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The neuropsychology of prospective memory in normal aging: A componential approach

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ABSTRACT

To guide understanding of the neuropsychology of prospective memory and aging, we highlight several components of prospective memory, including planning an intended action, retrieving the action at the appropriate moment, and executing the action. We posit that frontal systems are particularly important for prospective memory tasks that require planning, that require strategic monitoring to detect the appropriate moment for executing the prospective memory intention, or for which execution of the retrieved intention must be delayed briefly. Drawing from a variety of approaches, including neuroimaging (with young adults) and studies examining individual differences relating to frontal functioning, we assemble preliminary evidence that supports this hypothesis. Further, because aging especially disrupts frontal functioning, the above noted prospective memory tasks would thus be expected to display the greatest age-related decline. The available literature confirms this expectation. A second key hypothesis is that some prospective memory tasks—those requiring minimal planning and supporting spontaneous retrieval—do not rely extensively on frontal processes but instead rely on medial-temporal structures for reflexive retrieval. These prospective memory tasks tend to show minimal or no age-related decline. The literature, though sparse with regard to the neuropsychological underpinnings of this kind of prospective memory task, is consistent with the present hypothesis.

Understanding the neuropsychology of prospective memory in normal aging hinges on an appreciation of a key behavioral finding in the literature on prospective memory and aging. In some situations, older adults display impaired prospective memory performance, whereas in other situations older adults show relatively small or no declines in prospective memory performance (see Kliegel, Jager, & Phillips, 2008, for a metaanalysis, and McDaniel & Einstein, 2007, for a review; see also West, 2005). In this paper we adopt a componential analysis of prospective memory that helps organize the above behavioral findings, and we apply that analysis to organize and leverage the nascent literature on the neuropsychological underpinnings of prospective memory in healthy older adults.

As many theorists have noted, prospective memory can involve several components that include planning an intended action, retrieving the action at the appropriate moment, and executing the action (e.g., see Dobbs & Reeves, 1996). Further, we assume that the processes involved in these components may rely differentially on several neuropsychological systems, most prominently prefrontal systems and medial temporal systems, as well as different areas within these systems (West, 2005). Importantly for understanding prospective memory in healthy aging, we suggest that the degree to which these components are challenged or involved in prospective memory can vary widely across different prospective memory situations, and accordingly, our review will focus on the particular neuropsychological systems that we believe are relied upon in different prospective memory tasks. Critically, because the literature suggests that aging may disproportionately penalize some relative to other of these neuropsychological systems, delineating the particular prospective memory situation is paramount to characterizing the neuropsychological underpinnings of both spared and impaired prospective memory in older adults.

More specifically, on the view that normal aging preferentially disrupts prefrontal systems (Raz et al., 1997; West, 1996; see Braver et al., 2001, for a review of converging evidence from neuroimaging and neurophysiological results), the hypothesis proposed by Glisky (1996) is that prospective memory will be impaired in healthy older adults to the degree that the prospective memory task is heavily dependent on frontally mediated processes. Glisky's formulation provided an initial sketch on the processes involved in prospective memory tasks that may rely more or less on frontal processes. In this article, we further develop the Glisky hypothesis by reviewing the

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aging and neuropsychological literature through the lens of a more detailed characterization of prospective memory tasks and theoretical assumptions regarding the functions subserved by frontal and medial temporal (and other) systems in these tasks. Our approach will be an additive one, in which we first consider prospective memory tasks in which planning and execution components are minimally challenged, thereby isolating the retrieval processes involved in prospective memory. We then examine paradigms in which the execution component is demanding, and finally, examine situations in which the planning component is added.

1. Retrieval

Most of the laboratory prospective memory research has focused on event-based prospective memory. In event-based prospective memory, subjects are instructed to perform a particular action (e.g., press the F8 key) whenever they encounter a particular target event (e.g., the word *spaghetti*) during an ongoing activity. Under these typically simple prospective memory instructions, subjects need not form their own intention nor construct elaborate plans for executing the prospective memory task (as noted by Dobbs & Reeves, 1996). The major challenge for subjects is remembering the intended action at the appropriate moment, i.e., when the target event appears, and theoretical work in prospective memory has focused primarily on this remembering process. One current theory suggests that people can rely on (1) a spontaneous retrieval process, in which the occurrence of the target event spontaneously triggers retrieval of the intended action from long-term memory, or (2) a strategic monitoring process, in which the subject actively monitors the environment for the target event (McDaniel & Einstein, 2000). Further, characteristics of the prospective memory target event in conjunction with the demands of the ongoing activity will influence the degree to which strategic monitoring is required for prospective remembering as opposed to spontaneous retrieval.

Briefly, when the ongoing task encourages processing of the attributes of the target event that were processed during initial encoding (during the prospective memory instructions), then prospective remembering can be relatively spontaneous (for convenience and in keeping with the literature we will label this a *focal-cue* prospective task; for further details see Einstein & McDaniel, 2005). This view emanates in part from the encoding specificity principle, which proposes that retrieval is more likely when the features of the target that were processed at retrieval match those that were processed at encoding (Tulving, 1983). Another important facet of this idea is that the critical attributes of the target are somewhat *integral* to the information processed for the ongoing task. As an example, for an ongoing task in which pairs of words are presented in the middle of a computer monitor and subjects decide whether one word is a member of the category represented by the other word, specifying a particular word as a target event (*tortoise*) would be a focal prospective memory task. As an everyday example, you might form the intention to give your friends, who you are meeting later for dinner, the message that you have switched restaurants and now plan to meet at the new restaurant in town. As you form your intention, you assume that you will be encountering your friend Tom, thereby encoding his name and perhaps some of his facial features. When you later directly encounter Tom, your processing of these features encoded during intention formation is integral to your processing of Tom (i.e., saying his name and perceiving his facial features). In this situation, Tom serves as a focal cue.

By contrast, when the ongoing task does not require processing of the attributes of the target event, then prospective remembering is assumed to depend on monitoring of the environment for the target event (we label this a *nonfocal* task). For example, for the above category decision task, specifying a particular syllable as a target event (*tor*) would create a nonfocal prospective memory task. For the everyday example, after envisioning encountering Tom (as specified in the above paragraph), you might be wondering about the percentage of people who wear belts these days (perhaps you are on the dress-code committee), and accordingly as you pass people you are primarily attending to people's waists. In this case, the initially encoded features (of Tom) are unlikely to be extracted when you encounter him (because you would be noticing Tom's waist). In other words, the features encoded as part of the prospective memory intention are peripheral to those being extracted when you subsequently encounter the target event. Consequently the prospective remembering (to tell Tom about the change of restaurant) depends on a nonfocal cue. We acknowledge that this theoretical distinction may be most clear cut in the laboratory, where it is easier to infer and to control the overlap between the processing at prospective memory encoding and at retrieval. Also, it may be more apt to think of the distinction between focal and nonfocal tasks as reflecting a continuum, rather than as discrete categories (see Knight et al., in press).

With this theoretical groundwork in place, we can begin to specify the neuropsychological systems involved in various prospective remembering tasks. Theoretically, one proposed mechanism for spontaneous retrieval (see McDaniel, Guynn, Einstein, & Breneiser, 2004, for another mechanism) is that it is supported by a reflexive–associative memory subsystem that is linked to medial temporal structures such as the hippocampus (Moscovitch, 1994; see also Cohen & O'Reilly, 1996, for a similar idea). On the other hand, there is high agreement that strategic monitoring should be associated with frontal functioning (Burgess, Scott, & Frith, 2003; Reynolds, West, & Braver, 2009; Simons, Scholvinck, Gilbert, Frith, & Burgess, 2006). Accordingly, focal prospective memory tasks should be related to medial temporal processes, whereas nonfocal prospective memory tasks should be related to frontal processes. In the following sections we review neuroimaging evidence, behavioral work focused on individual differences related to the neuropsychological systems just mentioned, and neuropsychological studies that bear on these hypotheses; and we relate these findings to the age-related patterns in prospective memory. To align with the theoretical orientation adopted here, we consider nonfocal and focal prospective memory tasks in turn.

1.1. Neuropsychological processes in nonfocal prospective memory tasks

1.1.1. Frontal processes revealed by neuroimaging

As far as we know all of the published neuroimaging studies, with at most one exception, have used prospective memory tasks that could be considered to rely upon nonfocal cues. Though this work is limited to younger adults, we briefly consider it to provide initial glimpses of the neuropsychology of prospective memory. In Burgess et al. (2003) there were different domains of ongoing tasks (numbers, letters and pictures). In the number condition, a pair of numbers was presented on each trial, and subjects had to decide whether the higher number was on the left or the right (and then press the appropriate key). In the letter condition, subjects had to decide which of two letters came first in the alphabet. For the prospective memory task, subjects were instructed to try to remember to press both keys if two even numbers appeared on the trial (number ongoing task) or if two vowels appeared on the trial (letter ongoing task). Note that determining the parity of the numbers or the type of letters requires extracting information that was not required for the ongoing task, and thus these prospective memory cues would be classified as nonfocal. And, by our analysis, prospective remembering on this task should be highly dependent on monitoring processes.

Using positron emission tomography (PET), Burgess et al. (2003) reported that there were two frontal regions that clearly displayed activations related to prospective remembering, both of which were in anterior prefrontal cortex. The rostromedial area showed a decrease in activation during the prospective memory blocks, whereas the rostrolateral region showed an increase in activity during the prospective memory blocks (see also, Burgess, Quayle, & Frith, 2001). Using fMRI, Simons et al. (2006) found a strikingly similar pattern. In another fMRI study, using a different ongoing task (a working memory task) and a prospective memory cue that was nonfocal to the ongoing activity, Reynolds et al. (2009) also reported sustained anterior prefrontal cortex activation for prospective memory blocks, and this activity was related to improved prospective memory performance.

In sum, the neuroimaging studies converge on the conclusion that sustained anterior frontal activity is associated with nonfocal prospective remembering. It is not certain exactly what cognitive processes are reflected by the sustained anterior prefrontal activity, but the most likely interpretation is that the prefrontal activity is associated with maintenance of the prospective memory intention (Burgess et al., 2003)—perhaps more particularly as rehearsal in working memory (Gilbert, Gollwitzer, Cohen, Oettingen, & Burgess, 2009), or monitoring for the target information, or both. For present purposes, the most important implication is that given that the ability to sustain activation of these anterior frontal processes declines with age (Braver et al., 2001; Jimura & Braver, 2010), we would expect that older adults would consequently be particularly challenged by nonfocal prospective memory tasks (and prospective memory tasks that rely heavily on monitoring). This expectation is confirmed in the behavioral literature, as older adults often show substantial decline relative to younger adults on nonfocal PM tasks (see Henry, MacLeod, Phillips, & Crawford, 2004; Kliegel et al., 2008; McDaniel & Einstein, 2007; Uttl, 2008, for reviews). For instance, Kliegel et al.'s meta-analysis of 46 studies that tested age differences on nonfocal PM tasks indicated that this age-related decline reflected a large effect size, an effect size that was significantly larger than that observed with focal PM tasks. Unfortunately, little work has been done to isolate the cognitive process related to this age-related decline, with even less research available attempting to link older adults' prefrontal functioning to nonfocal prospective memory performance. Still, a few studies have been reported that provide some initial illumination on these issues.

1.1.2. Working memory as a proxy for frontal functioning

One line of evidence suggestive of an association between prefrontal functioning and age-related changes in (nonfocal) prospective memory is based on work that has examined the relation between individual differences in working memory and prospective memory. Our underlying assumption here is that working memory might be considered an index or a proxy for prefrontal functioning. This assumption is based on neuroimaging evidence indicating that working memory tasks are supported by prefrontal activation (e.g., Braver & Cohen, 2001; Cohen et al., 1997; D'Esposito et al., 1998; Smith & Jonides, 1999; see Owen et al., 1999, for evidence of activation in areas of lateral prefrontal cortex similar to that found with nonfocal PM tasks). Further, using a factor analytic approach over a wide age range, McCabe, Roediger, McDaniel, Balota, and Hambrick (2010) showed that the correlation between a working memory capacity construct (based on four measures) and an executive function factor (based on five neuropsychological measures) approached unity ($r = .99$). Because the executive function factor has been related to prefrontal functioning (see Glisky, Polster, & Routhieaux, 1995, for support), the implication is that working memory capacity is also reflective of prefrontal functioning. Note that our point here is not to strongly argue for installing working memory measures as a direct index of prefrontal functioning; we simply are suggesting that the relation is plausible and consequently that studies that have examined working memory capacity may provide hints regarding the contribution of prefrontal functioning to prospective memory in normal aging.

Two studies with older adults that assessed working memory capacity used prospective memory tasks that were clearly nonfocal in nature (Kidder, Park, Hertzog, & Morrell, 1997; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997). The subjects' ongoing task involved processing words presented one at a time in a white rectangle presented in the middle of the screen. At random intervals, the subjects were asked to recall the last three words that had been presented. As the words were being presented, the background screen (outside of the white rectangle) was changing in its patterning every 3 s. The subjects' prospective memory task was to try to remember to press the zero key when a particular background pattern appeared. Thus, the prospective memory target information was not extracted as part of the ongoing activity (i.e., the target was nonfocal), and accordingly, subjects would have to monitor for the particular background target to support prospective remembering. Measures of WM were also obtained.

Both studies found that working memory was related to nonfocal prospective memory performance. First, for older adults (but not younger adults) prospective memory performance was significantly correlated with working memory. One straightforward interpretation of this finding is that as working memory capacity declined, older adults were less able to sustain the strategic monitoring necessary to detect the nonfocal cue that signaled the prospective memory task. Second, working memory declined with age, as did prospective memory performance, suggesting that declining working memory capacity was associated with the age-related decrements in prospective memory (hierarchical regression analyses were not computed to explore this mediational hypothesis). To the extent that working memory is subserved by prefrontal systems, we can provisionally conclude that age-related disturbances in prefrontal functioning were associated with reduced ability to engage strategic monitoring for the nonfocal cue, and these disturbances penalized prospective memory.[1] Of course, returning to our componential analysis of prospective memory outlined at the outset of this article, it is possible that reduced working memory resources could hamper older adults' ability to coordinate execution of the prospective memory task with the demands of the ongoing activity (e.g., Einstein, McDaniel, Manzi, Cochran, & Baker, 2000) or to plan/encode the prospective memory task (cf. Cherry & LeCompte, 1999).

A more recent study that examined individual differences in working memory and aging contrasted prospective memory tasks that varied in the degree to which the prospective memory cue was focal versus nonfocal (Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010). Because the execution component was fairly equivalent across the range of prospective memory cues, the results allowed better localization for the involvement of working memory (and by extension, prefrontal functioning) in monitoring processes during prospective remembering. In Rose et al. (2010) the prospective memory tasks were embedded in a computerized board game simulating a "virtual week" of everyday activities (adopted from Rendell & Craik, 2000). In a "day", subjects move a token once around the board, with the square of the board progressing from the initial hour of the waking day until the hour prior to sleep. For each

[1] We use working memory as a proxy for frontal functioning (McCabe et al., 2010), and we also assume that working memory is directly involved in strategic processes that are prominent in nonfocal prospective memory tasks. In making this assumption, we do not mean to imply that there are not other frontally mediated processes also involved in strategic monitoring in nonfocal prospective memory (Burgess et al., 2003).

day, subjects completed 10 prospective memory tasks, thereby providing high reliability for the prospective memory measure. (To execute the prospective memory task, subjects had to click a "perform task" button and select the intended activity from a list of tasks, including distracters.) Critically, some of the tasks were cued by reading an event card that specified a particular activity (e.g., take an antibiotic at breakfast) and some were cued by passing the token across a particular time-square on the board (take asthma medication when the token lands on or passes the 11 A.M. square).

The researchers reasoned that the time-square prospective memory tasks[2] would be relatively nonfocal because subjects' activities did not require them to attend to the particular time that appeared on the time squares (that the token moved over). By contrast, event-card prospective memory tasks (four per virtual day) were relatively focal to the ongoing activities because the subject had to read event cards during the course of the day, and pretend to be engaging in the described events. Doing so would require full processing of the event-cue (e.g., "breakfast") associated with the prospective memory intention (take antibiotics). For present purposes, of interest are the correlations between working memory and the prospective memory performances.

Consistent with the findings reviewed above, for the nonfocal (time-square) tasks, older adults' working memory capacity was associated with prospective remembering ($r = .41$, $p < .007$) (though this was diminished for particular nonfocal tasks that were repeated across each of the five days). On the other hand, for the focal (event-card) tasks, the correlations (for both non-repeated and repeated tasks) were not significant ($r = .19$, $p = .24$). It is important to note that the execution demands of the prospective memory tasks (and initial encoding at the outset of each day) were identical across the time-square (presumably non-focal) and event-card prospective memory tasks. Theoretically, the two tasks differed primarily in terms of the strategic monitoring necessary to notice the cue and retrieve the intended action. Accordingly, assuming that working memory reflects prefrontal processes, these results suggest that prefrontal functioning in older (and younger) adults is important in supporting the strategic monitoring (or maintenance in working memory) required to detect and appropriately process nonfocal prospective cues. Moreover, these findings hint that working memory, and by extension at least some subsystems in prefrontal cortex, need not play a primary role in prospective-memory retrieval with focal cues. In the next sections, we augment this point by reviewing pertinent findings for focal prospective memory tasks.

1.2. Neuropsychological processes in focal prospective memory tasks

1.2.1. Processes revealed by neuroimaging

One initial study provides a hint of the neuropsychological systems associated with retrieval in a prospective memory task in which monitoring is arguably not required. Martin et al. (2007) embedded a prospective memory task within blocks of five ongoing tasks, several of which involved indicating which of two colors a circle appeared in and one involved synchronous tapping to a blinking circle. The prospective memory task was to remember to press a designated key on a response box whenever a target shape appeared (octagon, square, diamond, etc.). The target shape changed across each block, and in each block the shape was not presented on non-prospective memory trials (normal ongoing-task trials). That is, when the target shape appeared, subjects were to make the prospective memory response instead of the ongoing task response. The presentation of the target shape thus served as an exogenous orienting cue for the prospective memory task, thereby minimizing the need for monitoring (cf. McDaniel & Einstein, 2000). There were also two other trial types: catch trials, in which a new shape (oddball) was presented (subjects were told to ignore any shape not involved in the ongoing activity or prospective memory task) and retrospective memory trials which were preceded by the cue "Memory" (subjects had to make a particular key press previously encoded with a particular target shape).

The researchers used magnetoencephalography (MEG) to examine neural activation in parietal, hippocampal and frontal sources. The findings showed distinct patterns of activation for the prospective memory trials relative to the oddball or retrospective memory trials. For the posterior parietal source, onset latency was prompt and significantly faster after the prospective memory target than after the oddball or retrospective memory target. For the hippocampal source, onset latency was faster in prospective memory trials than in oddball trials, and activity was more prolonged for the prospective memory trials than the oddball or retrospective memory trials. Frontal sources were active in all conditions, but there were no differences in either onset latency or duration of activity across the different trial types.

These patterns were interpreted as suggesting that the posterior parietal region is involved in noticing the prospective memory target (see also West this issue for a detailed review of ERP findings), and that the hippocampal region is quickly involved in retrieving the intended action associated with the target. The frontal activations were not specifically related to prospective memory trials, suggesting that for this paradigm (with a prospective memory cue that might be considered focal) the frontal system was not uniquely involved. Interpretation of the frontal activation patterns is clouded, however, because there were no control blocks without the prospective memory task. Clearly much more neuroimaging work is needed on prospective memory paradigms using focal target events, but the preliminary indication from this MEG study is that sustained frontal activation is not necessary for prospective memory tasks that have external cues that effectively stimulate retrieval (i.e., cues that promote exogenous orienting to the prospective memory target [McDaniel & Einstein, 2000, 2007] as in the MEG study, and focal cues as discussed earlier). Unfortunately, to date no published fMRI study has examined focal prospective memory tasks. The expectation is that prefrontal systems would not be heavily involved in initiating prospective memory retrieval on focal tasks. The implication for aging is that age-related disruptions in prefrontal systems may not dramatically penalize retrieval in focal prospective memory tasks. In the next section we will review the research on individual differences in older adults' working memory and focal prospective memory performance to further examine this last claim.

1.2.2. Working memory, aging and focal prospective memory

In two studies, Cherry and her colleagues implemented a prospective memory task in the context of a set of short-term memory trials (the ongoing task), and they also assessed working memory capacity with two other working memory tasks (Cherry & LeCompte, 1999; Reese & Cherry, 2002). In the short-term memory trials, younger and older adults were presented short lists of words and immediately after presentation of the words recalled each list aloud. The prospective memory task was to try to remember to press the *F9* key whenever a particular word appeared in a word list (e.g., *dress*; Reese and Cherry). Because the ongoing short-term memory task required full processing of each word, the prospective memory target (a particular word) would be focally processed dur-

[2] Note that we label this as a *time-square* task to distinguish it from a time-based prospective memory task, which typically involves monitoring a clock for the appropriate time for performing an intention. We assume that time-based tasks are nonfocal, and consistent with the framework presented in this article, substantial age differences are generally found with time-based prospective memory tasks (see Einstein et al., 1995; Henry et al., 2004, for a review).

ing the ongoing activity. An additional feature of these studies was that groups of "low-ability" and "high-ability" younger and older adults were sampled; the low-ability groups were characterized by lower verbal intelligence (vocabulary) and education, whereas the high-ability groups were characterized by higher verbal intelligence and education.

In contrast to the patterns often reported with nonfocal prospective memory tasks, in both studies, there were no significant age differences in prospective memory (see also Einstein & McDaniel, 1990, for an identical finding using this prospective memory paradigm). Indeed the high ability old slightly outperformed the high ability young. Also, in both studies, there was no significant interaction of age with ability level (though in Cherry & LeCompte, 1999, but not Reese & Cherry, 2002, low ability old showed a decline in prospective memory relative to low ability young). Aggregating across published experiments shows a reasonably similar pattern. Across 18 studies reviewed in McDaniel and Einstein (2007), some of which contained multiple experimental conditions, on average older adults showed a minimal 11% difference in focal prospective memory tasks relative to young adults (compared to an average 23% difference on nonfocal tasks). These results are consistent with the theoretical assumption that retrieval in focal prospective memory tasks can be spontaneous, thereby minimizing the need for monitoring. For the focus of the present article, the implication is that prefrontal systems might thus be minimally involved in retrieval processes in focal prospective memory (and consequently, the age-related disruption in frontal processes would have minimal impact on prospective remembering with focal event cues). We next consider the working memory patterns to provide initial evidence for these neuropsychologically oriented implications.

Cherry and LeCompte (1999) and Reese and Cherry (2002) computed a composite working memory score based on two individual working memory tasks, and this composite score accounted for a small though significant amount of variance in prospective memory performance (4.2–4.7% across the two studies). To the extent that working memory scores reflect frontal functioning (see McCabe et al., 2010), this tentatively implies slight frontal involvement in the focal prospective memory task. However, it is unclear what prospective memory component might be associated with working memory (frontal) capacity. A critical aspect of the Reese and Cherry (2002) paradigm provides some insight into this issue. In their study, participants in a probe condition were asked to report "what you are thinking about" every so often throughout the task. The reasoning here was that if the focal target stimulated spontaneous retrieval of the intended action, thereby obviating the need for sustained (frontally mediated) monitoring processes, then participants' thoughts would rarely be related to the prospective memory task.

Their findings showed that participants very infrequently thought about the prospective memory task during the ongoing activity, with lower ability participants reporting prospective-memory thoughts only between 1 and 2% of the time (and higher ability only slightly more frequently). Instead participants typically were thinking about the short-term memory task or task-irrelevant information ("I'm thinking about playing soccer tonight"). The authors concluded that relatively automatic retrieval processes were supporting prospective remembering. Accordingly, the working memory resources related to prospective memory performance were unlikely reflecting sustained strategic monitoring. Instead, it may be that these resources (and by extension, prefrontal activity) were related to initial planning (perhaps processes related to integrating the cue-prospective response association; Cherry & LeCompte, 1999) or to executing the response once it was retrieved (e.g., coordinating the execution of the response with demands of the ongoing activity). We address these possibilities in following sections.

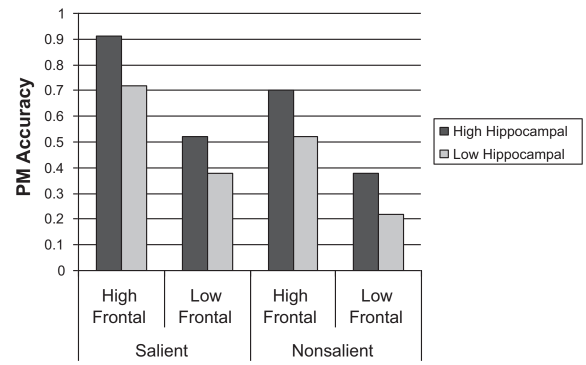

Fig. 1. Mean proportion of prospective memory responses in older adults as a function of hippocampal and frontal functioning and salience of the prospective memory cue (data from McDaniel et al., 1999). *Note*. Hippocampal and frontal functioning were determined by neuropsychological tests (see text for details).

1.2.3. *Neuropsychological studies with healthy older adults*

McDaniel, Glisky, Rubin, Guynn, and Routhieaux (1999) more directly examined the contribution of prefrontal and medial temporal systems in prospective memory functioning in healthy older adults. The ongoing activity was answering general knowledge and trivia questions, presented in multiple choice format. The prospective memory task was to try to remember to press the *F8* key whenever a question with a particular word (*president* or *state* counterbalanced across conditions) appeared. Arguably this is a focal prospective memory task, as the target word and its meaning are processed fully during the ongoing activity of reading and answering the questions. In line with this assertion, Einstein, McDaniel, Richardson, Guynn, and Cunfer (1995) found no age-related differences on this prospective memory task, consistent with Cherry and colleagues' findings presented above. To further augment the degree to which the target event might stimulate reflexive noticing, in some conditions the target word was presented in bold font (whereas all other words were in normal type font).

A central feature of this study was that older adults' levels of prefrontal and hippocampal functioning were gauged with a neuropsychological battery developed by Glisky et al. (1995). The scores from this battery were used to sample older adults to complete a 2×2 factorial, with one factor being frontal functioning (low, high) and the other factor being hippocampal functioning (low, high). Fig. 1 displays the prospective memory performances as a function of frontal status, hippocampal status, and the salience of the target cue (highly salient—bold font, less salient—normal font). As can be seen, frontal functioning was strongly related to prospective memory performance, with high frontal older adults significantly outperforming low-frontal older adults by an advantage of 34%. Further, the frontally related decline in prospective memory was as robust for the high-salient cue condition as for the less-salient cue condition.

Converging with the tentative conclusions drawn above from the working memory and focal prospective memory findings, the authors interpreted this pattern as indicating that frontal systems were playing a role in forming a coherent, integrated representation of the target event—intended action constellation during initial instructions or in executing the prospective memory intention once it was retrieved (which would involve maintaining the retrieved intention in working memory while interrupting the ongoing activity, and then coordinating response execution). The effects of frontal functioning were considered not related to strategic monitoring processes. The reasoning was that the less-salient cues would require more monitoring (if monitoring were being recruited for the task) and thus that condition should be

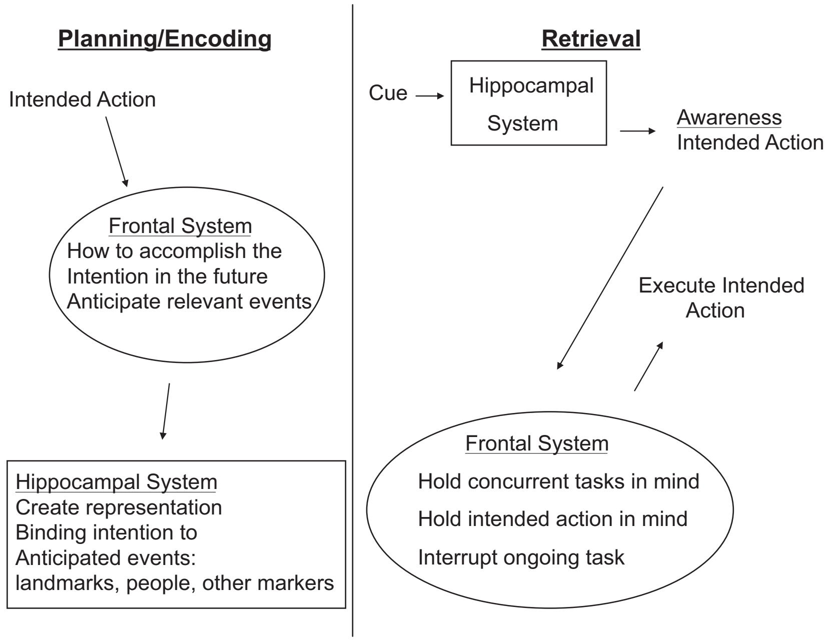

Fig. 2. A neuropsychological model of prospective memory, when retrieval is prompted by a focal event cue. Adopted from McDaniel and Einstein (2007).

most sensitive to any variables influencing monitoring (see e.g., Kliegel, Martin, McDaniel, & Einstein, 2004). However, frontal-related declines in prospective memory were not accentuated in the less-salient condition, suggesting that in this study frontal systems were playing a role in prospective memory components other than strategic monitoring (see e.g., Cockburn, 1995).

Fig. 1 reveals another key finding. Hippocampal functioning was also associated with prospective memory performance, with high hippocampal older adults displaying a 17% advantage in prospective remembering relative to the low hippocampal adults. This finding converges with the assumption that hippocampal systems play a role in associative retrieval processes that presumably support retrieval of the intended action in the presence of a focal target event (see also Adda, Castro, Alem-Mar e Silva, de Manreza, & Kashiara, 2008, for evidence of long-delay interval event-based prospective memory deficits for adults with hippocampal lesions, further supporting the role of hippocampal systems in spontaneous retrieval). Taken together, the findings reviewed suggest a neuropsychological model of focal prospective memory illustrated in Fig. 2. Frontal systems are involved in anticipating event cues that will be present when the intention needs to be executed and associating those cues with the intention. When the cue is encountered and fully processed in the course of the ongoing activity, hippocampal systems support a relatively reflexive retrieval of the associated intended action (cf. Moscovitch, 1994). Once the intended action is delivered to awareness through hippocampal processes, frontal systems play a role in coordinating the execution of the intended action (see Cohen & O'Reilly, 1996; McDaniel & Einstein, 2007, for elaboration).

To return to the theme introduced at the outset, assuming pronounced age-related disruptions in frontal systems but less so in hippocampal systems, the findings and theoretical work reviewed thus far provisionally suggest that healthy older adults show spared performances on focal prospective memory tasks because retrieval is presumably supported by relatively intact reflexive–assocative hippocampal processes (cf. Cohn, Emrich, & Moscovitch, 2008). Converging on this conclusion that reflexive–associative retrieval processes are preserved in older adults are the results of a study in our lab (Scullin et al., submitted for publication) in which we presented a focal prospective memory target event outside of the prospective memory context. Specifically, after being told about their imagery rating ongoing task, younger and older participants were given the prospective memory intention of pressing a designated key whenever either of two focal target events appeared. After we were convinced that participants understood these demands (and were able to report them to the experimenter), participants were told that they would get back to those tasks later and to suspend their intention during an intervening lexical decision task. It was heavily emphasized to participants that their sole demand during the lexical decision task was to make lexical decisions as accurately and quickly as possible (and to ignore all previous demands).

We then presented each prospective memory target several times during the lexical decision task. Our reasoning was that if the presentation of focal cues causes intentions to be reflexively retrieved (when participants are not monitoring), then lexical decision times to prospective memory cues should be slowed relative to lexical decision times for matched control items. Importantly, we could assume that participants were not monitoring for the prospective memory target during the lexical decision task because prior research has shown that monitoring does not occur outside of the prospective memory context (e.g., Marsh, Hicks, & Cook, 2006). As shown in Fig. 3, responding to prospective memory targets was significantly slowed, and critically, there were similar levels of slowing for younger and older adults. Thus, these results suggest spared reflexive–associative retrieval processes in older adults.

Taken together, there is good reason to believe that aging has minimal or no effects on focal prospective tasks. This would especially be the case for focal prospective memory tasks in which planning and execution are not demanding (as in many laboratory prospective memory tasks), because age-related declines in frontal processes would be less problematic. However, for prospective memory tasks in which planning, execution, or both are challenging, then age-related disruptions in frontal processes should penalize prospective memory performance, even in focal prospective memory tasks. For instance, consider again McDaniel et al. (1999) in which older adults answered general knowledge and trivia questions while performing the prospective memory task.

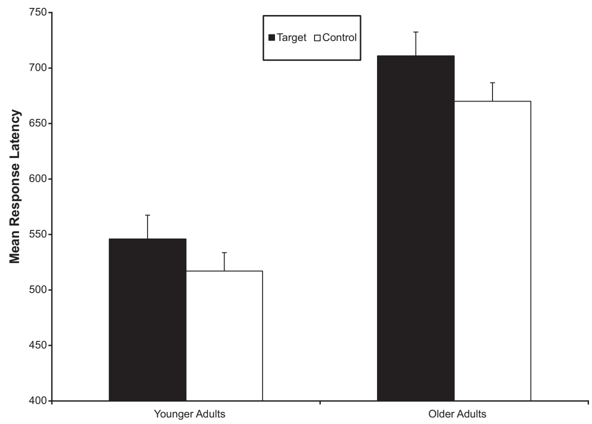

Fig. 3. Ongoing task reaction times to prospective memory targets and matched control items when prospective memory responding is not required.
Adopted from Scullin et al. (submitted for publication).

Participants may have successfully retrieved the prospective memory intention (especially in the high-salient cue condition), but because of frontal decline were then unable to interrupt their efforts to ponder and answer the question (see Cockburn, 1995). Further, after pondering and answering the question, the retrieved intention might have by then been forgotten (McDaniel, Einstein, Stout, & Morgan, 2003), again because of frontal deficits. We more directly examine this possibility by turning to studies with healthy older adults that have focused on these execution processes in prospective memory.

2. Post-retrieval processes: executing the intended action

An important assumption throughout the previous section is that a reflexive–associative process that is mediated by the hippocampal system can accomplish prospective memory retrieval with a focal prospective memory cue. Retrieval of the intention per se, however, does not necessarily guarantee its execution. Once retrieved, performing the intended action requires that we disengage from the ongoing task and also often that we maintain the activation of the intention until the conditions for performing the action are appropriate. Indeed, delaying the execution of an action seems to be a common characteristic of real-world prospective memory demands (McDaniel & Einstein, 2007). Consider for example remembering to take your medication when you are in the bedroom but then having to maintain the intention until you get to the kitchen where your medication is located. Or, consider remembering to give your friend a message when you see her but then needing to hold on to that intention for a while because she is engaged in a conversation with someone else.

Given that the focus of many conceptualizations of working memory is on its ability to maintain the activation of a representation in the face of distraction (Engle, 2002) and/or to maintain an accessible and integrated representation of the task concerns (Kimberg & Farah, 1993) and given that working memory is thought to be subserved by the prefrontal systems, one would expect extensive prefrontal involvement when the execution phase of the prospective memory phase of the prospective memory task is highly challenged. Unfortunately, there is no neuropsychological or neuroscience research that has directly examined the role of the prefrontal cortex in keeping *retrieved* intentions sufficiently activated until the time is appropriate for performing them. There are, however, studies that examined individual differences in working memory and aging on prospective memory tasks where retrieved intentions must be retained over brief delays (a so called *delayed-execute* procedure; Einstein et al., 2000; McDaniel et al., 2003). As represented in Table 1, participants in these experiments performed a series of ongoing tasks and were asked to press a designated key whenever a particular target word occurred. There were several important features of these experiments. One is that the target word, when it occurred, appeared in the third sentence of the three-sentence paragraph and was always capitalized (whereas the surrounding words were not capitalized). This was done in order to make the target item highly distinctive and to ensure retrieval of the prospective memory intention whenever it occurred. Another is that in the *immediate* condition, participants could perform the prospective memory action as soon as they noticed the target but in the *delayed-execute* condition, participants had to hold on to their intention and not execute the prospective memory response until they encountered the trivia question phase of that trial.

Table 1
Sequence of events for each of 20 trials in the delayed-execute task (from Einstein et al., 2000).

Ongoing task
A three sentence paragraph was presented one sentence at a time
Participants performed a multiple choice synonym task for 10–30 s or took a break for 10–30 s
Participants answered two multiple choice trivia questions
Participants answered two multiple choice comprehension questions about the initial three-sentence paragraph
The above sequence was repeated for 20 trials
Prospective memory task
A prospective memory target cue (TECHNIQUE or SYSTEM) occurred in the 3rd sentence of a paragraph on 8 of the 20 trials
Immediate prospective memory condition—participants were asked to make the prospective memory response as soon as they saw the target
Delayed-execute conditions—upon seeing a target, participants were asked to delay their prospective memory response until they encountered the trivia questions

As might be expected with such a salient prospective memory cue, prospective memory performance was high and near ceiling in conditions in which participants could perform their response immediately. There were robust age related deficits of introducing a delay and this was the case with both longer (30 s) and shorter (as short as 5 s) delays and occurred regardless of whether the delay interval was filled with other activities or not (Einstein et al., 2000; McDaniel et al., 2003; see also Kelly & Hertzog, 2010, for a similar pattern of results with a different paradigm). The intriguing result was that introducing delays disproportionately and severely interfered with the prospective memory of older adults. To illustrate the dramatic effects of delays on the prospective memory of older adults, McDaniel et al. found that older adults declined from 93% remembering when they could perform the task immediately to 45% remembering even after brief 5-s unfilled delays. That compares with a decline of 7% in younger adults—from 97% remembering in an *immediate* condition to 90% remembering with 5-s unfilled delays. Moreover, in two experiments, Einstein et al. measured each participant's working memory span and found that working memory scores were significantly related to performance on the delayed-execute prospective memory task. In fact, across various conditions in these experiments, working memory scores accounted for 38–100% of the age-related variance. Thus, although older adults and those with low working memory capacity may not be disadvantaged in terms of initially retrieving an intention (with a highly salient focal cue), they appear to have fundamental problems in executing intentions when they have to maintain the retrieved intention over a delay.

At this point, further neuropsychological and neuroimaging research is needed to confirm that the prefrontal systems are centrally involved in maintaining intentions over brief delays and to precisely specify the prefrontal area(s) involved (one tentative possibility is the dorso-lateral prefrontal cortex, an area involved in working memory). Nonetheless, the existing behavioral research showing that aging and working memory resources are highly associated with prospective memory performance on delayed-execute tasks strongly suggests that the prefrontal systems are critically important to the maintenance and execution of prospective memory responses when the retrieval conditions are highly challenging. In general, these findings are consistent with the view that the particular neurological systems that are involved in successfully performing a prospective memory task will depend on the nature of the task and the particular components of that task that are challenged in a given prospective memory demand. We turn now to reviewing research that examines prospective memory when more complex planning processes are required.

3. Planning in prospective memory

Planning in prospective memory tasks is not often studied, partly because the typical laboratory tasks obviate the need for much planning (i.e., a single simple prospective task is presented, and the target cue for when to respond is specified). Theoretically, however, given that planning is assumed to be intimately related to frontal processes (e.g., Shallice & Burgess, 1991) and that aging compromises frontal systems (West, 1996), one expectation is that older adults should show deficits in prospective memory tasks in which planning is beneficial and further that these deficits should be related to inferior planning for older adults. These expectations have been examined using a complex prospective memory task designed to require planning and for which planning improves performance (Kliegel, Martin, McDaniel, Einstein, & Moor, 2007; Kliegel, McDaniel, & Einstein, 2000).

At the outset of the experiment, participants were instructed that at some later point in the experiment they would have to remember to initiate a six-elements task (Shallice & Burgess, 1991), which itself involved remembering to initiate work on one of the elements, terminate that element after some short period of time, initiate work on another element, and so on. Essentially, this task involves a number of embedded prospective memory tasks cued in different ways (a feature of another experimental task, a feature of one of the embedded six-elements tasks, passage of time). The experimenters' intent was to try to approximate the complexity encountered when a number of prospective memory tasks are intertwined in our daily lives. In those situations, presumably planning is often engaged. In the experiments, young and older participants were required to plan aloud how they intended to execute and remember the prospective memory tasks.

Analysis of the quality of plans indicated that older adults' plans were less elaborate and specific than those generated by younger adults (Kliegel et al., 2000). In addition, older adults displayed significantly worse prospective memory than did younger adults (less frequent initiation of the entire six-elements task and fewer elements started), and the quality of the plans was correlated with successful execution of the six-elements task. In another study, to more directly establish that plan quality was influencing prospective memory, some participants were given guidance (scaffolding and hints) for developing higher quality plans (Kliegel et al., 2007). The plan-guidance conditions produced significantly better prospective memory performance than did the no-guidance conditions for younger and older adults, but especially so for older adults (Kliegel et al., 2007, Experiment 2). These patterns establish an effect of plan quality on prospective memory performance and suggest that age-related reductions in plan quality may in part underlie age-related declines in prospective memory.

Kliegel et al. (2000) also assessed individual difference measures, including working memory and inhibition, both of which have been associated with frontal functioning. Paralleling other studies, older adults had significantly worse working memory and inhibitory control than did younger adults. Further, these factors were related to initiation and successful execution of the six elements task (i.e., prospective memory), and once these factors were accounted for, age was no longer associated with prospective memory performance (but see Lindenberger & Pötter, 1998, for caution in over interpreting the implications of such regression analyses for identifying mediators of age-related decline). These findings tentatively suggest that the age-related deficits in prospective memory in this complex task might be associated with reduced frontal functioning in older adults. However, the working memory and inhibition measures were not significantly predictive of plan quality. Generally, the degree to which other frontally mediated processes might be associated with prospective memory planning merits focus in future research.

4. Summary

Because research on the neuropsychology of prospective memory in normal aging is limited, in this review we have proposed a provisional organizing framework with the following key assumptions. (1) Particular neuropsychological components of prospective memory will be differentially important depending on key parameters of the prospective memory task. (2) Because aging especially disrupts frontal functioning (e.g., Raz et al.'s, 2005, meta-analysis suggests that longitudinal volumetric decline is more pronounced in prefrontal cortex than in other regions, including the medial temporal areas; see also Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003), prospective memory tasks for which frontal involvement is pronounced will evidence the greatest age-related decline (see also Glisky, 1996). We suggest that these prospective memory tasks include those with a heavy planning component, those that require strategic monitoring to detect the appropriate moment (e.g., event) for executing the prospective memory intention, and those in which execution of the retrieved intention must be delayed briefly. The literature confirms that robust age differences are present on these types of prospective memory tasks. Further, drawing from a variety of approaches, including neuroimaging (with young adults) and studies examining individual differences relating to frontal functioning, we have assembled preliminary evidence that these prospective memory tasks are dependent on frontally mediated processes.

(3) In contrast to the prospective memory tasks just mentioned, we have identified other prospective memory tasks that require minimal planning, support spontaneous retrieval, and allow immediate execution upon the appearance of the target event. We suggest that these prospective memory tasks do not rely extensively on frontal processes, but instead rely on medial-temporal structures for involuntary or reflexive retrieval. Though age-related decline in these structures may challenge demanding explicit retrospective memory retrieval (Persson et al., 2006), more reflexive retrieval processes appear to be spared with normal aging (Jennings & Jacoby, 1997; Schmitter-Edgecombe, 1999; Scullin et al., submitted for publication). Accordingly prospective memory tasks like those just noted will show minimal or no age-related decline. The literature, though preliminary with regard to the neuropsychological underpinnings of this kind of prospective memory task, is so far consistent with these ideas.

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