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Age and Individual Differences in Prospective Memory During a "Virtual Week": The Roles of Working Memory, Vigilance, Task Regularity, and Cue Focality

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Young (ages 18–22 years) and older (ages 61–87 years) adults ($N = 106$) played the Virtual Week board game, which involves simulating common prospective memory (PM) tasks of everyday life (e.g., taking medication), and performed working memory (WM) and vigilance tasks. The Virtual Week game includes regular (repeated) and irregular (nonrepeated) PM tasks with cues that are either more or less focal to other ongoing activities. Age differences in PM were reduced for repeated tasks, and performance improved over the course of the week, suggesting retrieval was more spontaneous or habitual. Correlations with WM within each age group were reduced for PM tasks that had more regular or focal cues. WM (but not vigilance) ability was a strong predictor of irregular PM tasks with less focal cues. Taken together, these results support the hypothesis that habitual and focally cued PM tasks are less demanding of attentional resources (specifically, WM), whereas tasks that are more demanding of controlled attentional processes produce larger age differences, which may be attributable to individual differences in WM.

Keywords: prospective memory, working memory, vigilance, age, Virtual Week

Prospective memory (PM) ability, reflected by tasks such as remembering to take one's medication at the right time, is essential for successfully navigating the demands of everyday life. Studying the effects of age on PM performance in adulthood is important because PM failures can have severe consequences for one's ability to perform activities of daily living (e.g., forgetting to take one's medication or forgetting to turn off an appliance). The extant literature regarding the effect of aging on PM has revealed an interesting and complex pattern of results. Young adults tend to outperform older adults, particularly on PM tasks with high levels of controlled strategic demands, whereas age differences tend to be reduced when the demands on self-initiated retrieval are minimized (for reviews, see Henry, MacLeod, Phillips, & Crawford, 2004; Kliegel, Jäger, & Phillips, 2008; McDaniel & Einstein, 2007). For example, age differences tend to be reduced for the performance of both regular (habitual) PM tasks, such as simulating the performance of medical tasks in the laboratory during a "Virtual Week" (Rendell & Craik, 2000), and PM tasks with focal cues (Kliegel et al., 2008; McDaniel, Einstein, & Rendell, 2008; Reese & Cherry, 2002; Rendell, McDaniel, Forbes, & Einstein, 2007). In regular PM tasks, the cues are presented in a consistent routine (e.g., take medication every day at breakfast), and therefore, the preceding situational cues might provide a richer, more extensive set of cues for triggering retrieval (cf. Kvavilashvili & Fisher, 2007). With regards to cue focality, PM task cues are more focal when the ongoing task involves processing the defining features of the PM cues than when ongoing task processing is more peripheral. For example, during a word/nonword decision task, remembering to press the *q* key when the word "tortoise" is presented involves more focal processing of the PM cue than when the cue is the appearance of the syllable "tor" because the information extracted in the service of the ongoing task primarily involves words—not syllables (see Einstein et al., 2005). That both task regularity and cue focality tend to reduce age-related differences in PM is consistent with the hypothesis that PM cues that occur more regularly or are more focally processed may be more likely to spontaneously trigger intention retrieval, whereas tasks that are irregular or involve less focal processing may be more likely to involve strategic monitoring (Henry et al., 2004; Kliegel et al., 2008; McDaniel & Einstein, 2007).

Monitoring and Spontaneous Retrieval

The multiprocess theory of PM (McDaniel & Einstein, 2000, 2007) suggests that there are two approaches to successfully remembering to perform intended actions at the appropriate moment: relying on one's

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intentions being *spontaneously retrieved* at the appropriate moment (e.g., Kvavilashvili & Mandler, 2004; McDaniel & Einstein, 2000, 2007), or *monitoring* the environment for a cue that signals when the performance of the task is appropriate (Smith, 2003). For example, if an individual is to remember to take a medication at breakfast, the intention may spontaneously "pop" into mind while he or she is eating breakfast. The spontaneous retrieval of an intention is thought to occur rather automatically, without any self-initiation or deployment of controlled strategic resources (Brandimonte, Ferrante, Feresin, & Delbello, 2001; Einstein et al., 2005).

Alternatively, one could consistently monitor or ask one's self, "Is it breakfast time"? This monitoring approach would likely ensure successful PM performance; however, constantly monitoring the environment for cues that signal the time to perform an intended act is much more demanding of controlled attentional resources (Smith, 2003; Smith & Bayen, 2004). What might these attentional "resources" be? The controlled and sustained attentional processes involved in working memory and vigilance tasks are thought to be involved in monitoring for PM intentions (Brandimonte et al., 2001; Braver & West, 2008; Graf & Uttl, 2001; McDaniel & Einstein, 2007; Smith, 2003; Smith & Bayen, 2004; Winograd, 1988; Zeintl, Kliegel, & Hofer, 2007).

Working Memory, Vigilance, and Prospective Memory

Working memory (WM) ability is likely to be a key contributor to PM performance due to its role in several phases of PM. For example, WM is likely to be involved in the planning of an intended action as well as in the temporary maintenance of intentions while attention is switched between the simultaneous engagement of other ongoing tasks (Kliegel, Martin, McDaniel, & Einstein, 2002; McDaniel & Einstein, 2007; Smith, 2003; Zeintl et al., 2007). Maintaining representations in the face of distraction or interference from other ongoing activities depends on WM, and the number of representations that can be simultaneously maintained in WM is limited (Engle, Tuholski, Laughlin, & Conway, 1999; Kane, Conway, Hambrick, & Engle, 2007). Thus, situations that require juggling a set of task goals in WM may involve the same type of attentional control as PM tasks, as they are conceptualized by the typical laboratory dual-task paradigm (Ellis, 1996; Kvavilashvili & Ellis, 1996). However, because PM tasks may vary in the extent to which participants engage in strategic monitoring (as previously noted), certain situations may be more demanding of the type of attentional control captured by WM tasks than others. We directly examined this possibility in the present study.

The multiprocess framework (McDaniel & Einstein, 2000, 2007), suggests that older adults' difficulties with PM tasks should be particularly robust when WM demands are high, whereas their task performance should improve when the demands placed on WM are reduced. For example, tasks that are repeatedly or habitually performed should place fewer demands on WM because performance of such tasks should involve more spontaneous retrieval. In contrast, in order to remember to perform more irregular, nonrepeated tasks, participants are more likely to employ a monitoring strategy, thereby placing greater demands on WM.

Also of interest is the idea that if an intention is maintained in conscious awareness until it can be performed, as in the repetitive, uninterrupted performance of a task, the processes involved capture one's vigilance ability (Brandimonte et al., 2001; Graf & Uttl, 2001). Accordingly, one's ability to sustain attention throughout a task might play an important role in types of PM. However, a potentially critical difference with vigilance tasks is that they typically require maintenance of only a single goal, whereas WM and PM tasks require alternating between the performance of two tasks.

Therefore, WM and vigilance are different types of attentional "resources" that may underlie PM performance, especially in monitoring intensive PM tasks.[1] Age-related declines in WM are well established (e.g., Bopp & Verhaeghen, 2005; Park et al., 2002; Rose, Myerson, Sommers, & Hale, 2009; Salthouse, 1994), and vigilance ability is known to decline with age as well (Giambra & Quilter, 1988; Surwillo & Quilter, 1964). Therefore, it is possible that the age-related differences in certain types of PM are mediated by WM, by vigilance abilities, or by both. The present study was designed to test these hypotheses.

Thus far, there have been no studies (with either young or older adults) conducted to directly test predictions about the role of different types of attentional resources in different types of PM tasks (e.g., tasks differing along the dimensions of regularity and cue focality). In the sole empirical study in which the distinction between vigilance and PM processes was examined participants were instructed and trained to treat a typical dual-task PM paradigm as either a vigilance task or a PM task. Vigilance instructions led to a reduced number of PM errors but significant costs to ongoing task performance, whereas PM instructions did not. The authors concluded that "prospective memory and vigilance differ as to the degree of conscious monitoring that they require, with prospective memory being based more on automatic retrieval of the cue–action association and vigilance being based more on active search for the target" (Brandimonte et al., 2001, p. 97). Moreover, the strategies participants report using for PM tasks suggest that people do not believe it is necessary to sustain vigilance to support typical prospective remembering (cf. Einstein & McDaniel, 2007). On the basis of these initial findings, one might expect the *sustained* attentional processes captured by vigilance tasks to be associated modestly, if at all, with PM performance.

In contrast, *controlled* attentional processes involved in WM tasks that require encoding to-be-remembered stimuli, switching attention to ongoing secondary tasks, and retrieving stimuli at the appropriate moment might be more strongly related to certain types of PM performance. Yet, the few studies in which the relationship between WM and PM has been examined have produced an inconsistent pattern of results. On the positive side, Cherry and LeCompte (1999) using multiple regression models found that measures of WM accounted for a significant portion of age-related differences in PM. Other researchers have also found that the amount of variance in PM attributable to age was significantly reduced after controlling for individuals' WM ability, and in some cases, WM completely mediated the age effect (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000, Experiments 1 and 2; West & Craik, 2001, Experiment 1).

In a direct manipulation of the WM demands required by a PM task, Kidder, Park, Hertzog, and Morrell (1997) and Park, Hertzog, Kidder, Morrell, and Mayhorn (1997) embedded a PM task in a WM

[1] In the classic sense of endogenous and exogenous attention (Posner & Peterson, 1990), both vigilance and WM involve controlled attentional processes. In the present context, sustaining attention for the performance of a single task set is presented as a measure of an individual's vigilance ability, whereas controlling attention by switching between performance of both processing and storage tasks may be seen as capturing WM ability.

paradigm and found that PM performance was reduced as WM load increased, and this effect was exaggerated for older adults. In addition, two measures of WM tended to be significantly correlated with PM performance for the older adults; however, the correlations were nonsignificant for the young adults.

Although a number of studies have failed to show reliable associations between WM and PM (Brandimonte & Passolunghi, 1994; Breneiser & McDaniel, 2006; Einstein et al., 2000, Experiment 3; Maylor, 1990; West & Craik, 2001, Experiment 2), the lack of a correlation may be due to several reasons. As Kidder et al. (1997) noted, WM may fail to correlate with PM performance because of restricted ranges in performance (as was the case for their young adults whose PM performance typically exceeded 90%). Another reason may be the wide variety of tasks that have been used to measure WM. Not all measures may be particularly sensitive for assessment of those aspects of WM that are relevant for PM (e.g., attentional control). Perhaps even more important, PM paradigms vary greatly in terms of several critical features that affect the extent to which attentional control is required for monitoring.

In addition, the reliability and sensitivity of the measures used to reflect the constructs of interest are critical for investigations of the role of age and individual differences. One potential problem regarding the measurement of PM is that the typical paradigm includes very few observations of PM target events and, as a consequence, frequently yields low estimates of reliability (Kelemen, Weinberg, Alford, Mulvey, & Kaeochinda, 2006). Thus, one source for the mixed results regarding the relationship between WM and PM may be due to a problem with measurement reliability. Indeed, in some of the studies that have failed to show reliable correlations, a relatively small number of target observations were used, and their findings must be interpreted with caution (as noted by Breneiser & McDaniel, 2006).

In the present study, we attempted to remedy the shortcomings of previous attempts to examine the relationship between WM and PM by using a standard measure of WM (i.e., operation span) and a PM paradigm, the Virtual Week game, which we anticipated would have sufficient reliability (see next section). We also included a measure of vigilance in an attempt to separate the independent contributions of WM and vigilance in PM. In addition to assessing the extent to which WM and vigilance mediate PM performance in general, we sought converging evidence regarding their relationships. To this end, we examined the pattern of associations for the different types of PM tasks embedded in the Virtual Week game, which varied in features hypothesized to reduce monitoring demands: task regularity and cue focality.

The Virtual Week Game

In the Virtual Week board game (see Rendell & Craik, 2000), participants simulate going through the course of a day for 5 consecutive days. Along the way, participants have to remember to "perform" various PM tasks at certain points in time or in relation to certain events that take place during each day. A primary manipulation in the Virtual Week game is the regularity of the PM task: some of the PM tasks are repeatedly performed over the course of the "week," whereas others are not. We also attempted to assess the effects of cue focality by comparing performance on tasks with cues that were potentially more or less focal with other ongoing activities during the game. That is, during the performance of the game, PM tasks had signaling cues that presumably involved either a high or low degree of overlap with the processing involved in the game. A more detailed description of how these factors were operationalized is in the Methods section.

The Virtual Week game is also a potentially reliable index of PM because it incorporates 50 PM task observations over 5 virtual "days." Preliminary reliability findings with a shortened version of Virtual Week (3 virtual days) have been promising, with split-half reliabilities between .74 and .66 (Henry, Rendell, Kliegel, & Altgassen, 2007). Therefore, the Virtual Week game is ideally suited for assessing the role of individual differences in PM and potential mediators of age and individual differences.

To recapitulate, the primary question under consideration in the present study was whether attentional resources such as WM and vigilance mediate PM performance. We expected WM to be especially predictive of PM, particularly for the tasks that theoretically are more demanding of monitoring (e.g., irregular tasks with less focal cues).

Method

Participants

Data were available for a total of 106 young and older adult participants for the present study. See Table 1 for characteristics of the participants. The young adult participants were undergraduate students from Washington University in St. Louis who participated in exchange for course credit. The older adult participants were volunteers from the community who received a $10-per-hour remuneration for participation. The older adults were screened for visual acuity, the presence of neuropsychological trauma, use of psychoactive medication, and dementia with the Mini Mental Status Exam (MMSE; Folstein, Folstein, & McHugh, 1975). Older adults who scored below 27 on the MMSE were excluded from participation. The older adults reported more years of education and obtained higher vocabulary scores than the young adults.

Data were unavailable for the vigilance and WM task for three older adult participants because they did not return for their second session and for three young adult participants because either time ran out for their session (one participant), they did not follow directions (one participant), or they were an outlier (one participant for each task with scores greater than 3 standard deviations [*SD*s] from the mean). Data for one young adult was removed for the irregular less-focal tasks because the participant's score (0% correct) was greater than 3 *SD*s from the mean of the group and greater than 3 *SD*s from the

Table 1
Characteristics of Participants

Variable	Young adults (n = 61)	Older adults (n = 45)
Mean age (range)	19.3 (18–22)	73.3 (61–87)
Mean MMSE score	*NA*	28.8
Male:female ratio	27:34	13:32
Mean education (years)	13.4	14.8**
Mean Mill Hill Vocabulary Scale score	15.2	16.0*
Mean self rated health	4.4	4.3

Note. Self-rated health responses varied from 1 (*poor*) to 5 (*excellent*). MMSE = Mini-Mental State Examination (Folstein et al., 1975); Mill Hill Vocabulary Scales (Raven, 2003).
* $p < .05$. ** $p < .01$.

participant's own mean for all other PM tasks, suggesting that the participant did not understand the directions for this type of task.

Tasks

Computerized Virtual Week game. A recently computerized version of the Virtual Week game was used in the present study. We used the default settings of the program that closely followed the board game format of the original version developed by Rendell and Craik (2000; for a review, see Rendell & Henry, 2009). For replication purposes, the Virtual Week program is available upon request.

The object of the game is for each participant to move a token around the board by rolling a die, simulating going through the course of a day. The consecutive hours of the day that people are typically awake are marked on the board, with each circuit simulating a day (see Figure 1 for a diagram of the Virtual Week game as it is displayed on the computer screen).

Participants completed 5 days with 10 PM tasks per day: four regular (repeated), four irregular (nonrepeated), and two time-check tasks. Participants did not have to physically carry out the PM task. They were to use the mouse to click on a "Perform Task" button and select the appropriate task from a list of PM tasks and distractors (whereas, in the original version, participants were to state each PM task at the set moment to an experimenter).

After completing the practice day (before starting the first test day), participants were informed of the regular tasks and the time-check tasks that were to be performed on each day of the week. The regular tasks were (a) "take antibiotic at breakfast and dinner events" and (b) "take asthma medication when your token lands on or passes the 11 a.m. square and 9 p.m. square." The two time-check tasks were to take a lung capacity test when the stop clock displayed 2 min and 15 s (i.e., 2.15) and 4 min and 30 s (i.e., 4.30) after the start of each day. The stop clock was displayed in the center of the board in the information box and began counting from zero in seconds at the start of each day. Responses for the time-check tasks were considered "on time" if they were recorded within 15 s of the target time. Responses for the regular and irregular tasks were considered "on time" if they were recorded at the set moment, before the participant rolled the die to continue the game. All participants were required to learn the regular and time-check tasks to criterion (i.e., 100%) by completing a recall test three times, with feedback provided following each test.

At the start of each day, each participant was required to click on the "Start Card" button. The start cards indicated the day of the week and two of the irregular PM tasks that were to be performed during that day, and that day only. For example, on the Monday Start Card, the two tasks were "drop off dry cleaning when you go shopping" and "phone the bank at 12 noon to arrange an appointment." Each of the other two irregular tasks to be performed on that day was described on one of the event cards as the participant progressed through the day. For example, one event card read, "Your neighbor Brian drops by and asks if you could return a book for him when you go to the library today. In the meantime, do you and Brian: (a) have a coffee, (b) have a cool drink, or (c) not stop for a drink?" Then, later in the afternoon of that same day, an event card informed the participant that he or she would stop by the library to do some work. Upon reading this event card, the participant was to remember to return Brian's book by selecting that item from the perform task list.

Participants were cued for the regular and irregular PM tasks by either reading an event card that described a particular activity or

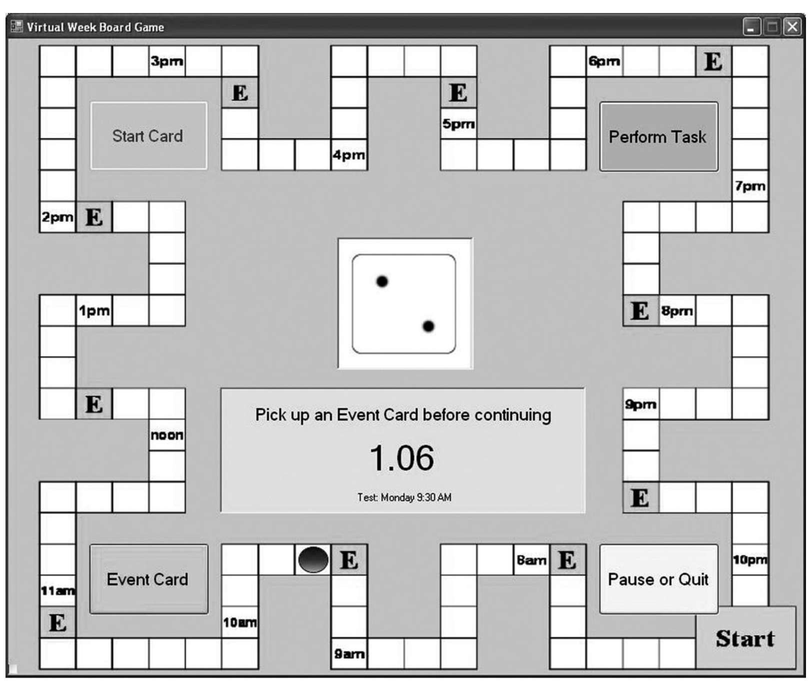

Figure 1. Computer screen display of the computerized Virtual Week game. Event Card squares are marked with an "E." Each hour of the day is represented on squares of the board (e.g., 8am, noon). The day and the specific time of the square that the token is currently on (i.e., Monday 9:30 am) are displayed in the center of the board in the information box, as is the stop clock time (i.e., 1.06).

by passing one's token across a particular time square on the board.[2] The distinction between whether a task was cued by reading an event card or passing a time square was critical in that they differed in the extent that focal processing was involved. That is, tasks with event-card cues involved processing that was *more* focal to the other ongoing activities of the game (i.e., reading event cards and pretending to be engaged in the events that were described on the cards). Therefore, reading an event description (e.g., "breakfast") should have provided focal processing of the PM cue, which may have helped to trigger retrieval of the intention ("take medication with breakfast"). By contrast, tasks with time-square cues involved *less* focal processing because attending to the time of day on the square that one's token passed was not critical to the ongoing activities of the game. Less focal cues are more likely to require monitoring processes for successful PM (Einstein et al., 2005). Therefore, we hypothesized that the relationship between WM and PM would be robust for irregular, nonrepetitive tasks, particularly when cues were less focal to the rest of the game. It is important to note, however, that in the present context cue focality is more a matter of degree than an absolute distinction as in previous studies (Einstein et al., 2005).

Operation span task. The WM task used was a standard measure of WM capacity: the operation span task (Conway et al., 2005; Turner & Engle, 1989). The operation span task, like PM tasks, is a dual-task situation. Participants must alternate between solving math problems and encoding to-be-remembered letters. After a series of math problems were performed and letters were presented (between two and six sets), the participant was to recall the letters in the order presented by clicking on the appropriate letters with the mouse. Three trials of each list length were performed, and list length was varied randomly. We scored performance by summing the number of items from correct trials.

Psychomotor vigilance task (PVT). In addition to the WM and PM tasks, participants also completed the PVT task (Loh, LaMond, Dorrian, Roach, & Dawson, 2004) because vigilance is another attentional control ability that has been implicated in PM performance (Brandimonte et al., 2001; Graf & Uttl, 2001) and is known to decline with age (Giambra & Quilter, 1988; Surwillo & Quilter, 1964). The PVT is a simple reaction time test that requires monitoring a timer, represented by a string of numbers in the center of the computer screen. Participants were instructed to click the mouse button as fast as possible when the timer started counting up in numerical order by the millisecond. The amount of time between each start of the timer ranged from 3,000 and 7,000 ms in steps of 500 ms. This variable intertrial interval ensured that constant monitoring was required, and a routine pattern of responding could not be developed. Trials with a response less than 200 ms or greater than 1,000 ms were removed, resulting in a loss of 0.02% of the data. We obtained a participant's PVT score by averaging his or her trimmed reaction time data.

Procedure

Participants played the Virtual Week game seated in front of a desktop computer, using the mouse to interact with the software, while moving their game token around an actual board game placed on the desk in front of the monitor. Participants received verbal instructions about how to play the game and completed 1 trial day (one circuit of the board). Then, participants learned of the regular and time-check tasks and recalled them three times.

While moving the token around the board, the participant was required to click on the "Event Card" button to reveal an event card each time the token landed on or passed an event square (labeled *E*). Each card described a specific activity and three options relevant to the activity. The participant was to read the card, select the activity they preferred, and pretend to be engaged in that activity. After the participant selected an option, the event card indicated a number that was to be rolled on the die before the participant could continue on with the day, for example, "roll any number to continue," "roll an even number to continue," or "roll a 6 to continue." The demands of rolling the die, moving the token around the board, and making decisions about the activities to participate in served as the ongoing activity for the Virtual Week game. The PM tasks were embedded within this ongoing activity.

Following the Virtual Week game, participants performed the operation span and PVT tasks. To minimize fatigue, we allowed the older adult group to return to the lab to complete these tasks at a later date, scheduled within 1 week's time.

Results

PM Performance on the Virtual Week Game

Mean proportions correct for regular (repeated) and irregular (nonrepeated) tasks on the Virtual Week game are presented in Table 2. A 2 (age group) × 2 (task type) repeated measures analysis of variance (ANOVA) revealed that, as expected, young adults outperformed older adults overall, $F(1, 104) = 116.82$, $p < .001$, $\eta_p^2 = .53$. The main effect of task type was significant, $F(1, 104) = 85.72$, $p < .001$, $\eta_p^2 = .45$, and age interacted with task type, $F(1, 104) = 25.86$, $p < .001$, $\eta_p^2 = .20$. The interaction was driven by the fact that the mean age difference for the irregular, nonrepeated tasks ($\Delta M = .51$, $\eta_p^2 = .59$) was larger than that for the regular, repeated tasks ($\Delta M = .34$, $\eta_p^2 = .38$). Although the primary focus of the present study did not concern time-based PM, it may be noted that performance on the time-check tasks showed an age-related decrement as well: mean proportion correct was .84 ($SD = .18$) for the young adult group and .44 ($SD = .38$) for the older adult group, $t(104) = 7.36$, $p < .001$. The age difference for irregular tasks was larger than that for the time-check tasks ($\Delta M = .40$, $\eta_p^2 = .34$): the interaction was significant when irregular task performance and time-check performance were compared separately, $F(1, 104) = 5.40$, $p < .05$, reflecting older adults' greater deficit on irregular PM tasks.

Regarding the effect of task regularity, repeatedly performing the same PM task on each day of the Virtual Week was expected to result in performance becoming more habitual and therefore, improving over the course of the Virtual Week. To test this hypothesis, we examined performance on the regular PM tasks for each day of the

[2] Although the latter type of task involved a time square, it did not require monitoring a clock as in typical time-based PM tasks (e.g., Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). Therefore, both types of cues may be conceptualized as event-based PM cues. The original version of the Virtual Week game incorporated tasks with event-card and time-square cues in order to capture differences between event-based and time-based PM (see Rendell & Craik, 2000); however, moving one's token past a time square is indeed an event—not a time cue in the traditional sense. Here we propose that event-card cues and time-square cues may differ in terms of cue focality.

Virtual Week game. The data are presented in Figure 2. A 2 (age group) × 5 (day of the week) ANOVA revealed that as predicted, a significant positive linear trend was observed over the course of the week, $F(1, 104) = 14.84$, $p < .001$, $\eta_p^2 = .13$. This effect marginally interacted with age, $F(1, 104) = 3.32$, $p = .07$. The standardized slopes of the lines in Figure 2 for the young and older adult groups were .95 and .61, respectively. It is important to note that for both groups, performance was better on Friday than on Monday: young, $t(60) = 3.85$, $p < .001$; older, $t(44) = 1.96$, $p = .057$. To test whether this effect could be attributed simply to the participants becoming more practiced with the game in general, we analyzed performance on the irregular (nonrepeated) tasks as a function of day as well. In contrast to regular PM tasks, performance did not improve as a function of day: the linear trend was not significant, $F < 1$.

Therefore, task regularity over the course of the Virtual Week resulted in improved performance; however, age differences were present for each day of the week. In order to ensure that older adults' PM deficit was not due to an inability to remember what the tasks were (i.e., retrospective memory failure), we administered a retrospective memory questionnaire upon participants' completion of the Virtual Week game.[3] On average, retrospective memory accuracy exceeded 96%, suggesting that older adults' PM difficulties with the regular (repeated) tasks were not due to an inability to remember the content of the tasks.

Regarding the effect of cue focality, PM tasks cued with event cards were hypothesized to involve more focal processing than tasks cued by squares on the board game labeled with a particular time, and therefore, we suspected that performance would be better when cued by event cards than by time squares. To test this hypothesis, we compared performance on regular and irregular tasks cued by event cards with performance on regular and irregular tasks cued by time squares. A Cue Type (event card, time square) × Task Regularity (regular, irregular) × Age (young, older) ANOVA revealed that, as predicted, performance was better for tasks with event-card cues, $M = .64$ ($SEM = .02$), than time-square cues, $M = .59$ ($SEM = .02$), $F(1, 104) = 8.99$, $p < .01$, $\eta_p^2 = .08$. This effect did not interact with age ($F < 1$); however, the three-way interaction was significant, $F(1, 104) = 5.04$, $p < .05$, $\eta_p^2 = .05$. The three-way interaction was driven by the fact that cue type had no effect on regular task performance either for young adults (event card = 85% vs. time square = 87%), or older adults (event card = 54% vs. time square = 49%), $F < 1$, but for the irregular tasks, event-card cues tended to improve performance for both young (event card = 85% vs. time square = 73%), $t(60) = 4.4$, $p < .001$, and older (event card = 30% vs. time square = 25%) adults, although the effect did not reach significance for the latter group, $t(44) = 1.4$, $p = .17$.

Table 2
Means and Standard Deviations for Proportion Correct on Prospective Memory Tasks in the Virtual Week Game for Young and Older Adults

Group	Regular (repeated) *M*	Regular (repeated) *SD*	Irregular (nonrepeated) *M*	Irregular (nonrepeated) *SD*
Young adults	.86	.12	.79	.16
Older adults	.52	.31	.28	.27

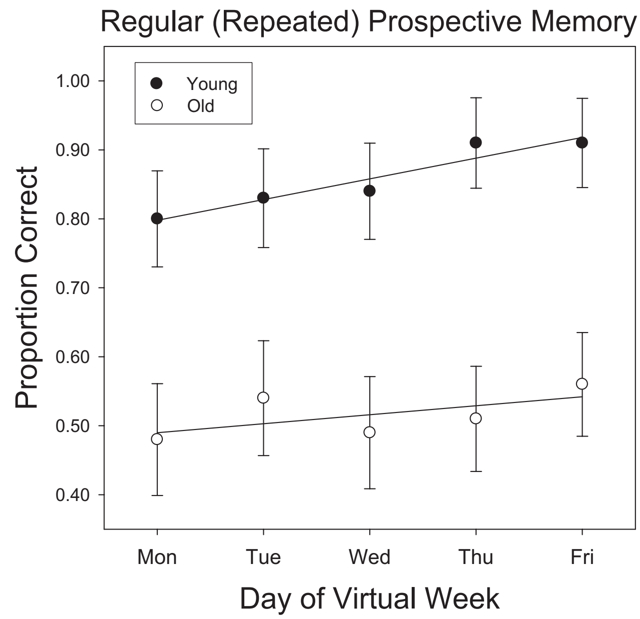

Figure 2. Mean proportion correct for regular (repeated) prospective memory tasks by day of Virtual Week for young and older adults. The standardized slopes of the lines for the young and older adult groups were .95 and .61, respectively. Error bars are 95% confidence intervals.

Predicting PM Performance

In order to assess the relationships among WM, vigilance, and PM performance, we first needed to determine whether the Virtual Week game was a reliable measure of PM. The Spearman–Brown split-half reliability coefficients for the PM measures and the predictor variables for the whole sample are presented on the diagonal of Table 3. The values within each age group separately may be found in the Appendix. These data confirm that the Virtual Week game is a highly reliable PM paradigm, particularly for the older adult group. The predictor variables also demonstrated adequate levels of reliability. Reliable age differences in performance on the predictor variables were observed as well. As expected, young adults outperformed older adults on the operation span task, $M = 60.4$ ($SD = 11.6$) versus 41.3 ($SD = 18.0$), $t(99) = 6.49$, $p < .001$, and on the PVT, $M = 301.8$ ($SD = 34.3$) versus 326.6 ($SD = 37.5$), $t(99) = 3.44$, $p < .01$.

Next, we examined the correlations between WM, vigilance, and PM tasks as a function of task regularity and cue focality within each group, after controlling for age, so as to focus on individual differences over and above differences due to age. If, as predicted by the multiprocess framework, associations between WM and PM are strongest for conditions most demanding of monitoring processes, the strongest correlations should be for tasks that were nonrepeated (irregular tasks) and had less focal cues (time-square cues). The correlations for the young adult group appear below the diagonal in Table 3, whereas those for the older adult group appear above the diagonal. As may be seen, individual differences in WM were predictive of PM for both groups, but only for the tasks hypothesized to place the

[3] The retrospective memory questionnaire, which involved matching each regular PM task with its cue, was included for the final 23 older adults tested.

Table 3
Correlations Among the Prospective Memory, Working Memory, and Vigilance Tasks

Variable	1	2	3	4	5	6
1. Regular PM task/more focal cue	.90	**.57****	**.61****	**.54****	−.07	.18
2. Regular PM task/less focal cue	**.39***	.87	**.54****	**.57****	.10	.29
3. Irregular PM task/more focal cue	**.30**	**.39***	.92	**.52****	−.04	.30
4. Irregular PM task/less focal cue	**.26**	**.54****	**.48****	.87	.19	**.50***
5. Psychomotor vigilance task	**−.41***	**−.27**	−.21	−.22	.97	.01
6. WM task	.17	.15	.16	**.40***	**−.29**	.86

Note. Correlations for the young adult group are below the diagonal. Correlations for the older adult group are above the diagonal. Spearman–Brown split-half reliability coefficients are on the diagonal. PM = prospective memory; WM = working memory. Bolded values < .05.
* $p < .01$. ** $p < .001$.

greatest demands on monitoring processes—irregular, nonrepeated tasks, but only when the cues were less focal ($r = .40$ for the young adults and .50 for the older adults). Task regularity and focal cueing of irregular tasks reduced this association.[4]

As can be seen in Table 3, performance on the regular (repeated) tasks was not significantly correlated with WM in either group. However, when the correlations were assessed for each day of the week, WM was moderately correlated with regular task performance on the first day when the tasks were relatively novel ($r = .22$, $p < .10$, for the young adults, and $r = .31$, $p < .05$, for the older adults), but by the end of the week, the correlations were nonsignificant ($r = .07$ and .15, respectively, $ps > .33$).[5] Overall, the pattern of correlations is consistent with the hypothesis that individual differences in WM account for PM performance, but when more spontaneous retrieval was supported by either task regularity or focal cueing, the association between WM and PM was eliminated.

With respect to vigilance, a clear pattern of associations with PM did not emerge. For the young adult group, the PVT was not correlated with the PM tasks hypothesized to be more demanding of monitoring processes, but was correlated with performance on regular, repeated tasks. For the older adult group, the PVT was uncorrelated with all task types. These findings suggest that if there is a reliable correlation between vigilance ability and PM, then the correlation may not be with PM conditions that require monitoring for PM targets to a greater extent, and, moreover, such an association may be orthogonal to age-related variation in PM (Lindenberger & Pötter, 1998).

Discussion

We conducted the present study to investigate age and individual differences in PM. Specifically, we tested the hypothesis that WM and vigilance are attentional resources that underlie the performance of PM tasks, particularly for tasks presumed to have greater monitoring demands. To this end, we compared the effects of task regularity and cue focality on young and older adults' PM performance during the Virtual Week game. Because participants were tested on the regular tasks when the tasks were initially encoded and because the tasks were repeated on each day of the week, it was hypothesized that retrieval of the intentions would be more spontaneous and performance would become more habitual over the course of the week. As expected, performance for these tasks started out higher than that for irregular tasks and improved over the week, suggesting participants transitioned from having to remember novel intentions to remembering to perform more habitual actions.[6] In contrast, it was hypothesized that participants were more likely to employ a strategic monitoring approach to perform the irregular, nonrepeated tasks and, therefore, that age differences would be more robust for these tasks. As expected, age differences were largest for the irregular tasks.

The correlational analyses predicting PM performance showed that individual differences in WM ability, a measure of *controlled* attention, was a strong predictor of PM performance under the conditions hypothesized to be the most demanding of monitoring (i.e., irregular PM tasks when the cues to signal performance were less focal to the other ongoing activities). In contrast, for irregular tasks with more focal cues, performance was not significantly correlated with WM, suggesting that a variable hypothesized to facilitate spontaneous retrieval of prospective intentions (i.e., cue focality) reduced monitoring demands. Similarly, task regularity (another variable hypothesized to reduce monitoring demands) eliminated the association between PM and WM for both young and older adults. On the other hand, a measure of an individual's *sustained* attentional ability (i.e., vigilance) was not a consistent predictor of PM, even for the irregular PM tasks with less focal cues.

[4] Hierarchical regression analyses to determine the amount of age-related variance in PM that was attributable to WM are not reported due to the problems with mediational analyses discussed by Lindenberger and Pötter (1998).

[5] We thank an anonymous reviewer for suggesting this analysis.

[6] Although regular or habitual PM cues produced benefits to PM performance (see also Rendell & Craik, 2000), these benefits may come with a cost. Einstein, McDaniel and colleagues have found that older adults commit more repetition errors in habitual PM tasks than young adults (Einstein, McDaniel, Smith, & Shaw, 1998; McDaniel, Bugg, Ramuschkat, Kliegel, & Einstein, 2009). Although the conditions of the present study were quite different, we tried to determine if one source of age differences in regular task performance was due to the older adults committing more repetition errors. By and large, omission errors were the most common type of error, which is consistent with previous reports on the Virtual Week game (Rendell & Craik, 2000). Yet, despite the relatively low frequency of repetition errors, older adults did commit a greater number of such errors ($M = 1.4$ per participant) than did young adults ($M = 0.2$ per participant), $t(104) = 4.06$, $p < .001$. This finding is consistent with the hypothesis that older adults' problems with internal source monitoring lead to repetition errors in habitual PM (Einstein et al., 1998; McDaniel et al., 2009). In the future, researchers should consider the role of output monitoring on age-related PM, particularly for intentions that are to be habitually performed. We thank an anonymous reviewer for raising this possibility.

WM, Vigilance, and PM

It is interesting that the pattern of correlations between vigilance and PM performance was not as predicted. Although the PVT was correlated with regular PM task performance in the young adult group, the fact that older adults' PM performance was uncorrelated with the PVT makes theoretical interpretation of the role of vigilance in PM difficult. The lack of a consistent association between PM and vigilance is particularly intriguing given that the constructs of PM and vigilance may seem so closely related that a PM task may "turn" into a vigilance task if the intention simply remains in consciousness until it can be enacted. The present patterns show that sustained attention required for maintaining a single intention, as in the simple, repetitive responding on vigilance tasks, may not be a crucial attentional resource for PM, at least for older adults or for young adults under PM conditions that are most demanding of monitoring. Participants may not have sustained vigilance for performing the PM tasks because it was too demanding to do so, because the tasks were spaced too far apart, or because they did not believe it was necessary.

By contrast, there was a strong association between WM and PM that was modulated by features of the PM tasks that affect the degree of controlled strategic processing. The performance of monitoring intensive PM tasks may have led participants to actively maintain the set of intentions while switching attention between other ongoing tasks. The controlled attentional processes involved in such a monitoring strategy are similar to those processes required by WM tasks. Therefore, the capacity and efficiency of WM are likely important determinants of PM ability, as well as age-related changes in PM.

Although we found a strong association between WM and PM, it is not yet clear what fundamental process is shared between the two domains. Recent neuroscientific studies have demonstrated some differences, as well as some overlap, in the pattern of neural recruitment between WM and PM (Reynolds, West, & Braver, 2009; West & Bowry, 2005; West, Bowry, & Krompinger, 2006). One possibility is that WM and monitoring for PM intentions involve both similar and different processes, and not all situations tap those processes that are shared. It may be that individual differences in controlled attentional processes become important for PM when the conditions require maintaining the task set (i.e., PM intentions) and preventing mind-wandering, to which individuals with low WM are more susceptible (Kane et al., 2007; McVay & Kane, 2009).

What is encouraging regarding the relation between WM and PM is that older adults with relatively good WM functioning may have preserved PM functioning. Consider, for example, one of the older adult participants of the present study. A 71-year-old woman who obtained a score of 61 on the operation span task (slightly higher than the average score of the young adult group) was able to get 95% of the regular and 79% of the irregular PM tasks correct—better than the average percentage correct for the young adult group for each task type. Cherry and LeCompte (1999) also showed that higher functioning older adults (with higher WM scores) did not have a PM deficit, relative to young adults. Although researchers should continue to explore the role of WM in age-related PM, ideally in a longitudinal study of adults within a continuous age range, an emerging body of evidence suggests that WM might be an important mediator of age-related decline in PM (Cherry & LeCompte, 1999; Einstein et al., 2000; Kidder et al., 1997; Kliegel et al., 2002; Park et al., 1997; West & Craik, 2001; Zeintl et al., 2007). With the present study, we have extended previous findings by pointing to specific PM conditions for which the demands placed on WM may be reduced—namely, task regularity and focal cueing.

When Are Associations Between WM and PM to Be Expected?

Many factors may increase the strategic, controlled demands of laboratory-based PM paradigms and, as a result, may increase WM demands and age differences (McDaniel & Einstein, 2000, 2007). The multiprocess theory suggests that these factors include situations in which (a) there is a weak association between the cue and the intended action or (b) the processing of the PM cue is peripheral (i.e., less focal) to the processing carried out in the ongoing task (McDaniel & Einstein, 2000, 2007).

The present study provides tests of these hypotheses. First, because we tested participants' memory for the regular tasks three times during the instructions in order to ensure successful encoding of the tasks, the association between the cue and the intended action was strengthened relative to the irregular tasks that were not tested. The impact of this difference was evident on the first day of the Virtual Week, as regular task performance—when the task was novel—exceeded that of irregular task performance. In addition to the enhanced encoding of the cue–target association for regular tasks at the beginning of the week, repeatedly performing the regular tasks on each day in response to the same cues also likely enhanced the participants' cue–target association for the regular tasks. That repeated performance of PM tasks results in improvements may be due to increased familiarity, analogous to the benefit of item repetition to recognition memory (Guynn & McDaniel, 2007) but could also be due to the presence of preceding situational cues that provide a richer, more extensive set of cues for triggering retrieval (cf. Kvavilashvili & Fisher, 2007).

Second, PM tasks that were cued by event cards were likely to involve slightly more focal processing. Although the Virtual Week game was not originally designed to address the role of cue focality on PM, here we have proposed that event-card and time-square cues may differ in terms of cue focality because reading event cards was crucial to the ongoing task, whereas attending to the time square that one's token was passing was relatively more peripheral.[7] Support for this proposal was provided by the pattern of relationships among age, WM, and PM with more or less focal cues, which converged with the effects of task regularity.

Taken together, young and older adults' performance on the Virtual Week game and the results of the correlational analyses

[7] Although, the pattern of some of the age effects in the present study may seem somewhat at odds with studies that have shown elimination of age differences for focal-cue tasks (Einstein & McDaniel, 1990; Einstein et al., 1995), it is important to note that the present conceptualization of focal cues was not as strictly determined as in previous work. For example, in the present study, during encoding of PM tasks with event-card cues, we did not present participants with the exact cue that would be presented during the game. Also, because participants were required to select a preferred activity for each event card, it is possible that participants went straight to selecting one of the options rather than fully processing the PM cue (i.e., the event that was described on the card). Moreover, consistent with the findings of the present study, a recent meta-analysis of age effects on focal and nonfocal PM showed that, on average, focal cues reduce age differences but do not eliminate them (Kliegel et al., 2008).

converge on two key points. Conditions that are presumably most demanding of strategic monitoring tend to result in poorer PM performance, larger age differences, and stronger associations with WM. In contrast, the conditions that facilitate more spontaneous PM retrieval tend to result in enhanced PM performance, smaller age differences, and a decreased association with WM.

Conclusion

This is the first study in which predictions derived from the multiprocess theory were used to directly test the role of specific types of attentional resources (i.e., WM and vigilance) that may underlie age and individual differences in PM performance on tasks that rely on theoretically distinct processes. In sum, we presented evidence that for the conditions most demanding of monitoring, WM partially accounted for PM performance on the Virtual Week board game and vigilance did not. Furthermore, when more spontaneous retrieval was likely involved, WM was not correlated with PM performance, consistent with the predictions of the multiprocess theory.

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(*Appendix follows*)

Appendix

Spearman–Brown Split-Half Reliability Coefficients

Task	Young adults	Older adults
All regular	.64	.93
Time-check	.58	.87
All irregular	.77	.92
Regular event	.39	.93
Regular time	.59	.86
Irregular event	.70	.87
Irregular time	.59	.86
WM	.72	.90
PVT	.98	.94

Note. WM = working memory; PVT = psychomotor vigilance task.

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