants checked reminders more often than distractors under both high load, $F(1, 78) = 51.224$, $p < .001$, $\eta_p^2 = .387$, but not under low load, $F(1, 78) = 2.530$, $p = .116$, $\eta_p^2 = .031$. There were no other interactions, *Age* × *Reminders:* $F(1, 78) = 1.293$, $p = .259$, $\eta_p^2 = .017$; *Age* × *Load:* $F < 1$; *Age* × *Reminders* × *Load:* $F(1, 78) = 2.046$, $p = .157$, $\eta_p^2 = .026$. Thus, younger and older adults similarly checked reminders, specifically under high load.

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Figure 2
Primary Results for Experiment 1



Note. The results show target detection (Panel A), reminder checking frequency (Panel B), and metacognitive calibration (Panel C) as a function of reminders and load, separately for younger and older adults. Error bars reflect the standard error of the mean. PM = prospective memory. See the online article for the color version of this figure.

Metacognitive Calibration (Figure 2C)

Nine participants did not make judgments of learning during each block and were excluded from analyses. Calibration was worse without reminders, *Reminders:* $F(1, 85) = 12.261$, $p < .001$, $\eta_p^2 = .126$, and under high load, *Load:* $F(1, 85) = 8.091$ $p = .006$, $\eta_p^2 = .087$, but did not differ by age (*Age:* $F < 1$). There was also an interaction between reminders and load, *Reminders* × *Load:* $F(1, 85) = 9.243$, $p = .003$, $\eta_p^2 = .097$. This interaction reflects that calibration was worse without reminders than with reminders under high load, $F(1, 85) = 18.042$, $p < .001$, $\eta_p^2 = .173$, but not under low load ($F < 1$). There were no other interactions, *Age* × *Reminders:* $F(1, 85) = 2.968$, $p = .089$, $\eta_p^2 = .034$; *Age* × *Load:* $F < 1$; *Age* × *Reminders* × *Load:* $F(1, 85) = 1.348$, $p = .249$, $\eta_p^2 = .016$. Thus, younger and older adults were similarly calibrated in their predictions, both being overconfident in their unaided memory ability under high load.

Discussion

The results showed that reminders were beneficial to PM performance under high load, but there was no age difference in performance with or without reminders. Although these results are consistent with the original findings of Einstein and McDaniel (1990) that used a single specific target and our Pilot Study that used five targets (see Supplemental Material), we assumed that having participants learn multiple PM targets in the present study might place sufficient demands on memory maintenance that lead to age differences in performance without reminders. However, multiple specific targets may still elicit a strong discrepancy signal that can result in spontaneous (bottom-up) retrieval (Peper et al., 2023). That is, the repetition of targets from encoding may increase processing fluency, which leads to a search for the source of this discrepant processing and retrieval of the intention. These bottom-up processes remain intact with age (Ball et al., 2023) and can produce negligible age-related differences in PM performance (Mullet et al., 2013).

We assumed that if age differences in performance were found, this pattern could be explained by differences in metacognitive monitoring or control. However, as with PM target detection, there was striking similarity in performance. Younger and older adults were equally calibrated in the performance predictions prior to starting the task (i.e., metacognitive monitoring), although both were overconfident in their ability to complete the PM task without reminders under high load. Despite this overconfidence, both age groups similarly compensated by checking reminders more frequently under high load (i.e., metacognitive control). These findings suggest that younger and older adults performed the task similarly, consistent with research demonstrating that metacognitive processes generally remain intact with increased age (Dunlosky & Metcalfe, 2009).

Experiment 2

Experiment 2 used nonspecific targets that have been shown to produce high demands on proactive, preparatory attention, processes, and substantial age-related declines in performance (B. H. Ball & Aschenbrenner, 2018; Jáger & Kliegel, 2008). Participants learned one (low load) or four (high load) categories (e.g., animal, fruit, etc.) and were instructed to make a special keypress any time an exemplar from that category (e.g., horse, peach, etc.) appeared during the syllable judgment task. Although prior research has shown age differences in target detection with a single nonspecific target, we anticipated that age differences would be most evident under high load. Thus, reminders should be most beneficial for older adults under high load. Increased reminder checking frequency under high load would indicate that older adults can strategically compensate for the poorer internal memory abilities without reminders. Of course, we also thought it was possible that we replicate the results from the Pilot Study and Experiment 1 in which no age differences in performance emerge, even under high load without reminders.

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Method

Power calculations indicated that 66 participants were needed in each experiment to detect a medium-sized interaction effect ($f = .25$) with 80% power and $\alpha = .05$. A minimum sample of 70 participants was chosen (younger adult $n = 35$; older adult $n = 35$) to account for potential exclusionary data. Undergraduate students from the University of Texas at Arlington received research credits for a class requirement for their participation. Older adults were recruited from the Dallas–Fort Worth metroplex and were paid $20 for their participation. Data collection started in 2022 and finished in 2023. The entire experiment lasted approximately 1 hr. The original sample consisted of 46 younger and 41 older adults. However, six participants were excluded for failing to understand the instructions, resulting in 44 younger ($M_{age} = 20.98$, $SD = 4.75$, Min = 18, Max = 43)[4] and 37 older adults ($M_{age} = 67.52$, $SD = 4.05$, Min = 59, Max = 76) in the final sample.[5] Demographics can be found in Table 1.

Design

We used a 2 (Offloading: reminder vs. no reminder; *within-subjects*) × 2 (Load: low vs. high; *within-subjects*) × 2 (Age: younger adult vs. older adult; *between-subjects*) mixed-factorial design.

Materials and Procedure

The materials were identical to Experiment 1, except that the PM targets, reminders, and distractors consisted of categories (e.g., animal, fruit, etc.) instead of specific words and category exemplars were presented during the ongoing task. The procedure was identical to Experiment 1, with the exception that participants were instructed to study categories and make a PM response to exemplars from those categories during the PM blocks. In the low load blocks, participants studied a single category (e.g., animal), and a single exemplar from that category (e.g., horse) was presented every 20 trials in the 84-trial block. In the high load blocks, participants studied four separate categories (e.g., fruit, sport, etc.), and a single exemplar from each category (e.g., peach, hockey, etc.) was presented every 20 trials. Participants also used a chin rest throughout the task to reduce head movements during the task.

Results

The primary dependent variables were submitted to a 2 (Offloading: reminder vs. no reminder; *within-subjects*) × 2 (Load: low vs. high; *within-subjects*) × 2 (Age: younger adult vs. older adult; *between-subjects*) mixed-factorial design.

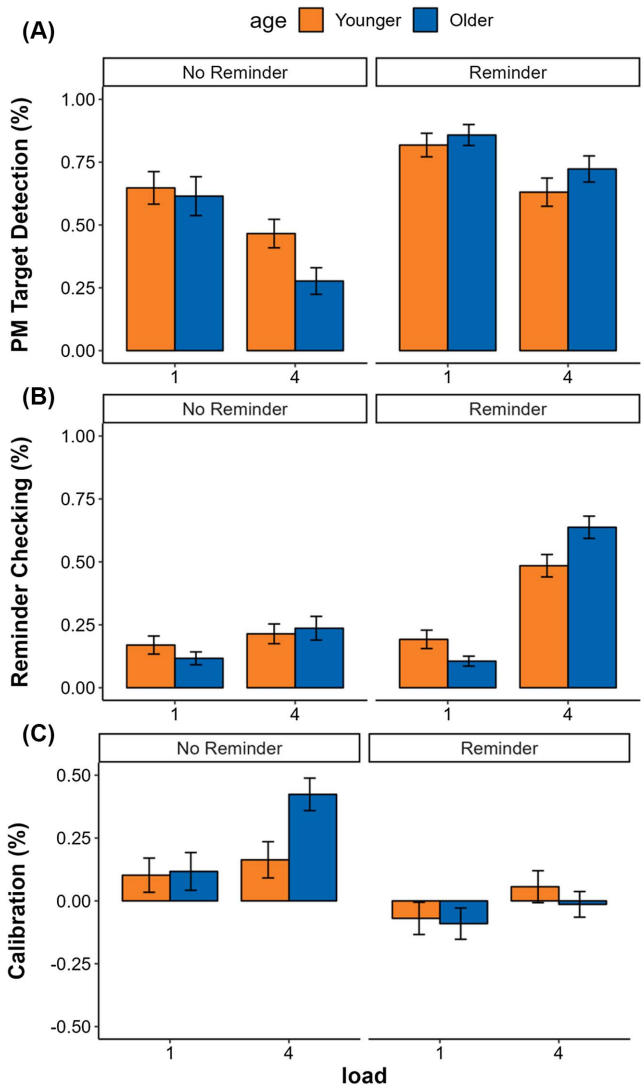
Target Detection (Figure 3A)

Target detection was higher with reminders, *Reminders:* $F(1, 79) = 47.046$, $p < .001$, $\eta_p^2 = .373$, and under low load, *Load:* $F(1, 79) = 49.172$, $p < .001$, $\eta_p^2 = .384$, but did not differ by age (*Age:* $F < 1$). There was also an interaction between age and reminders, *Age* × *Reminders:* $F(1, 79) = 5.617$, $p = .020$, $\eta_p^2 = .066$. This interaction indicates that while both younger, $F(1, 43) = 11.269$, $p = .002$, $\eta_p^2 = .208$, and older, $F(1, 36) = 38.227$, $p < .001$, $\eta_p^2 = .515$, adults benefitted from reminders, older adults did so to a greater degree. There were no other interactions, *Reminders* × *Load:* $F(1, 79) = 2.524$, $p = .116$, $\eta_p^2 = .031$; *Age* × *Load:* $F < 1$; *Age* × *Reminders* × *Load:* $F(1, 80) = 2.824$, $p = .097$, $\eta_p^2 = .035$. Thus, older adults benefitted more from reminders.

Although the three-way interaction was not significant, we examined age differences in target detection separately for each of the four PM blocks based on a priori hypotheses. Results showed

Figure 3

Primary Results for Experiment 2



Note. The results show target detection (Panel A), reminder checking frequency (Panel B), and metacognitive calibration (Panel C) as a function of reminders and load, separately for younger and older adults. Error bars reflect the standard error of the mean. PM = prospective memory. See the online article for the color version of this figure.

[4] Younger adults from our student population are typically classified as aged 18–35. Because the results are identical if the 43-year-old student is excluded, we elected to retain their data as part of the younger adult sample.

[5] Excluded participants either failed to make an ongoing task response in the first half of the first block ($n = 2$) or in any block ($n = 1$), had <50% ongoing task accuracy on the task ($n = 1$), or primarily pressed the same ongoing task response ("J" key) across all blocks ($n = 2$).

that older adults did worse than younger adults under high load without reminders, $F(1, 79) = 5.782$, $p = .019$, $\eta_p^2 = .068$, but not in any other block, all Fs < 1.420, ps > .236, η_p^2s < .019. Thus, the benefit from offloading for older adults appears to primarily be driven by improvements under high load.

Reminder Checking (Figure 3B)

Two participants were missing over half of their pupillary data and were excluded from analyses. Checking was higher with reminders, *Reminders:* $F(1, 77) = 84.013$, $p < .001$, $\eta_p^2 = .522$, and under high load, *Load:* $F(1, 77) = 158.262$, $p < .001$, $\eta_p^2 = .673$, but did not differ by age (*Age:* $F < 1$). While there was no interaction of age and reminders, *Age* × *Reminders:* $F(1, 77) = 1.685$, $p = .198$, $\eta_p^2 = .021$, there was a significant interaction between reminders and load, *Reminders* × *Load:* $F(1, 77) = 90.527$, $p < .001$, $\eta_p^2 = .540$, and between age and load, *Age* × *Load:* $F(1, 77) = 16.003$, $p < .001$, $\eta_p^2 = .172$. However, these were qualified by a significant three-way interaction, *Age* × *Reminders* × *Load:* $F(1, 77) = 5.604$, $p = .020$, $\eta_p^2 = .068$.

To probe the three-way interaction, we examined age differences in checking separately for each of the four PM blocks. Results showed older adults checked more frequently than younger adults under high load with reminders, $F(1, 77) = 5.830$, $p = .018$, $\eta_p^2 = .070$, but not in any other block, all Fs < 3.892, ps > .052, η_p^2s < .049. Thus, the improvements to target detection under high load for older adults may be attributed to increased reminder checking.

Metacognitive Calibration (Figure 3C)

Three participants did not make judgments of learning in each block and were excluded from analyses. Calibration was worse without reminders, *Reminders:* $F(1, 76) = 33.608$, $p < .001$, $\eta_p^2 = .307$, and under high load, *Load:* $F(1, 76) = 26.077$, $p < .001$, $\eta_p^2 = .255$, but did not differ by age (*Age:* $F < 1$). Although there was no interaction of reminder and load, *Reminders* × *Load:* $F(1, 76) = 1.481$, $p = .227$, $\eta_p^2 = .019$, there was a significant interaction of age and reminders, *Age* × *Reminders:* $F(1, 76) = 4.638$, $p = .034$, $\eta_p^2 = .058$, and of age and load, *Age* × *Load:* $F(1, 76) = 4.320$, $p = .041$, $\eta_p^2 = .054$. However, these interactions were qualified by a significant three-way interaction, *Age* × *Reminders* × *Load:* $F(1, 76) = 4.780$, $p = .032$, $\eta_p^2 = .059$.

To probe the three-way interaction, we examined age differences in calibration separately for each of the four PM blocks. Results showed that older adults were less well calibrated under high load without reminders, $F(1, 77) = 5.963$, $p = .017$, $\eta_p^2 = .073$, but not in any other block (all Fs < 1). Thus, older adults were overconfident in their internal memory ability relative to younger adults only under high load without reminders.

Discussion

Using nonspecific PM targets, Experiment 2 replicated the primary finding from Experiment 1 that reminders helped both younger and older adults. However, there were several notable differences in performance. While unaided (i.e., internal) memory was comparable between younger and older adults under low load, older adults detected fewer targets under high load. When reminders were available, however, there were no age differences in performance, meaning that reminders effectively eliminated age differences in performance under high load. These findings suggest that offloading can be used to circumvent capacity limitations during tasks that require attentionally demanding monitoring processes.

Regarding metacognitive monitoring and control processes, it is interesting to note that older adults were overconfident relative to younger adults in their unaided memory ability under high load. Perhaps, older adults did not anticipate the difficulty of maintaining multiple nonspecific intentions, and by the time they realized it (i.e., during the task), it was too late to strategically change behavior (e.g., encode more effectively) to improve performance. However, older adults in the reminder blocks were able to compensate for their poorer internal memory ability by checking reminders more frequently. Thus, despite some metacognitive miscalibrations prior to beginning the task, older adults could make real-time adjustments by enacting control behavior to improve target detection.

General Discussion

The purpose of the present study was to examine the role of offloading in mitigating age differences in PM. Consistent across all experiments was that reminders benefitted both younger and older adults. However, no age differences in unaided memory emerged with specific targets (Pilot Study and Experiment 1) regardless of load, and no age differences were found with nonspecific targets under low load (Experiment 2). Critically, when age differences in unaided memory *did* emerge under with nonspecific targets under high load, having the option to offload these memory representations eliminated age differences in target detection (Experiment 2). This improvement to performance was associated with increased reminder checking frequency, suggesting that older adults can strategically compensate for poorer unaided memory ability when given the option. Together, these findings suggest that offloading is an effective strategy to improve fulfillment of a variety of intentions for all age groups and can be especially beneficial for older adults in instances which unaided memory differences do arise. Below we discuss the theoretical and applied ramifications for these findings.

The multiprocess framework of PM posits that target detection can occur via bottom-up spontaneous retrieval (i.e., specific intentions) or top-down preparatory monitoring (i.e., nonspecific intentions; Einstein & McDaniel, 2005), with age differences most pronounced for the latter. The results of the present study are consistent with this idea, whereby age differences without reminders were only evidenced with nonspecific intentions (under high load; see also Einstein & McDaniel, 1990). This suggests that reminders can help, at least in part, by reducing the need to proactively maintain nonspecific intentions in awareness, which can be demanding. Instead, reminders may reactively be checked to verify whether a certain word fits within a learned category, essentially turning a nonspecific PM task into something similar to a specific PM task (Peper et al., 2023). That is, bottom-up features of the stimulus may reactively cue search for PM target-relevant information—in this case, by searching through the reminder list. Alternatively, participants may periodically check the reminders to refresh the intention when the memory representations start to fade. In either case, this should be particularly beneficial for older adults who typically show deficits in proactive, preparatory monitoring (Ball et al., 2023; Paxton et al., 2008). Directly comparing specific and nonspecific conditions (at least under high load) within the same

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group of participants, however, might better elucidate the processes underlying age differences in reminder effectiveness.

One interesting question is whether reminder checking in the present study can be considered a *strategic* metacognitive control process. For example, the reminders presented at the top of the screen could automatically capture attention, detracting focus away from the goal of completing the ongoing task quickly and accurately. Unintentionally making a saccade to the reminders could refresh the contents of the intention and thereby improve target detection. Prior research has shown that having reminders available throughout the task can aid in rehearsal (Vortac et al., 1995; but see Loft et al., 2011, for evidence that participants can habituate to these continuous reminders). If this were the case, the benefits to performance should be especially pronounced for older adults given age-related declines in attention control (see Ball et al., 2023; Lourenço & Maylor 2015, e.g., where attentional declines can *improve* PM performance). However, from a perceptual load viewpoint, older adults should be *less* likely to check reminders under high load (Maylor & Lavie, 1998). Moreover, there were no age differences in reminder checking in any of the other three block types in Experiment 2, including both the low and high load no-reminder condition in which actual distractors were presented at the top of the screen, or in any block of Experiment 1. This finding suggests that older adults *intentionally* (i.e., strategically) checked reminders under high load to improve nonspecific target detection.

It should be noted, however, that the metacognitive monitoring results in Experiment 2 showed that older adults were *overconfident* in their ability to complete the task under high load without reminders. From a metacognitive viewpoint of PM offloading, overconfidence by older adults should have resulted in *less* frequent reminder checking when given the opportunity (Tsai et al., 2023). Notably, Scarampi and Gilbert (2021) found that older adults were also overconfident in their unaided memory ability under high load using the intention offloading task, yet older adults did *not* use reminders more often to compensate for poorer unaided memory ability when given the option. The primary difference between the two studies was that Scarampi and Gilbert gave participants the option to *set* reminders, and assuming they correctly dragged the PM targets near the correct side of the screen when setting the reminders, this effectively eliminated the decision to *check* reminders as they were naturally encountered as part of the ongoing task sequence (i.e., dragging circles in numerical order). In the present study, we effectively eliminated the decision to *set* reminders by instructing participants when reminders would be available, but then assessed the frequency with which the reminders were *checked* during the task. If participants are overconfident in their unaided memory ability when the intention is formed and fail to set reminders, there is no way to strategically compensate when they later realize they no longer remember the intention since no reminder is available. However, participants can compensate for this initial overconfidence when reminders are set for them by checking reminders more frequently when given the option. Metacognitive differences underlying decisions to set versus check reminders may explain why previous research failed to find that offloading eliminated age differences in PM performance while the present study did. Future studies could examine age differences in reminder checking using a lookup table (e.g., "press 'R' to see list of reminders"), in which case the reminders are still set for participants, but require a more demanding self-initiated search process (relative to a saccade to the top of the screen) that may be more influenced by confidence (Ball & Peper, 2024). This is similar to the approach used by Henry et al. (2012), although notably, PM performance was largely similar between experimenter and self-initiated reminder conditions.

Regarding the optimality of reminder checking, it was clear that both age groups were sensitive to the difficulty of high load on unaided PM performance and checked reminders more frequently only under high load for both specific and nonspecific intentions. This suggests that participants were largely able to maintain a single target in mind, but under increased load, were more likely to rely on the reminders to reduce the demands of maintaining intentions internally. Thus, both age groups appeared to have some awareness that checking reminders requires some additional processing resources and do not unnecessarily exert effort to check when memory demands are relatively minimal.

It is worth noting that we had anticipated that age differences in unaided memory under high load-specific intentions would emerge in Experiment 1 (Ballhausen et al., 2017; Einstein et al., 1992). Although younger and older adults had comparable self-reported proficiency with English, the older adult participants had higher levels of education and were less likely to have learned English as a second language, which could have influenced performance. However, these findings were replicated in the online Pilot Study, which examined age as a continuous variable (aged 18–78) where there were no educational or English as second language differences across the age ranges (see Supplemental Materials). The Pilot Study also had a slightly higher memory load (five PM targets) and used arguably more difficult-to-remember targets (multisyllabic abstract words) than Experiment 1. Alternatively, previous research shows that age-related declines in PM are more apparent in "old-old" groups (age >75) than "young-old" groups (age 60–75; Kvavilashvili et al., 2009, 2013). The average age in each experiment was approximately 66 years old, meaning that most older adults would be classified as "young old." It is possible age-related declines in spontaneous retrieval processes using multiple specific PM targets may be observed in old-old group. More diverse older adult recruitment may help eliminate this concern in future studies.

Lastly, it is worth noting that the laboratory task used in the present study lacks in ecological validity. For example, previous research has shown that standard laboratory tasks do not always predict real-world PM failures (Unsworth et al., 2012; but see Rummel et al., 2023) and that older adults often do *better* in naturalistic settings (referred to as the age-PM paradox; Aberle et al., 2010; Schnitzspahn et al., 2020). Thus, performance in the tasks used here may not generalize to real-world settings in which memory failures can have important consequences. The reminders may also seem somewhat contrived, as they were always provided by the experiment rather than being set by the participants. Of course, there are numerous examples in which a reminder is not self-set, such as a significant other providing their partner with a grocery list, a caregiver setting a daily reminder for a patient to take medication, an administrator sending an automatic calendar invite to a meeting for employees, or a "check engine" light presented on a display for a pilot. In each of these cases, one must check the reminder to successfully complete the task if the intention was not maintained internally. While we agree that understanding the processes underlying setting reminders are critical, we argue that understanding how people check reminders is equally important. If people do not effectively check reminders even in the most optimal of situations

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(i.e., provided for them and easy to use), what would be the utility of setting reminders in the first place? Controlled laboratory studies are important for isolating specific processes that underlie performance, and we hope that this work can ultimately be used to inform a broader research program in applied settings where external validity is more of a concern.

Conclusions

PM failures are associated with a variety of difficulties in instrumental activities of daily living, including medication adherence, maintaining social relations, and running errands (Woods et al., 2012). The results of the present study suggest that offloading may provide a promising solution to reduce everyday memory failures. However, there remains a paucity of existing laboratory-based studies on offloading. Future research aimed at understanding optimal offloading decisions (e.g., Tsai et al., 2023) and where age-related breakdowns in these decisions occur (e.g., encoding, maintenance, and/or retrieval) will increase the ability to design effective interventions to use offloading as a strategy to improve memory.

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