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Implementation Intentions and Prospective Memory Function in Late Adulthood

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Prospective memory (PM) is a critically important component of memory that often declines in late adulthood. Implementation intentions, an encoding strategy, consisting of an explicit if–then "I will . . ." statement, has been effectively used to enhance older adults' prospective memory function. However, it remains to be established whether forming a mental representation of carrying out the task when forming the intention enhances these age effects, as well as whether the type of cue (event or time based) moderates age-related benefits. To test these questions, we randomly allocated 125 younger and 125 older adults to 1 of 5 conditions, in which they were directed to use different strategies when forming their PM intentions (Statement Only, Imagine in Game, Statement and Imagine Combined, Imagine in Daily Life, Control). The results indicated that use of the implementation intentions statement alone and in combination with forming a mental representation of carrying out the task substantially enhanced older adults' event- but not time-based PM. In addition, while the Statement Only condition reduced age-related difficulties for event-based tasks, the condition that combined this statement with visualization led to the greatest reduction in age effects. These data suggest that both rehearsing the implementations intention in the specific statement format combined with visualizing may be optimally effective for enhancing PM function in late adulthood but that the type of PM cue is an important moderator of these age effects. In addition to theoretical implications, these results may inform the refinement of interventions focused on enhancing PM function in late adulthood.

Keywords: aging, prospective memory, implementation intentions, Virtual Week

Prospective memory (PM) is a critically important component of memory that refers to the implementation of delayed intentions, such as remembering to take medications and to turn off appliances. Because PM failures are a common and potentially debilitating feature of normal adult aging, a large literature has now emerged focused on testing how PM function may be improved. To date, most studies have focused on the value of compensatory training, an approach that involves teaching strategies to circumvent deficits or compensate for possible cognitive losses. Implementation intentions is one of the most successful of these strategies and involves generating and saying aloud a simple statement that has a precise format and structure whereby a specific cue is stated first, followed by an action, that is, "When situation X (cue) arises, I will perform response Y (action)" (Gollwitzer, 1999, p. 494). For example, the intention to pick up dry cleaning when shopping becomes "When shopping, I will pick up dry cleaning."

In keeping with extensive early literature that showed that implementation intentions can be used to enhance PM function in younger adults, recent studies have shown that these benefits also extend to older adults (Brom et al., 2013; Bugg, Scullin, & McDaniel, 2013; Chasteen, Park, & Schwarz, 2001; Lee, Shelton, Scullin, & McDaniel, 2016; Liu & Park, 2004; McFarland & Glisky, 2011; Schnitzspahn & Kliegel, 2009; Shelton et al., 2016).

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However, important questions remain about the limits and specificity of these age-related implementation intentions effects. In particular, although implementation intentions effects appear to be stronger for younger adults when there is an additional mental visualization component, whether similar benefits are also evident for older adults remains to be tested. This study will provide a novel test of how combining implementation intentions with mental visualization influences age effects in PM and the potential benefits of different visualization strategies when presented independently of the implementation intentions statement. We were also interested in establishing the boundaries of any observed effects—and, specifically, whether any benefits of implementation intentions (presented alone, as well as in combination with mental visualization) vary as a function of the type of PM cue (event vs. time based).

Theoretical Accounts of Implementation Intentions

There are at least four viable mechanisms by which implementation intentions benefit PM. First, when using implementation intentions, the mental representation of the situational cue may become highly activated and more accessible. According to Cohen and Gollwitzer (2008), this heightened accessibility creates a state of perceptual readiness, which means that when later encountering the situational cue in real life, the initiation of the intention is more easily triggered. A second, related explanation is that spontaneous retrieval of the intention is more likely because the implementation intention statement leads to the formation of a strong association between the content of the intention (the PM action) and the situational cue (PM cue) at encoding (see Ellis & Freeman, 2008; McDaniel, Howard, & Butler, 2008; McDaniel & Scullin, 2010). A third explanation focuses on the personal commitment aspect of implementation intentions, particularly the emphasis on the personal pronoun "I . . ." in relation to the action and the cue (Ellis & Freeman, 2008). By this view, implementation intention increases the personal salience and importance of the PM task, both of which have been shown to enhance PM (Phillips, Henry, & Martin, 2008). The fourth potential mechanism is relevant for the implementation intentions studies that have included not only the statement of intention but also an instruction to imagine carrying out the intention (a mental visualization component). Event simulation may assist with later retrieval of the intention during the delayed performance interval because it allows for preexperiencing the specific visual-spatial context through imagination. This suggestion could be seen as having some parallels with the encoding specificity principle, which refers to the enhancement of recall of a past event when the encoding context is reinstated (Tulving & Thomson, 1973). Specifically, preexperiencing the context may increase the salience of the retrieval cues that signal that the PM task should be performed, thereby increasing the likelihood that the cues will be detected and the PM task successfully completed (Mioni et al., 2017; Terrett et al., 2016).

Integrating aspects of the first two of these mechanisms, Martiny-Huenger, Martiny, Parks-Stamm, Pfeiffer, and Gollwitzer (2017) proposed a novel simulation account of action planning, which explains how it is possible for conscious thought to elicit behavioral automaticity via the creation of direct stimulus–response links. By this view, the implementation intentions statement (i.e., verbally planning an action in an "if [situation]–then [action]" format) elicits sensorimotor simulations, thereby establishing a direct perception–action link. The creation of this direct link then means that encountering the anticipated situation triggers the intended action via relatively automatic, reflexive processes. In support of this model, Martiny-Huenger et al. (2017) refer to simulation theories of cognition, which suggest that conscious thought alone is sufficient to create stimulus-triggered links. They also provide empirical support for their framework in four experiments, which collectively show how subtle changes in verbally formulated action plans elicit systematic differences in subsequent behavioral responding.

Central to Martiny-Huenger et al.'s (2017) model is the argument that conscious thought can create a direct perception–action link via the elicitation of sensorimotor simulations. However, even if the implementation intentions statement is sufficient to create this link, theoretically it may be possible to strengthen it, thereby eliciting behavioral responses that are quicker, stronger, and/or longer lasting. In this regard, one cognitive activity that seems a particularly viable candidate is mental visualization. As noted earlier, several studies that have tested the effects of implementation intentions on PM have additionally asked participants to visualize engaging in the to-be-performed behavior. Consistent with the possibility of an additive effect, these studies have typically shown that greater PM benefits are evident where the implementation intention statement is accompanied by event simulation via visual imagery (see, e.g., Kardiasmenos, Clawson, Wilken, & Wallin, 2008; McDaniel & Scullin, 2010). However, none of these studies included older adults, and as will be discussed, it remains unclear whether older adults would also benefit when there is this additional requirement to engage in mental visualization.

Aging and Mental Simulation

Relative to their younger counterparts, older adults have greater difficulty engaging in many mental simulation processes, particularly when there is the requirement for them to mentally place themselves in the future (Addis, Musicaro, Pan, & Schacter, 2010; Lyons, Henry, Rendell, Corballis, & Suddendorf, 2014; Rendell et al., 2012). However, even if task instructions refer to visual imagery in the relevant context—as opposed to visual imagery in the future—older adults may still have greater difficulties than their younger counterparts applying and benefiting from a visualization strategy. This is because older adults also perform more poorly relative to young when asked to imagine atemporal scenarios (Rendell et al., 2012). Indeed, in a life span study that looked at the impact of age on different visual mental imagery processes, age was associated with decline in three of the four processes argued to be involved in mental imagery. While the abilities to generate, inspect, and transform mental images were all associated with negative age effects, only the ability to maintain mental images was intact across the adult life span (Palermo, Piccardi, Nori, Giusberti, & Guariglia, 2016). Such findings therefore suggest that an added visualization component may be less effective for older relative to younger adults.

Based on prior research, the first key prediction was that use of an implementation intentions encoding strategy (Statement Only condition) would reduce the otherwise large age differences typically seen on tests of PM (and indexed in the present study via a no-strategy Control condition). However, combining implementation intentions with mental visualization (a Statement and Imagine Combined condition) may confer greater benefits for young relative to older adults, due to the latter groups' reduced capacity for mental visualization. Consequently, the condition that combined these two strategies was predicted to reduce age effects but to a lesser extent than the Statement Only condition.

Two additional visual imagery conditions (Imagine in Game; Imagine in Daily Life) were also included to allow us to assess whether visual imagery is sufficient to enhance PM when presented independently of the implementation intentions statement. Predictions here were less clear. On the one hand, Martiny-Huenger et al. (2017) have argued that it is the specific planning of actions in an "if (situation)–then (action) format," which induces the sensorimotor simulations that create the direct stimulus–response link argued to underlie behavioral automaticity. However, even if preexperiencing the specific visual-spatial context through imagination is not sufficient to create this hypothesized direct stimulus–response link, visual simulation may increase the salience of the retrieval cues that signal that the PM task should be performed (Mioni et al., 2017; Terrett et al., 2016).

The inclusion of these two visualization conditions also allowed us to assess whether different types of visual imagery instructions differ in their subsequent effects on PM. As noted, Palermo et al. (2016) showed that three of the four processes involved in mental imagery decline with age, including the initial imagery generation component. By contrast, the subsequent maintenance component is intact. We therefore tested whether altering the demands placed on the initial generative component of visual imagery led to differential age effects on PM. The creation of visual mental images from immediate perceptual information is less demanding than creation of these images from previously stored information held in long-term memory (Pearson, 2007). Consequently, our first visual imagery condition (Imagine in Game) required participants to imagine performing the to-be-remembered task in the context of the PM task itself. The second condition (Imagine in Daily Life) asked participants to imagine performing the task in their everyday lives. If visual imagery by itself is sufficient to reduce age effects in PM, these effects should be strongest in the condition where participants imagine performing the future intention in the context of the PM task itself, as this condition places fewer demands on the initial generative component.[1]

Time-Based Versus Event-Based Cues

Finally, we were also interested in testing whether the observed beneficial effects of implementation intentions differ for tasks that involve event- versus time-based PM cues. As noted, in Martiny-Huenger et al.'s (2017) model, implementation intentions are argued to improve PM because they create a direct perception–action link. However, the extent to which one can create an association between a cue and an action differs fundamentally as a function of the type of PM cue. Whereas the cues for event-based tasks are the occurrence of a particular event, such as remembering to pass on a message *when you see a colleague,* for time-based tasks, the appropriate time for PM execution is marked by either time of day (e.g., attend a doctor's appointment *at 11 a.m.*) or short-interval time delays (e.g., turn the oven off *in 10 min*). By definition, an event-based task therefore has the target event as a cue, and noticing this event cue is critical to performing the PM task. However, most time-based tasks do not inherently have an environmental cue—instead, monitoring time is critical to performing these PM tasks.

In the context of this model, the type of cue (event or time) is therefore an important factor that should determine any benefit of implementation intention–related strategies, as for the latter it may often not be possible to create a direct perception–action link. In the only three prior studies to investigate whether the effects of implementation intentions on PM vary as a function of cue type, inconsistent results have been reported, but this is perhaps not surprising since each of these studies focused on heterogeneous clinical groups (Foster, McDaniel, & Rendell, 2017; Liu et al., 2018; Mioni, Rendell, Terrett, & Stablum, 2015). The present study is the first to test the role of cue type in understanding how implementation intentions (both alone and in combination with visualization) influence age effects in PM function. The key prediction here was that any benefit of implementation intentions in reducing age effects should be greater for event-based relative to time-based PM tasks. This is because for the time-based task used in the current study, it may not be possible to generate a direct perception–action link.

Method

Participants

In total, 125 young adults (18–30 years, $M = 22.9$, $SD = 3.45$) and 125 older adults (65–85 years, $M = 73.8$, $SD = 5.57$) participated. Table 1 shows the characteristics of the two age groups. Both groups were recruited from the general community and received $30 AUD for participating in a 2- to 3-hr testing session. All older adults had normal mental status as indexed by scores ≥ 83 on the Addenbrooke's Cognitive Examination–Revised ($M = 92.7$, $SD = 3.76$) and scores ≥ 26 on the Mini Mental State Examination ($M = 29.4$, $SD = 0.86$). The two groups did not differ in years of education, verbal fluency, self-ratings of health on the day of testing, self-ratings of sleep, or gender composition (71.2% and 69.6% female in the younger and older adult groups, respectively). Relative to the younger group, older adults had higher verbal IQ, based on the National Adult Reading Test (NART) vocabulary test, and lower levels of depression, as indexed by the Geriatric Depression Scale.

Design

A 2×5 between-groups design was used to investigate the effect of encoding conditions on PM performance, with the between-subjects variables of *age* (young, older) and *encoding strategy* (Statement Only, Imagine in Game, Statement and Imagine Combined, Imagine in Daily Life, Control). PM performance was measured using a modified version of Virtual Week (Rendell & Craik, 2000), in which participants were directed to use different strategies when forming intentions for the 16 irregular PM tasks

[1] For the Imagine in Game condition, there was a greater match between the conditions of encoding and retrieval than in the Imagine in Daily Life condition. Better performance for the former condition might therefore also be anticipated because of the encoding specificity principle.

Table 1
Descriptive and Inferential Statistics for Younger and Older Adults' Demographic and Cognitive Background Measures

Measure	Young adults		Older adults		Inferential statistics			
	M	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
Education	13.9	2.16	13.3	3.61	1.72	248	.086	0.22
Health	2.1	0.84	2.2	0.94	0.85	248	.395	0.11
Sleep quality	2.6	0.93	2.7	1.00	0.79	248	.432	0.10
GDS	7.2	4.75	4.04	3.84	3.21	248	<.001	0.41
NART IQ	98.2	8.13	110.2	8.44	11.42	248	<.001	1.46
Verbal fluency	57.4	13.07	56.3	14.14	0.61	248	.543	0.08

Note. Education refers to years of education. Health refers to self-rated health on the day of the test. Sleep quality refers to self-rated sleep quality over the past month, rated from 1 (*excellent*) to 5 (*poor*). GDS = Geriatric Depression Scale; NART IQ = National Adult Reading Test Intelligence Quotient.

over 4 virtual days: eight event based and eight time based. Although the regular tasks that are part of the standard version of Virtual Week were also included in this study, the encoding manipulation was only applied to the irregular tasks.

As in the standard version, the irregular tasks were all different "one-off" tasks. Before starting each day, participants read aloud a start card that indicated what day of the week it was as well as two of the four irregular PM tasks (one time based and one event based) to be performed during that day and that day only. For example, on the Monday Start Card, the two tasks were "drop dry-cleaning in when shopping" and "phone bank to arrange appointment at 12 noon." In addition, as participants progressed throughout the day, two of the event cards they encountered also described another PM task (one time based and one event based) that would need to be performed later on in that day. In the standard version, the presentation of task cards is self-paced, but in the present study, all task cards stayed open for a fixed period of 45 s. Thus, in all conditions, participants had the same set time (45 s) to study each task. Each condition varied only on the following instructions that were additional to reading the contents of the task card.

In the Statement Only condition, participants had to also form the "When . . . then" statement and recite it three times. In the Imagine in Game condition, participants had to imagine carrying out the task in Virtual Week. In the Statement and Imagine Combined condition, participants had to use both encoding strategies: reciting a verbal statement and imagining. In the Imagine in Daily Life condition, participants had to imagine carrying out the task in their daily life. The Control condition was a "read-only condition" in which participants were asked to learn the task.

Materials and Procedure

Virtual Week is a measure of PM designed to more closely represent PM in daily life (Rendell & Craik, 2000) using an engaging board game format. Prior studies that have used Virtual Week have consistently shown that older adults perform more poorly than younger adults on this task (see, e.g., Henry, Rendell, Phillips, Dunlop, & Kliegel, 2012; Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010) and that task performance is a key predictor of their functional independence (Hering, Kliegel, Rendell, Craik, & Rose, 2018).

The present study used the computerized version of Virtual Week (see Figure 1 for screen display). Participants move around the board with the roll of a die, with each circuit of the board representing a virtual (waking) day. The selection of activity options, rolling die, and moving the token constitute the ongoing activity for the PM tasks embedded in Virtual Week. Each day includes 10 PM tasks (four regular, four irregular, and two time-check). The four regular PM tasks are the same each day: Two are event based (triggered by specific event cards), and two are time based (triggered by specific virtual times of day). The four irregular PM tasks were different each day; these also consisted of two event-based and two time-based tasks. The two time-check tasks were the same tasks each day but required the participant to "break set" from the board game activity and monitor real time on the top clock that was displayed prominently. Participants performed each PM task by clicking on the perform task button on the screen and selecting the appropriate action from the drop-down menu consisting of a list of target and distractor actions. Participants were encouraged to perform each PM task on time but, even if they were late to remember a task, to still perform the task.

In Virtual Week, the key distinction between the regular and irregular tasks is not about routine and habit but the fact that they impose relatively low and high retrospective memory demands,

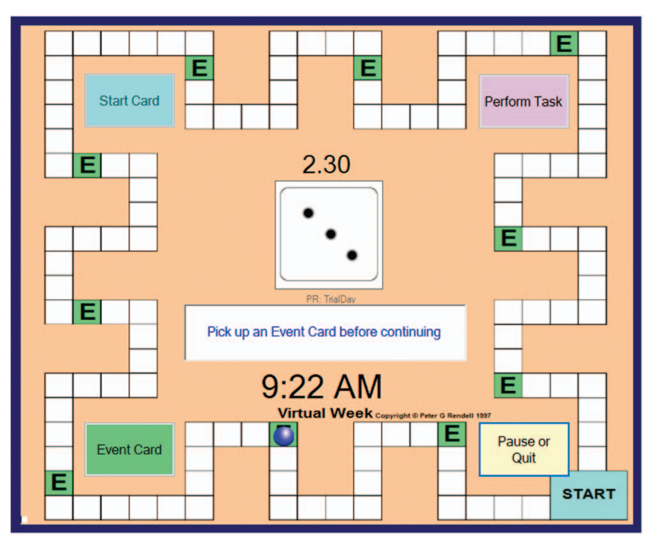

Figure 1. The Virtual Week computer screen display. See the online article for the color version of this figure.

respectively. In the present study, the manipulation of the retrospective memory demands was further refined with regular PM tasks included in the trial day, thereby providing practice on these tasks prior to beginning the actual task; moreover, additional reminders for the regular tasks were presented at the start of each virtual day.

All participants completed the practice day and 4 virtual days. The present study included three specific modifications just for irregular tasks. First, in the standard version, presentation of task cards is self-paced, as participants click an "OK" button to close the instruction card and proceed with game. In all conditions in this study, there was no "OK" button, and each task card stayed open for exactly 45 s before the card automatically closed. This set time allowed enough time for the encoding strategies to be completed and to provide a constant time for studying each task instruction across all conditions. As the task card closed, there was an auditory beep to notify the participant that the task card was closing and the game was about to proceed. A second modification was that the task card for each encoding condition had an additional instruction that summarized the required encoding strategy (see Figure 2). The instructions for the conditions were as detailed below. Each task card stayed open for 45 s, but participants were told they had 30 s to learn the task, to allow for reading time.

- *Statement Only:* "Repeat aloud three times the 'when . . . then' statement."
- *Imagine in Game:* "Imagine for 30 s yourself performing the task. Remember to close your eyes and visualize, for 30 s, completing the task. Remember to include as much sensory detail as possible and imagine it in the context of the game."
- *Statement and Imagine Combined:* "Repeat aloud three times the 'when . . . then' statement and imagine for 30 s yourself performing the task."
- *Imagine in Daily Life:* "Imagine for 30 s performing this task in your daily life. Remember to close your eyes and visualize, for 30 s, completing the task. Remember to include as much sensory detail as possible and imagine it in the context of your own life."
- *Control (read only):* "You will now have 30 s to learn this task."

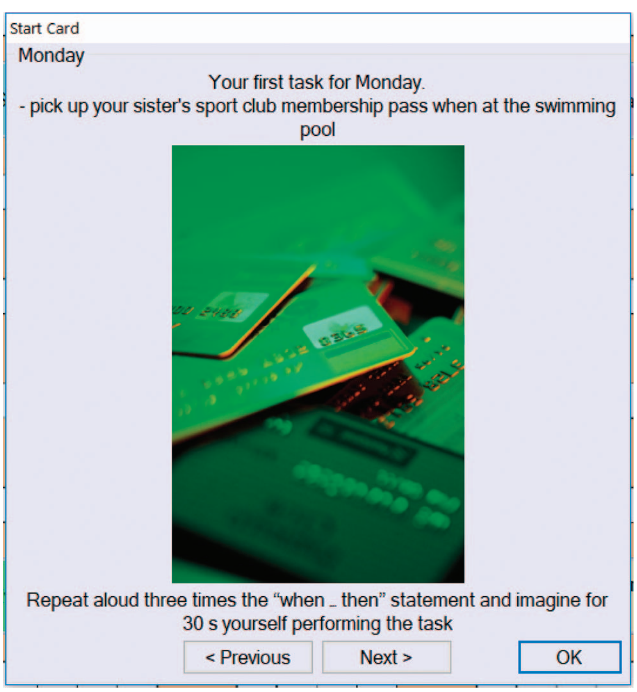

Figure 2. An example of the card displayed on the computer screen to inform participants of the irregular prospective memory tasks. The text at bottom provides a brief summary of the encoding instructions, so varied according to encoding condition. See the online article for the color version of this figure.

The third modification to the irregular tasks involved always presenting the task description on each task card in the same order, with the action followed by cue (e.g., drop in dry cleaning, when you go shopping). Having the action followed by the cue is in the opposite order for the implementation intentions statement. This meant that in the conditions involving the implementation intentions statement, participants had to reorder the task description (and ensured that participants in the other conditions did not inadvertently end up using an implementation intentions strategy during encoding).

In the practice day, a standardized set of instructions was used. Participants were tested individually, and an experimenter sat with them throughout the practice day, ensuring that they understood all procedures before starting their first virtual day. After randomly being assigned to one of the experimental conditions, the appropriate strategy was introduced during the practice day and practiced with four irregular PM tasks. During this practice day, participants allocated to one of the memory strategy conditions were also presented with a hard copy of the detailed instructions of the strategy and given the opportunity to ask questions if required. Just prior to starting the first virtual day, the experimenter informed the participant that there would be no more help messages on the screen or assistance provided by the experimenter. However, during the measurable component of the game, simple standardized prompts via computer screen messages were provided to ensure instructions were clear. The study was approved by the Human Research Ethics Committee at the Australian Catholic University.

Results

Regular and Time-Check Tasks

We first report the performance on the PM tasks that did not have encoding conditions manipulated but rather were presented according to standard Virtual Week procedures: regular event based, regular time based, and time-check. These data are reported in Table 2 and were analyzed with a 2×3 mixed-design analysis of variance (ANOVA) with the between-groups variable, age group, and the within-group variable, PM task. There was a main effect of age group, $F(1, 248) = 160.22$, $p < .001$, $\eta_p^2 = .39$, and PM task, $F(2, 496) = 383.90$, $p < .001$, $\eta_p^2 = .61$, but no interaction, $F(2, 496) = 1.82$, $p = .163$, $\eta_p^2 < .01$. The young adults ($M = 0.66$, $SD = 0.30$) outperformed the older adults ($M = 0.37$, $SD = 0.32$) consistently across the three types of tasks. All participants performed better on regular event-based tasks ($M = 0.74$, $SD = 0.29$) than on regular time-based tasks ($M = 0.56$,

SD = 0.31) and in turn were better on both of these than on time-check tasks (M = 0.26, SD = 0.23).

Irregular Tasks

The primary analyses of interest concerned performance on PM tasks where the encoding conditions were manipulated, that is, irregular event- and time-based PM tasks. Figure 3 shows the mean proportion of correct responses for these tasks as a function of *age group* (young, older) and *encoding condition* (Statement Only, Imagine in Game, Statement and Imagine Combined, Imagine in Daily Life, Control). These data were analyzed with separate 2 × 5 between-groups ANOVAs for event- and time-based PM tasks.

On the event-based tasks, there were main effects of age group, $F(1, 240) = 70.06$, $p < .001$, $\eta_p^2 = .23$, and encoding condition, $F(4, 240) = 3.36$, $p = .011$, $\eta_p^2 = .05$. There was also an interaction between age group and encoding condition, $F(4, 240) = 5.63$, $p < .001$, $\eta_p^2 = .09$.

Formal analysis of this interaction using tests of simple effects revealed a simple main effect of encoding condition for older adults, $F(4, 240) = 8.75$, $p < .001$, $\eta_p^2 = .13$, but not young adults, $F(4, 240) = 0.24$, $p = .917$, $\eta_p^2 < .01$. We followed up this main effect for the older adult group with five planned independent samples t tests, applying a Bonferroni-corrected p value of .01. We also calculated effect sizes (Cohen's d) for each contrast: 0.2 is conventionally regarded as a small effect, 0.5 as a moderate-sized effect, and 0.8 as a large-sized effect.

Relative to the Control condition, older adults' performance did not differ in either the Imagine in Daily Life condition, $t(48) = 0.06$, $p = .953$, $d = 0.02$, or the Imagine in Game condition, $t(48) = 1.32$, $p = .195$, $d = 0.37$. These findings indicate that, in isolation, neither type of imagery strategy led to improvements in older adults' performance. In contrast, relative to the Control condition, there was a trend for older adults to perform better in the Statement Only condition, $t(48) = 2.55$, $p = .014$, $d = 0.77$, consistent with broader literature showing that use of the standard implementation intentions statement benefits older adults. However, the contrast involving the Control condition with the Statement and Imagine Combined condition was not only significant but large in magnitude, with older adults performing substantially better in this latter condition, $t(48) = 3.30$, $p = .002$, $d = 0.93$. Performance in the Statement and Imagine Combined condition did not differ significantly from the Statement Only condition, $t(48) = 1.15$, $p = .255$, $d = 0.33$.

However, further follow-up analysis of the interaction between age group and encoding condition revealed that only for the Statement and Imagine Combined condition was there no simple main effect of age group, $F(1, 240) = 0.67$, $p = .413$, $\eta_p^2 < .01$. By contrast, a simple main effect of age group was seen for the Control condition, $F(1, 240) = 39.21$, $p < .001$, $\eta_p^2 = .14$; Imagine in Daily Life condition, $F(1, 240) = 32.78$, $p < .001$, $\eta_p^2 = .12$; and Imagine in Game condition, $F(1, 240) = 16.51$, $p < .001$, $\eta_p^2 = .06$, and a nonsignificant trend was identified for the Statement Only condition, $F(1, 240) = 3.41$, $p = .066$, $\eta_p^2 = .01$.

For time-based PM tasks, encoding condition did not affect performance. There was neither a main effect of encoding condition, $F(4, 240) = 0.97$, $p = .424$, $\eta_p^2 = .02$[2], nor any interaction

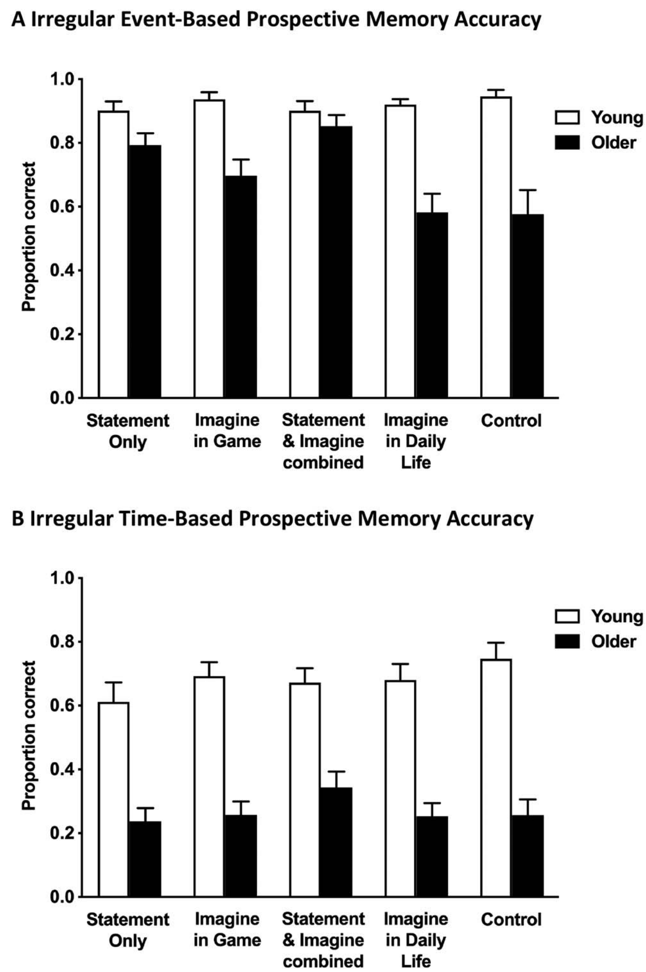

Figure 3. Younger and older adults' proportion of correct responses on the irregular prospective memory tasks for the five different encoding conditions (Statement Only, Imagine in Game, Statement and Imagine Combined, Imagine in Daily Life, Control). Data are reported separately for event-based cues (A) and time-based cues (B). Error bars depict standard error of the mean. See the online article for the color version of this figure.

Table 2
Descriptive Statistics for Younger and Older Adults' Performance on the Virtual Week Prospective Memory (PM) Tasks That Did Not Have Encoding Conditions Manipulated

	Young adults		Older adults	
Measure	M	SD	M	SD
Regular event-based PM	0.87	0.19	0.61	0.30
Regular time-based PM	0.72	0.26	0.39	0.28
Regular time-check PM	0.39	0.21	0.12	0.16

Note. PM = prospective memory.

[2] Although there was no significant effect of encoding condition for time-based PM tasks, on the recommendation of a reviewer, we tested all specific contrasts using a series of independent samples t tests. Collapsed across age group, these revealed that, relative to the control condition, none of the encoding conditions led to any significant improvement in time-based PM (all ts ≤ 1.15, all dfs = 98, all ps ≥ .252).

with age group, $F(4, 240) = 0.86$, $p = .490$, $\eta_p^2 = .01$. There was a main effect of age group, $F(1, 240) = 187.57$, $p < .001$, $\eta_p^2 = .44$, because the young ($M = 0.68$, $SD = 0.25$) substantially outperformed older adults ($M = 0.27$, $SD = 0.22$).

Retrospective Memory for the PM Tasks

After completing Virtual Week, participants were asked to try and recall the content of the PM tasks. Figure 4 shows the mean proportion of correctly recalled irregular tasks as a function of *age group* (young, older) and *encoding condition* (Statement Only, Imagine in Game, Statement and Imagine Combined, Imagine in Daily Life, Control). As part of this assessment, we also quantified participants' ability to recall the regular PM tasks. Young and older adults both performed at a high, almost identical level (young: $M = 0.76$, $SD = 0.42$; older: $M = 0.75$, $SD = 0.38$).

As with PM accuracy, these data were analyzed in separate age group (2) × encoding condition (5) between-groups ANOVAs for event- and time-based irregular PM tasks. On the event-based irregular PM tasks, there was a main effect of age group, $F(1, 240) = 74.27$, $p < .001$, $\eta_p^2 = .24$, but there was neither a main effect of encoding condition, $F(4, 240) = 1.79$, $p = .131$, $\eta_p^2 = .03$, nor an interaction effect, $F(4, 240) = 0.72$, $p = .583$, $\eta_p^2 = .01$. Young adults ($M = 0.56$, $SD = 0.22$) recalled more of the irregular event-based task content than older adults ($M = 0.31$, $SD = 0.23$). On the time-based irregular PM tasks, there was a main effect of age, $F(1, 240) = 156.62$, $p < .001$, $\eta_p^2 = .40$, but there was neither a main effect of encoding condition, $F(4, 240) = 0.24$, $p = .91$, $\eta_p^2 < .01$, nor an interaction effect, $F(4, 240) = 2.04$, $p = .089$, $\eta_p^2 = .03$. Younger adults ($M = 0.48$, $SD = 0.21$) recalled more of the irregular time-based task content than older adults ($M = 0.18$, $SD = 0.15$).

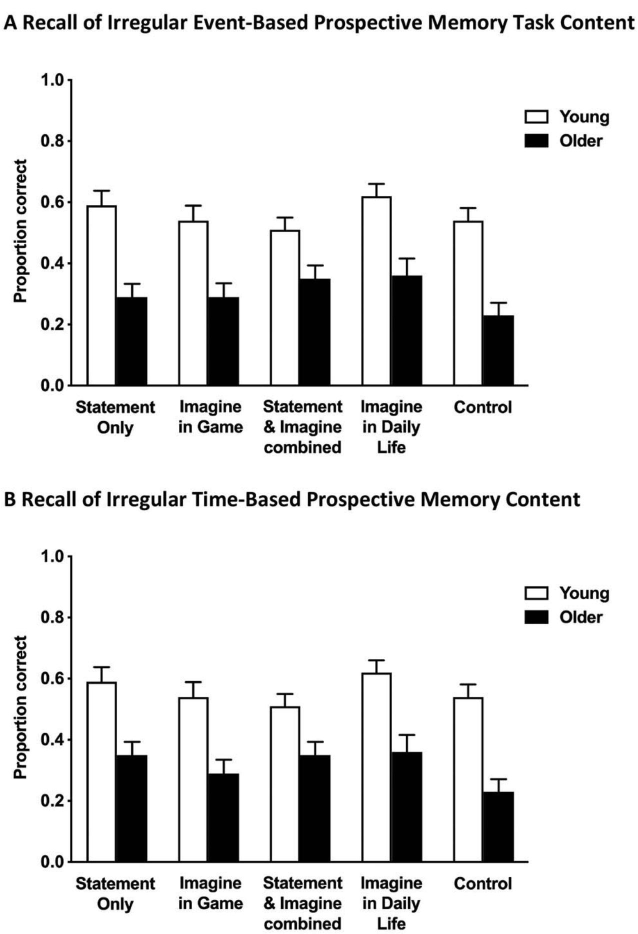

Figure 4. Younger and older adults' recall (retrospective memory) of the irregular prospective memory task content after completing Virtual Week for the five different encoding conditions (Statement Only, Imagine in Game, Statement and Imagine Combined, Imagine in Daily Life, Control). Data are reported separately for event-based cues (A) and time-based cues (B). Error bars depict standard error of the mean. See the online article for the color version of this figure.

Discussion

These data provide a clearer and more nuanced understanding of the circumstances in which implementation intentions function as an effective mnemonic to reduce PM age effects. First, and consistent with considerable prior literature, the results show that substantial age-related PM difficulties were evident when a standard version of Virtual Week was used, but these age effects were substantially reduced for event-based PM following use of the implementation intentions encoding strategy. However, the most important finding was that the greatest reduction in age effects emerged when participants combined this encoding statement with a mental visualization strategy that involved forming a mental representation of carrying out the task.

Contrary to our original predictions, these data therefore suggest that rehearsing the implementations intention in the specific statement format combined with visualizing may be optimally effective for reducing age differences in PM function, consistent with there being an additive effect of these two strategies. This is an interesting finding, particularly in light of broader literature showing that older adults exhibit difficulties engaging in many different types of mental simulation processes relative to young adults. While these age-related difficulties appear to be greatest for tasks that invoke the need for autoneoetic consciousness (Addis et al., 2010; Lyons et al., 2014), difficulties are also evident for tasks that are similar to the present study, in that they emphasize image generation in the current, relevant context (Rendell et al., 2012). The current data cannot speak to whether there were any age differences in how easily participants were able to engage in mental visualization or in the clarity of the images generated across the different mental imagery conditions. However, they do show that, when asked to apply simple, clearly specified visualization strategies in combination with an implementation intentions statement, older adults may benefit.

As noted earlier, a central tenet of Martiny-Huenger et al.'s (2017) model is that conscious thought alone is sufficient to create a direct perception–action link via the elicitation of sensorimotor simulations. The current findings are consistent with the possibility that use of additional strategies could influence the development of this link. For instance, visual imagery may lead to the induction of stronger, more extensive, and/or more sustained activity patterns reenacting the event in the sensory and motor areas of the brain. However, it is also possible that the additive effects reflect an entirely different process. For instance, as noted previously, visual imagery could hypothetically increase the salience of the retrieval cues that signal the PM task needs to be performed. A third possibility might be that the combined condition functioned to enhance retrospective recall of the to-be-remembered events.

We would cautiously suggest that the current data are most consistent with the former of these potential explanations. This is because, first, there were no beneficial effects for either of the two visual imagery conditions when presented in isolation of the implementation intentions statement. Whether participants visually imagined the to-be-remembered task in the context of the PM task itself or in the context of their everyday lives, age-related deficits in PM remained. This speaks against a specific effect of mental visualization in enhancing PM but rather more toward an additive effect when combined with the implementation intentions statement.

It also seems unlikely that the effects were attributable to enhanced retrospective recall of the to-be-remembered tasks. This is because there was no interaction between age group and encoding condition for retrospective recall of the irregular tasks and consequently no evidence that retrospective memory was better in the encoding conditions relative to the control condition. This said, there is an important caveat to this conclusion. Our method of assessing retrospective recall of the PM tasks was to ask participants to remember all 20 of the to-be-remembered tasks upon the conclusion of the Virtual Week game (16 of which were irregular). This represented a challenging task—as was evident by the fact that accuracy levels for the free recall of irregular tasks were relatively low for both age groups. However, because each of the 4 days of Virtual Week involved presentation of four different irregular PM tasks to complete, there was no requirement for participants to continue remembering previously presented irregular tasks. Indeed, a potentially adaptive strategy would be to try not to retain memory of earlier irregular tasks across successive days, to allow for stronger encoding of each set of four newly presented irregular tasks. Thus, although assessing participants' free recall upon completion of the task has the advantage of being optimally sensitive to age effects, it does not speak to whether participants remembered relevant irregular PM tasks at the time they needed to complete these tasks in the context of the Virtual Week game. To provide a stronger test of whether the benefits of the implementation intentions statement and mental visualization condition seen in the present study were attributable to improved retrospective memory of the to-be-remembered PM tasks, future studies are needed that assess retrospective recall immediately at the end of each Virtual Day.

Nevertheless, regardless of the mechanism(s) by which mental visualization may potentially enhance the effects of implementation intention on older adults' PM, the current findings have practical implications. Specifically, they indicate that asking older adults to apply very simple, clearly specified visualization strategies alongside implementation intentions may be a valuable strategy for reducing age-related difficulties in PM.

However, the final key finding to emerge in this study also indicates that such interventions may need to be restricted to tasks that involve event- and not time-based cues. This is because, as predicted, only for the former type of cue did benefits of implementation intentions (both alone and in combination with visualization) emerge. As noted, this finding was anticipated because a central tenet of Martiny-Huenger et al.'s (2017) model is that implementation intentions facilitate PM via the creation of a direct perception–action link. In the current study, only for event-based cues was it easy to create such a link, as only for this type of cue was noticing an event critical to performing the PM task (for time-based tasks, monitoring time is instead more likely to be the key determinant of performance).

Demonstrating the limits and modifiers of implementation intentions' mnemonic effect is interesting, not only for theoretical reasons but also because it provides novel evidence-based information that pinpoints the specific circumstances in which older adults should be encouraged to use this encoding strategy to enhance PM. In light of the rapidly aging demographic, there is a growing need to identify effective ways to optimize older adults' autonomy. Remembering to pay an electricity bill, take medication, or turn off household appliances are all real-world PM tasks that highlight the critical role that PM plays in the maintenance of functional independence. Indeed, in everyday life, older adults are acutely aware of PM failures, and these errors tend to dominate self-reported memory failures in daily life (Smith, Del Sala, Logie, & Maylor, 2000). The need for a better understanding of how to optimize PM function in older age is therefore a question of considerable applied importance. The current data point to a potential disconnect between implementation intentions' ability to reduce age effects for event- and time-based PM tasks. In particular, they suggest that while this approach may have considerable benefit for the former, this may not be true for the latter.

However, there is a caveat to this conclusion. In the present study, we applied encoding manipulations to only one of two key types of time-based PM. In the interim since this study was completed, we have identified an important distinction between *time-of-day* and *time-interval* tasks, which may be of similar importance to the distinction frequently made within event-based tasks between cues that are *focal* or *nonfocal* to the ongoing task (Haines et al., 2020). This is because *time-of-day* tasks—such as phoning the doctor at 1 p.m.—lend themselves to being associated with a constellation of environmental cues (known as *conjunction cues*), which might be expected to occur in the relevant window of time, and support the creation of a direct perception–action link. In contrast, *time-interval* tasks—such as returning a phone call in 10 min—offer relatively few or no time-relevant environmental cues to support the creation of this link. This distinction between time-interval and time-of-day tasks is a critical determinant of the magnitude and even direction of age effects in PM (Haines et al., 2020).

Although Virtual Week distinguishes between these two types of time-based tasks, in the present study, the manipulation of encoding strategies was restricted to time-of-day tasks. This was because, while half of the time-of-day tasks are regular and the other half irregular, all of the time-interval tasks are regular. Consequently, our conclusions from this particular study (that implementation intentions may not enhance time-based PM) need to be qualified to refer only to *time-of-day* time-based tasks. However, because relative to time-of-day tasks, time-interval tasks have fewer environmental cues to support the creation of a direct perception–action link, these should theoretically be even less likely to benefit from the use of these strategies. Potentially more beneficial for enhancing time-of-day time-based PM may be interventions that focus on improving strategic use of time monitoring, a capacity that appears to decline in late adulthood (Vanneste, Baudouin, Bouazzaoui, & Taconnat, 2016).

Finally, it is important to acknowledge that younger adults generally performed very well on the event-based PM tasks, and this was true regardless of whether they completed an encoding condition or the Control (standard) condition. Consequently, the main determinant of whether age effects emerged in the present study was variability in older adults' performance. Thus, although the current study shows that age effects are reduced by implementation intentions, particularly when combined with visualization, the next step in this literature is use of a more difficult, demanding PM measure that manipulates access to these encoding strategies. This would allow a stronger test of whether age parity can be achieved by using an implementation intention encoding strategy in combination with visualization.

To conclude, these data align with a broader literature showing that implementation intentions are an effective strategy for enhancing PM. The benefits of this strategy have been demonstrated in numerous health-related activities involving PM, including breast self-examination (Luszczynska & Schwarzer, 2003; Orbell, Hodgkins, & Sheeran, 1997), regular intake of vitamin supplements (Sheeran & Orbell, 1999), physical exercise (Milne, Orbell, & Sheeran, 2002; Sniehotta, Scholz, & Schwarzer, 2005), blood glucose monitoring (Liu & Park, 2004), and eating healthy foods (Verplanken & Faes, 1999). The current study both supports and adds to prior literature focused on use of this strategy for older adults. It aligns with prior studies, which have shown that implementation intentions enhance older adults' prospective cognition, but also adds by identifying some of the key limits and modifiers of this effect. Specifically, these data suggest that implementation intentions may be particularly beneficial for tasks that involve event-based cues and point to the potential value of including a visualization strategy to reduce age effects.

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