Age-related Changes in Event Cued Prospective Memory Proper

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Summary. Prospective memory proper (ProMP) is required to bring back to awareness previously formed plans and intentions at the right place and time, and to enable us to act upon those plans and intentions. This chapter defines ProMP and distinguishes it from other subdomains of prospective memory (ProM) such as vigilance/monitoring, reviews previous research on and presents the results of a quantitative meta-analysis of age-related changes in event-cued ProM, and reports on a new study examining the relations between ProMP, retrospective memory (RetM), processing resources, and sensory abilities (visual and auditory acuity). The review of previous research indicates that both ProMP and vigilance show substantial declines with aging, that age-declines in ProMP are larger than in vigilance/monitoring, and these age declines have been underestimated in a large portion of the previous studies due to methodological shortcomings such as ceiling-limited scores (ceiling effects) and age confounds in research design. The new study reveals age-related declines in both visual and auditory ProMP that are partially mediated by declines in processing resources and sensory abilities. The combined results highlight the importance of processing resources and sensory functions in mediating age declines in ProMP and delineate the similarities and differences between RetM and ProMP.

Key words. Memory, prospective memory, aging, sensory functions

Introduction

To bring back to awareness previously formed plans and intentions at the right place and time, we rely upon prospective memory (ProM). A typical situation requiring prospective memory is to buy groceries en route home from work, as modeled and illustrated in Figure 1. First, we make a plan to get the groceries; second, we go about our daily activities and perform

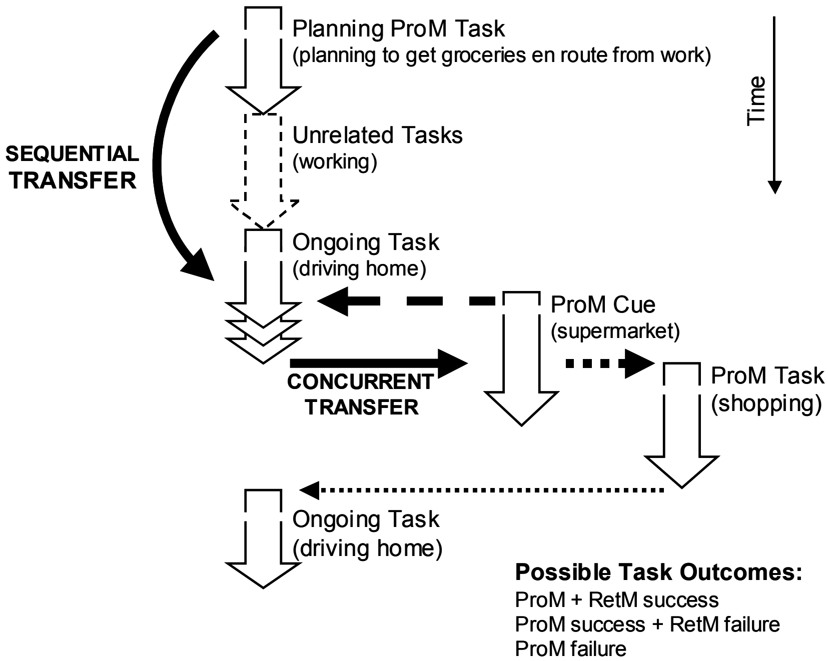

Fig. 1. A task analysis of a typical ProMP situation: A plan to buy groceries en route from home.

various tasks unrelated to our plan; third, we commence the ongoing task of driving home. While driving home, the ProM cue, the supermarket, appears, and the critical question is whether the cue interrupts the ongoing activity and we become aware of its relevance to the previously formed plan. If so, we have succeeded on the defining component of prospective memory function: becoming aware of the plan. The success in performing the ProM task now depends on retrospective memory, the ability to recollect what groceries to buy. Accordingly, when we arrive home, we may arrive without the groceries due to either a ProM failure or a retrospective memory (RetM) failure (i.e., which groceries to buy). Alternatively, if both ProM and RetM functions succeed, we arrive home with all of the groceries (or at least those that the supermarket had in stock!).

The main goal of this chapter is to examine age-related changes in event-cued ProM. Toward this end, the chapter is divided into three sections. The first section defines ProM Proper (ProMP; Graf & Uttl, 2001), distinguishes it from RetM as well as from other subdomains of ProM such as vigilance and monitoring, highlights the dynamic interplay between the ongoing task and the ProM cue, and outlines issues in the assessment of

ProM Proper. The second section reviews previous research on ProM and aging from both conceptual and methodological perspectives, and presents a meta-analysis of age-related changes in ProM Proper as well as in vigilance/monitoring. The third section presents new research that investigates both age-related changes in visual and auditory ProM Proper, and whether age declines in visual and auditory ProM are mediated by declines in processing resources and sensory functions such as visual and auditory acuity.

Prospective Memory Proper (ProMP)

Prospective Memory vs Prospective Memory Tasks

As demonstrated by the example given earlier, ProM tasks have two components: prospective and retrospective (Dobbs & Rule, 1987). Although it is widely recognized that only the prospective component involves prospective memory and that the retrospective component is no different from recollecting a list of words (e.g., groceries to buy) upon demand, the majority of previous studies have confounded the two components into a single binary measure of prospective memory task success or failure. However, as shown in Figure 1, making inferences about the prospective component based on task success or failure data alone is not optimal and may even be wrong.

Following Dobbs and Rule (1987), we have argued that the prospective component can be measured more directly (Graf & Uttl, 2001; Uttl, Graf, Miller, & Tuokko, 2001). Participants in our study (Uttl et al., 2001) – 133 community-dwelling older adults from 65 to 95 years of age – were required to perform a variety of cognitive tasks. For one of the ProM tasks, participants were told that, in the course of the experiment, when I [the experimenter] say "this is the end of the task, I would like you to ask for a pen and a piece of paper, and then I would like you to write your name on the paper." Participants then performed various tasks and at the end of one the experimenter said, "this is the end of the task." Participants indicated that they recognized this cue as a sign to perform the ProM task by responding to it with comments such as "we need to stop here for another task" or "oh, there is something I have to do now," by explaining that they have to do something, or by asking for the pen and/or the paper. These responses to the cue indexed the ProM component success and were independent of the RetM component. Our results showed similar age-related declines in both ProMP and RetM and revealed only a weak relationship between the indexes of ProMP and RetM.

Subdomains of Prospective Memory

A quick survey of the research that has been conducted under the umbrella of prospective memory reveals that the "prototypical" ProM task encompasses such diverse behaviors as preventing a kettle from boiling over, monitoring air traffic on a radar screen, buying groceries en route home, booking an airline ticket, taking medication at prescribed times, and paying bills.

Although all of these situations involve making a plan and performing the plan sometime in the future, the tasks differ in important ways. For some tasks, a plan is maintained in consciousness throughout the retention interval (e.g., scanning for airplanes) whereas for other tasks, the plan leaves consciousness. The critical question is whether the ProM cue brings the plan back to consciousness (Kvavilashvili, 1998; Mantyla, 1996; Graf & Uttl, 2001). We (Graf & Uttl, 2001) have argued that this difference in conscious experiences associated with different prospective memory tasks is analogous to the experiences that characterize primary and secondary memory (James, 1890). By analogy to William James (1890), we have proposed that prospective memory proper requires that "we are aware of a plan, of which meanwhile we have not been thinking, with the additional consciousness that we had made the plan earlier" (Graf & Uttl, 2001, p. 444). This definition distinguishes ProM Proper from vigilance and monitoring, that is, from prospective memory tasks that dominate working memory and conscious awareness during the retention interval.

Moreover, some tasks, such as taking medication at bedtime, are referred to as habitual ProM tasks (Harris, 1984; Meacham, 1982) and involve the execution of the same plan in response to the same cue many times over; other tasks, such as buying groceries, are referred to as episodic ProM tasks and require the execution of the plan only once. This distinction between habitual and episodic ProM tasks is analogous to the distinction between semantic and episodic memory tasks (Graf & Uttl, 2001).

Table 1 highlights the correspondence between the subdomains of retrospective and prospective memory. Although these distinctions have been recognized in the literature, they are frequently ignored. Only a careful reading and analysis of the method section of an article reveals whether a particular study is concerned with ProM Proper rather than with vigilance/monitoring or habitual ProM.

Table 1. The subdomains of retrospective and prospective memory.

Retrospective memory	Prospective memory
Short-term/Working Memory	**Vigilance/Monitoring**
Looking up and dialing phone number	Preventing a kettle from boiling over
Long Term Memory	**ProM Proper**
Encoding and recollecting past events	Buying groceries en route home
Semantic Memory	**Habitual ProM**
Knowing facts, things, and procedures	Taking medication every day

ProM vs Retrospective Memory

One of the distinguishing features of ProM, as opposed to RetM, is the recognizing of cues as signs of previously formed plans when the cues appear as part of ongoing thoughts, actions, or situations (Craik, 1983, 1986; Graf & Uttl, 2001). To illustrate, when driving by the supermarket, no one alerts us to pay attention to this cue and no one instructs us that we should stop there and get the groceries. These similarities and differences are highlighted in Table 2 (adapted from Graf & Uttl, 2001). As illustrated, the critical difference between ProM and RetM tasks is that for all RetM tasks participants are alerted to the cues and instructed to work with them in a task-relevant manner. In contrast, for ProM tasks, participants are not alerted to the presence of the cues nor are they reminded to work with them in the manner relevant to the previously conceived plan.

In applying the idea of transfer appropriate processing (TAP; Morris, Bransford, & Franks, 1977) to the ProM domain, Meier and Graf (2001) highlighted another difference between ProM and RetM. For RetM tasks, TAP predicts that RetM test performance depends on the degree of processing overlap between study and test. In contrast, the ProM tasks allow for two kinds of processing transfers: a sequential transfer dependent on the overlap between planning stage processing and ongoing task process-

Table 2. Properties of Explicit, Implicit, and Prospective Memory test

Type of memory test	Cues provided at test	Participants alerted to cues at test	Participants alerted to relevance of cues
Explicit	Yes	Yes	Yes
Implicit	Yes	Yes	No
Prospective	Yes	No	No

ing, and a concurrent transfer dependent on the overlap between ongoing ongoing task processing and ProM cue processing (see Figure 1; see also Maylor, 1996; Darby & Maylor, 1998). Early studies support TAP both for sequential transfer (McDaniel, Robinson-Riegler, & Einstein, 1998) and for concurrent transfer (Meier & Graf, 2001); they suggest that the TAP principle also applies within the domain of ProM.

Dynamic Interplay Between ProM Cue and Ongoing Task

As stated earlier, ProM Proper depends critically on whether the cue interrupts the ongoing activity and whether we become aware of its relevance to the previously formed plan. However, whether the ProM cue manages to interrupt the ongoing activity is dependent upon the nature and momentum of the ongoing activity. Thus, ProM depends on the dynamic interplay between the ongoing task demands and the ProM cue properties.

Research has already identified several properties of ProM cues that make them more intrusive, more likely to be noticed, and more likely to interrupt the ongoing task. These factors include the appearance of the ProM cue on center vs off center of ongoing task focus (Uttl & Ohta, 2004), ProM cue size (Graf, Uttl, & Dixon, 2002; Uttl & Graf, 2000a), ProM cue distinctiveness (Brandimonte & Passolunghi, 1994; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; Graf et al., 2002; Uttl & Graf, 1999), and ProM cue novelty (Brandimonte & Passolunghi, 1994; Einstein & McDaniel, 1990; McDaniel & Einstein, 1993).

On the other side of this dynamic equation are the properties and demands of the ongoing task. First, ongoing tasks vary in the degree to which they demand resources and, consequently, they leave more or fewer resources for processing of ProM cues. Moreover, participants may decide to allocate more or fewer resources to the ongoing task. To illustrate, Uttl and Graf (2000a) required 111 older participants to perform a resource-demanding A/B card sorting task (i.e., ongoing task) on three consecutive blocks of trials. Participants performed the ongoing task alone on the first block. On the second block, they performed the ongoing task while various photos of common objects appeared on the computer screen at the same time as each to-be-sorted card. The third critical block of trials was the same as the second block except that the ProM cue appeared embedded among the photos of objects. Uttl and Graf found that ProM performance—stopping the ongoing task when the ProM cue was noticed and recognized as relevant to the previously formed plan—was strongly related (r = -.74) to the difference between speed of A/B card sorting on the third vs the first block of trials. Participants who allocated more resources to the ongoing task performed more poorly on the ProM task and vice versa. Other researchers have reported similar negative effects of the ongoing task demands on ProM performance using a variety of tasks located closer to the vigilance/monitoring end of the prospective memory task continuum (e.g., Marsh, Hancock, & Hicks, 2002; Kidder, Park, Hertzog, & Morrell, 1997; West & Craik, 1999).

Second, ongoing tasks also vary in the flow of ongoing activities, making some tasks easier to interrupt than other tasks. Graf (2004, also see this volume) distinguishes between high vs low ongoing task momentum. High momentum tasks are smooth and rapid-flowing with minimal unfilled pauses whereas low momentum tasks are slow-moving and include many unfilled pauses. To illustrate, in the study by Uttl and Graf (2000a) discussed earlier, each decision immediately triggered the appearance of the next card and the start of the next trial. Thus, the flow of the ongoing activities was rapid and a strong negative correlation was observed between the degree of resource allocation to the ongoing task and ProM Proper. In contrast, Uttl & Graf (2002) used the same A/B card sorting task but participants had to wait and watch for the start of the next trial that appeared several hundred milliseconds later. The insertion of these inter-trial pauses slowed down the flow of the ongoing task and lowered the correlation between the index of resource allocation to the ongoing task and ProM performance.

Assessment of ProM Proper

Despite a growing interest in ProM, progress has been impeded by a lack of valid, reliable, and efficient measures of ProM. As already noted, most of the previous investigations have measured ProM by recording either success or failure on ProM tasks, thereby confounding ProM and RetM components in a single index of performance. Moreover, the vast majority of prior investigations has indexed ProM performance either by a single success/failure trial or by an average of multiple success/failure trials. The principal limitation of single success/failure indexes as measures of any ability is that they are inefficient; they provide only a very coarse measurement of underlying abilities, and they frequently are limited by ceiling and floor effects. Unfortunately, the averaging of success/failure data across multiple trials to obtain a more finely-graded index of ProM performance is also problematic because repeated responding to ProM cues ensures that the ProM plan remains in participants' consciousness and such a summary indexes no longer reflects ProM Proper but rather vigilance/monitoring. Thus, a critical challenge in the assessment of ProM

Proper is to develop and validate multiple measures that gauge ProM independently of RetM (see above) and yield continuous indexes of performance.

We have recently developed a continuous index of Visual ProM Proper based on a simple idea. Our approach employs ProM cues (pictures) whose intrusiveness (i.e., size) increases over time to the point of being almost impossible not to notice. The dependent variable is the cue size when participants respond to it. Specifically, participants are shown a ProM cue – a picture of a helicopter or a teddy bear – and they are told to stop whatever they are doing when they notice the ProM cue anytime and anywhere in the experiment. In the experiment, participants are engaged in an attention-demanding ongoing task, the A/B card-sorting task described earlier. While sorting the cards, pictures of common objects appear in various sizes in the four corners of the screen and the pictures are replaced by different pictures with each key press. The size of each picture is determined randomly from trial to trial within the specified range. At some random point, the ProM cue appears among these pictures. If a participant fails to notice the ProM cue, it appears again a few trials later, but this time in a larger size. The cue grows larger across trials until the participant responds to it or until the maximum size is reached. In a series of experiments, we have demonstrated that this method provides a valid and reliable index of ProM Proper in both young and older adults (Uttl & Graf, 1999, 2000a, 2000b, 2000c, 2002; Graf, Uttl, & Dixon, 2002).

Section Summary

ProM is divided into subdomains of ProMP, vigilance, and habitual ProM. Failure to acknowledge the differences between ProMP, vigilance, and habitual ProM hinders the interpretation of previous research findings, leads to contradictory findings, and likely impedes progress in ProM research. Moreover, although it has long been recognized that performance on ProM tasks reflects both prospective and retrospective components, one of the current challenges in measurement of ProM is to measure the prospective component uniquely, eliminating or at least reducing the RetM load on ProM task performance. Another challenge is to replace inefficient binary success/failure indexes of ProM with reliable and valid continuous indexes of ProM.

Age-related Differences in Prospective Memory Proper

Theoretical Expectations

In his influential account, Craik (1983) proposed that all memory tasks can be arranged on a continuum according to the degree to which they provide environmental support (e.g., cues). Moreover, tasks providing little or no environmental support require the greatest amount of subject-initiated processing. By this view, augmented by the assumption that aging results in a reduction of processing resources, memory tasks providing little or no environmental support would be expected to show the largest age-related declines. Craik's view predicts that, in general, ProM Proper will show larger age-related deficits than will explicit episodic RetM because by their very nature ProM tasks provide little or no environmental support. Overall, the wealth of accumulated research on RetM supports Craik's theoretical account, but thus far there has been insufficient research to clarify whether ProM Proper is consistent with it. Previous research has revealed age-related declines in ProM Proper in adults 65 years and older (Uttl & Graf, 1999; Graf et al., 2002) but it is not yet clear whether such declines are larger than in RetM.

In related theoretical accounts, Pichora-Fuller, Schneider, and Daneman (1995) and Schneider and Pichora-Fuller (2000) have argued that age-related declines in performance on a variety of cognitive tasks may be the result of impoverished stimulus representations due to age-related declines in sensory functions (Anstey, Stankov, & Lord, 1993; Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994; Salthouse, Hancock, Meinz, & Hambrick, 1996). By this view, declines in sensory functions (e.g., visual acuity, auditory acuity) lead to impoverished or inaccurate representations of stimuli, and in turn, the impoverished representations demand more top-down processing, deplete limited processing resources, and in turn lead to degradation in other resource-demanding cognitive processing. Cast in Craik’s (1983) framework, age declines in sensory functioning result in less environmental support for older adults and demand more self-initiated processing. Given the age declines in sensory functioning and the necessity for the ProM cue to be noticed and to interrupt the ongoing activity, we may expect large age declines on ProM tasks and a strong relation between sensory functioning and ProM task performance.

It is also possible, however, that declines in both cognitive and sensory functioning are caused by a third factor, such as widespread neural degeneration, decrements in the vascular system, or a loss of temporal synchrony (Lindenberger & Baltes, 1994; Salthouse et al., 1996). According to this perspective, for example, age-related changes in neuronal matter serving both peripheral and central processing cause declines both in sensory abilities such as visual and auditory acuity and in cognitive abilities such as memory and reasoning. Regardless of which theoretical view ultimately prevails, all accounts predict age declines in performance on ProM tasks, and all emphasize the relation between sensory functioning and ProM performance.

Review of Prior Research and Methods

The starting point for the majority of research on age-related changes in prospective memory has been Craik's (1983) prediction that age effects would be particularly large on prospective vs other memory tasks. Surprisingly, in one of the early attempts to examine Craik's prediction, Einstein and McDaniel (1990) found no age-related deficits in prospective memory and proposed that "prospective memory seems to be an exciting exception to typically found age-related decrements in memory" (p. 724). In the flurry of studies that have followed their unexpected discovery, Einstein, McDaniel, their colleagues and others who adopted Einstein and McDaniel's prospective memory task (Cherry & LeCompte, 1999; Cherry et al., 2001; Einstein et al., 1995; Kliegel, McDaniel, & Einstein, 2000; McDaniel, Einstein, Stout, & Morgan, 2003) continue to find no age-related declines in prospective memory. Yet other researchers continue to find substantial age-related declines on ProM Proper as well as on other prospective memory tasks (e.g., Uttl & Graf, 1999; Graf et al., 2002; Huppert, Johnson, & Nickson, 2000; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; Rendell & Craik, 2000; Uttl et al., 2001). What could account for these discrepant findings and contradictory claims?

Age effects are limited by ceiling effects

Figure 2 reviews the size of age effects found in various experimental conditions in studies that have investigated age-related differences in event-cued prospective memory. This figure shows the magnitude of age declines (i.e., young minus older adults' performance) as a function of older adults' performance. The figure highlights that (a) older adults performed more poorly than younger adults in the vast majority of conditions, and (b) older adults' performance strongly predicts, in linear fashion, the size of age-related declines: The closer the older adults are to the ceiling, the smaller are the age-related declines. In the extreme, when older adults reach maximum scores, age declines are predicted to be zero. This is not because of the lack of age-related decline in any ability, however, but

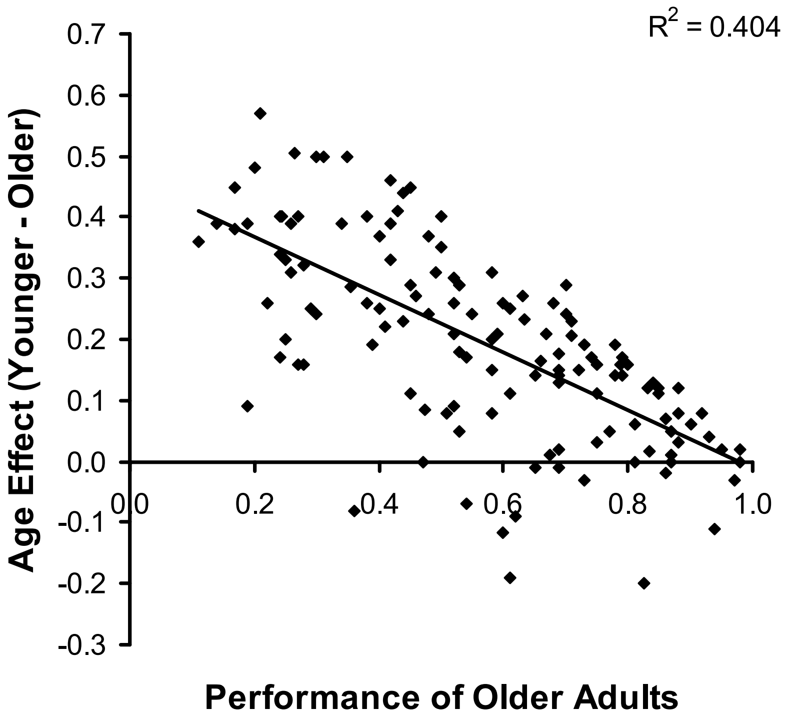

Fig. 2. The size of age declines (i.e., performance of younger minus performance of older adults) in prospective memory as a function of older adults' performance. Each data point is based on mean performance of younger and older adults expressed as proportion correct in one experimental condition. The figure is based on data from 40 published studies with 133 experimental conditions.

rather because of ceiling effects in performance due to ProM tasks that are too easy.

Figure 2 highlights that ceiling effects in measurement likely reduce age-related differences in the majority of studies that have investigated age-related changes in ProM and are responsible for at least some of the null findings. Although some researchers acknowledge that their ceiling-limited data should not be used to make inferences about the lack or size of age-related differences in performance (e.g., Maylor, Smith, Della Sala, & Logie, 2002; Uttl et al., 2001), others have nevertheless interpreted them as indicating that age does not impact the abilities necessary for performance on prospective memory tasks. Such interpretation of ceiling-afflicted data is unwarranted.

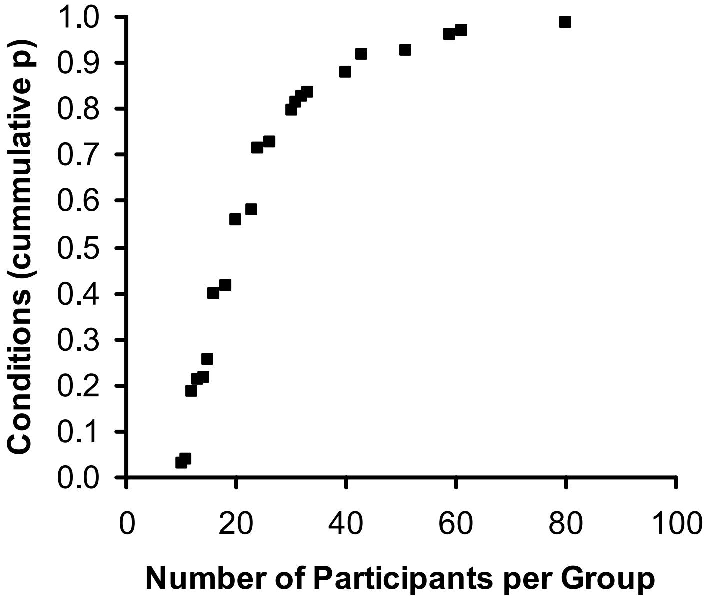

Fig. 3. The cumulative proportion of experimental conditions as a function of number of participants in each age group.

Low statistical power ensures null age effects

The review of previous research indicates that many studies have used such small numbers of participants in various experimental conditions that the chance of finding even a large age effect (0.8 SD) has been smaller than that of flipping heads on a fair coin. If we assume that age declines in ProM are as large as 0.8 SD, we need at least 26 participants per age group to find such a large effect statistically significant 80 times out of 100 (Cohen, 1988, 1992a, 1992b). However, the review reveals that experimental conditions rarely have included more than 26 participants per age group.

Figure 3 shows a cumulative proportion of experimental conditions as a function of the number of participants in each age group and in each experimental condition. This figure shows that more than 70% of all comparisons in prior research were based on fewer than 26 participants in each of the two age groups, and that a substantial proportion of studies (40%) used 16 or fewer participants per group. Thus, the null effects of age observed in some of the smaller-sized studies may be due to low statistical power. Any claims that aging does not affect performance on prospective memory tasks based on such small sample sizes are not warranted by existing data.

Binary success/failure measures are inefficient and imprecise

To measure an individual's performance on prospective memory tasks, almost all previous investigations of ProM have used either a single success/failure trial (with a success scored as 1 and a failure scored as 0) or an average across multiple success/failure trials. As discussed earlier, the principal limitation of a single success/failure index as a measure of any ability is that it provides only a very coarse measurement of any underlying ability and is unable to measure fine individual differences in relevant abilities.

In the absence of continuous measures of prospective memory, many investigators have chosen to present participants with a ProM cue repeatedly and to average success/failure data over repeated ProM cue presentations. To illustrate, Einstein and McDaniel (1990) presented each participant with three ProM cues and averaged the three success/failure observations to obtain less coarse performance estimates for each participant. However, even this measurement gradation, combined with only 12 participants in each condition, results in large jumps in condition means caused entirely by a single participant's performance: one participant's poor performance could lower the mean proportion in an experimental condition by as much as 0.08.

To obtain a finer gradation in measurement, other investigators have presented examinees with as many as 20, 30, or even more ProM cues (e.g., Martin, Kliegel, & McDaniel, 2003; McDermott & Knight, 2004; Rendell & Craik, 2000; Vogels, Dekker, Brouwer, & de Jong, 2002). To illustrate, Rendell and Craik (2000) engaged participants in a board game called "virtual week." During the course of the game, participants moved a token around the board according to the number shown on a simulated die. Each circuit of the board represented one day and was completed by participants in 5 to 10 minutes. Each "day," participants were to perform ten ProM tasks including four irregular (event-based) tasks. Accordingly, on average, participants were to perform one ProM task every 30 to 60 seconds. Similarly, participants in the Martin et al. (2003) study were encountering a ProM cue every 120 seconds. As explained earlier, the difficulty with this approach is that repeated responding to ProM cues ensures that the ProM plan remains in participants' consciousness and that the performance index no longer reflects ProM Proper but rather vigilance/monitoring.

Low reliabilities ensure null effects and small effect sizes

In general, a large measurement error associated with unreliable measures increases the variability of observed scores, decreases the likelihood of finding statistically-significant effects, and results in smaller variability-based indexes of effect size. Whereas reliabilities of many standard word list memory tests have been established and are generally high, typically ranging from 0.70 to 0.80, reliabilities of the various prospective memory tasks are mostly unknown. Only a few studies have attempted to examine the reliability of prospective memory scores, and the results of these studies are not encouraging. To illustrate, Einstein et al. (1997) found that reliability, assessed by a correlation between two blocks of trials, each based on two ProM cue presentations, was only 0.46. However, this correlation was computed using all participants regardless of specific experimental conditions and reflects not only the reliability of measurement but also large differences in performance among experimental conditions. The actual reliability of Einstein and McDaniel's task is unknown; it may be higher, lower, or even the same. Thus, the extent to which observed scores on most of the prospective memory tasks reflect random measurement error or variability in true abilities is unknown.

If prospective memory measures are less reliable than retrospective memory measures, age-related differences (indeed, differences due to any manipulations) in prospective memory will be more difficult to find due to larger standard deviations and greater dispersions of observed scores. Moreover, the error-inflated variability in observed scores will reduce effect size indexes based on variability (i.e., d, r, r^2, η^2, etc.) and underestimate the magnitude of age-related declines in prospective memory. Finally, a lack of reliability will underestimate any relation between performance on prospective memory tasks and other measures of cognition, such as indexes of processing resources, measures of frontal functions, and intelligence. In turn, unknown reliabilities of prospective measures make many interpretations of the magnitude of age effects (except those expressed as a simple difference between two proportions) and strengths of relations between prospective memory and other aspects of cognition superfluous and any derived theoretical claims questionable.

Many studies include age-related confounds

A number of studies frequently cited as evidence of no age decline in ProM have incorporated into their design age-related confounds that most likely improve performance of older adults, decrease performance of younger adults, and consequently minimize age-related differences on ProM tasks (studies with age confounds). First, many investigators have made the ongoing task easier for older adults (e.g., Cherry & LeCompte, 1999; Cherry et al., 2001; Einstein et al., 1990, 1992, 1995, 2000; McDaniel et al., 2003; Reese & Cherry, 2002). Second, Cherry and LeCompte (1999) and Reese and Cherry (2002) compared highly intelligent older adults with low intelligence younger adults. To the extent that intelligence is positively related to performance on ProM tasks as observed by these authors, any claims about effects of age in these studies are confounded by an intelligence difference between the age groups.

Moreover, several studies have failed to ensure that the experimental conditions were the same for both younger and older adults and that younger and older adults were comparable on important participant characteristics (studies with other confounds). In several studies (Cockburn & Smith, 1994; Martin et al., 2003; Kliegel et al., 2000), participants were to ask for their belonging at the end of the experiment, and different participants gave experimenters different items. Mantyla and Nilsson (1997) conducted a population-based study of ProM, and inspection of participant characteristics reveals that those in their older groups frequently scored within the impaired range on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975).

These age-related confounds are certain to reduce the magnitude of the observed age-related declines; failing to recognize such confounds will result in incorrect conclusions about the size of age-declines (see discussion below and Figure 4).

Age declines are larger on ProM Proper than on vigilance

Based on the theoretical distinction between ProM Proper and vigilance/monitoring, we might expect larger age effects on tasks indexing primarily ProM Proper than on tasks indexing primarily vigilance/monitoring, at least to the extent to which noticing and recognizing the relevance of the ProM cue to the previously formed plan requires processing resources.

Any quantitative analysis of previous research, however, is complicated by severe ceiling effects as well as by other methodological problems already discussed. To the extent that ceiling effects are more frequent in

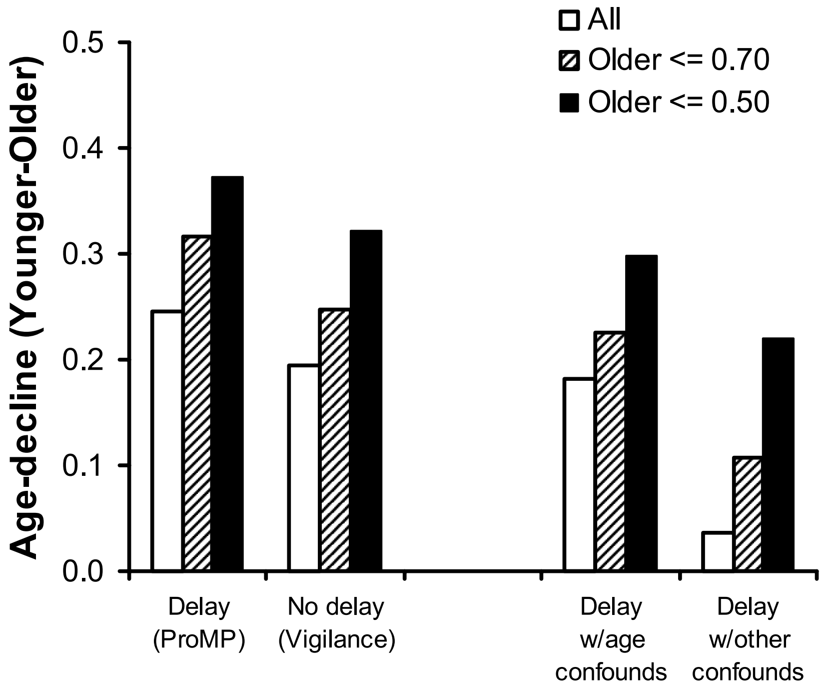

Fig. 4. Mean age declines observed in previous research. The left panel shows the mean age decline observed in conditions that incorporated a delay between ProM instructions and ProM test phase (Delay) vs conditions that included no such instruction-test delay (No-Delay) and did not confound age with other experimental or participant variables. The right panel shows the mean age decline observed in conditions that included an instruction-test delay but also included age-related confounds benefiting older adults (Delay with age confounds) and conditions that included other confounds (Delay with other confounds). Three means for each type of condition are shown: The first mean includes all age comparisons; the second mean includes only conditions where performance of older adults was equal to or below 0.70; and the third mean includes only conditions where performance of older adults was equal to or below 0.50.

studies focusing on either ProM Proper or vigilance/monitoring, the comparison of age effects in these two subdomains of ProM may be confounded by ceiling-limited scores.

The left panel of Figure 4 shows the mean age decline observed in conditions that incorporated a delay between ProM instructions and the start of the ProM test phase (Delay) vs conditions that included no such instruction-test delay (No-Delay) and did not confound age with other experimental or participant variables. The Delay group includes conditions that allowed the plan to leave consciousness, and therefore, are the most likely to measure ProMP (Cohen et al., 2001; Dobbs & Rule, 1987; Einstein et al., 1995; Graf et al., 2002; Huppert et al., 2000; Kliegel et al., 2000; Martin et al., 2003; Rendell & Craik, 2000; Rendell & Thomson, 1999; Tombaugh et al., 1995; Uttl et al., 2001; West, 1988). The No-Delay group includes conditions that most likely measure vigilance/monitoring rather than ProMP (Cohen et al., 2003; d'Ydewalle et al., 1999; d'Ydewalle et al., 2001; Einstein et al., 1997; Kidder et al., 1997; Logie et al., 2004; McDermott & Knight, 2004; Mantyla, 1993; Maylor, 1994, 1996, 1998; Maylor et al., 2002; Park et al., 1997; Vogels et al., 2002; West et al., 2003; West & Craik, 2001).

Figure 4 shows three means for each type of task: the first mean includes all age-comparisons, the second mean includes only conditions where performance of older adults was equal to or below 0.70, and the third mean includes only conditions where performance of older adults was equal to or below 0.50. As expected from the analyses shown in Figure 2, age declines are larger when condition means are less limited by ceiling effects, giving age effects a chance to emerge. More importantly, the figure shows that age declines are larger on ProMP than on vigilance, highlighting the distinction between the two ProM subdomains (see also Brandimonte, Ferrante, Feresin, and Delbello, 2001).

The right panel of Figure 4 shows the mean age decline observed in conditions that have included an Instruction-Test Phase Delay (i.e., indexing primarily ProMP) but have also included age-related confounds benefiting older adults, as well as other confounds (see the earlier section). As expected, age declines are smaller in conditions with age confounds benefiting older adults (Delay w/age confounds) than in Delay (ProMP) conditions. The mean age declines in Delay with other confounds conditions are difficult to interpret for at least two reasons. First, the effect of these confounds is unclear and second, only a few conditions are included in this group of conditions.

Section Summary

In light of the preceding review and the evidence summarized in Figures 2 and 4, the notion that older adults perform as well as younger adults on prospective memory tasks is incorrect. Rather, the previous research indicates that both ProMP and vigilance show substantial declines with aging, and that these declines have been underestimated in a large portion of the previous studies due to methodological shortcomings such as ceiling-limited scores and age confounds in research design. Indeed, based on the data in Figure 2, one might wish to claim that the strongest predictor of age declines is researchers' ability to avoid ceiling effects in measurement (Uttl, in press)!

Aging and Visual and Auditory Cued ProM Proper

The previous research on aging and ProMP has focused exclusively on visually cued ProMP. The new study described below examines age-related changes in both visually and auditorily cued ProMP. The motivations for this study were three-fold: (1) to generalize the previous findings to a new modality, (2) to examine the notion that age-declines on cognitive tasks are related to declines in sensory functions (e.g., Anstey, Stankov, & Lord, 1993; Baltes & Lindenberger, 1997) within ProMP domain, and (3) to examine predictions about ProMP and aging using a stronger, multivariate design.

The specific aims were to examine the prediction that ProMP is more sensitive to aging then RetM, to determine if age declines in visually and auditorily cued ProMP are comparable, to examine the relation between sensory functions and ProMP, and to determine the extent to which age declines in ProMP can be explained by age declines in sensory functions and processing resources. To examine these questions, the study employed a continuous index of Visual ProMP developed in our recent research (Uttl & Graf, 1999, 2000a, 2000b, 2000c; Graf et al., 2002) and a newly developed continuous index of Auditory ProMP (Uttl & Graf, 2002).

Participants and Design

Participants were 29 younger (*M* =19.5 years, range = 18 to 22) and 36 older (*M* = 74.1 years, range = 46 to 94) adults. The younger adults were undergraduate student volunteers who participated for course credit. The older adults were volunteers recruited via newspaper advertising and word of mouth.

Table 3 shows the design of the study. Younger adults participated in only one session whereas older adults participated in two sessions separated by a one-week delay. In each session, participants' ProM was assessed once with an Auditory ProMP task and once with a Visual ProMP task.

Table 3. The study design and the sequence of critical tasks. Younger adults participated in only one session whereas older adults participated in two sessions separated by a one-week delay.

Younger	Older
Session 1	**Session 1**
...	...
ProM Instructions	ProM Instructions
VLT/U	VLT/U
A/B Card Sorting + Auditory ProMP	A/B Card Sorting + Auditory ProMP
...	...
ProM Instructions	ProM Instructions
...	...
A/B Card Sorting + Visual ProMP	A/B Card Sorting + Visual ProMP
...	...
	Session 2 (one week after Session 1)
	...
	ProM Instructions
	VLT24/RA
	A/B Card Sorting + Auditory ProMP
	...
	ProM Instructions
	...
	A/B Card Sorting + Visual ProMP

Procedure

Participants were tested individually as part of a larger study on cognitive aging. Testing took place in a quiet room with ambient noise levels below 45 dB. All visual stimuli were presented on a 17-inch Sony Trinitron Flat Screen monitor and all auditory stimuli (except pure tones for testing auditory acuity) were presented using a pair of high-quality Yamaha speakers. Young participants were tested in a single session lasting about 1.5 hours whereas older participants were tested in two 1.5 to 2 hour long sessions scheduled one week apart. The order of critical tasks was fixed as shown in Table 3 only the assessment instruments relevant to the present report are described below.

Visually Cued ProMP. The index employs ProM cues (pictures) whose intrusiveness (i.e., size) increases over time to the point of being almost impossible not to notice and the dependent variable is the cue size when a participant responds to it. During the ProM instruction phase,

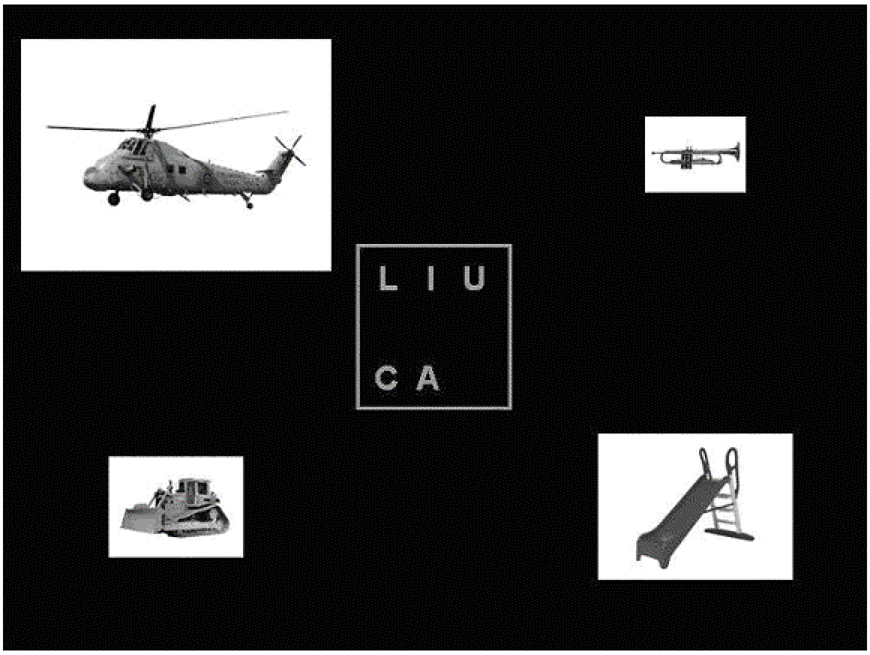

Fig. 5. An example of the material displayed for the A/B Card Sorting task and for assessing ProM on Visual ProMP. In the actual experiment, pictures were presented in color.

participants are shown the ProM cue and told to stop whatever they are doing when they notice the ProM cue anytime and anywhere during the experiment. During the ProM test phase, participants are engaged in an attention-demanding ongoing task – sorting cards displayed on a computer monitor by pressing either left or right arrow keys. While sorting the cards, pictures of common objects appear in various sizes in the 4 corners of the screen; the pictures are replaced by different pictures with each key press. The size of each picture is determined randomly from trial to trial within the specified range. The ProM cue appears at random among these pictures. If a participant fails to notice the ProM cue, it appears again a few trials later, but this time in a larger size. The cue grows larger across trials until a participant responds to it or until a maximum size is reached. A sample display is shown in Figure 5. In a series of experiments, we have demonstrated that this method provides a valid and reliable index of ProM Proper in both young and older adults (Uttl & Graf, 1999, 2000a, 2000b, 2000c; Graf et al., 2002).

Auditorily Cued ProMP. A newly-developed continuous index of Auditory ProMP is based on the same idea: The ProM cues are sounds whose intrusiveness (i.e., loudness) increases over time to the point of being difficult not to notice, and the dependent variable is the cue loudness when a participant responds to the cue. Specifically, participants are played a ProM cue – a camera clicking or the sound of a car horn – and are told to stop whatever they were doing when they notice the ProM cue anytime and anywhere during the study. In the experiment, participants are engaged in the same card sorting task used for assessment of Visual ProM Proper. While sorting the cards, digitized natural sounds (e.g., water running, door bell) are played from the speakers via a SoundBlaster card. The loudness of the sounds is determined at random within the specified range. The ProM cue appears at random among these sounds. If a participant fails to respond to the ProM cue, the cue appears again a few trials later, but this time louder. The cue becomes louder across trials until the subject detects it or until the maximum loudness is reached. Preliminary findings with undergraduate students showed that this new Auditory ProM Proper index is reliable (test-retest reliability $r = .81$) and only weakly correlated with measures of retrospective memory ($r < .30$), thereby demonstrating divergent validity in college students (Uttl & Graf, 2002).

Explicit RetM. Explicit RetM was assessed using two verbal learning tests (VLT) patterned after the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1964; Spreen & Strauss, 1998). The first VLT included lists of 20 unrelated words (VLT/U); the second VLT included lists of 24 related words selected from four different categories (VLT/R). Both tests were administrated according to the instructions for the RAVLT published in Spreen and Strauss (1998) except that only three study-test trials were given instead of five.

Visual Acuity. Far and Near visual acuity was assessed with standard Snellen charts. Far Visual Acuity (FVA) was measured from a distance of 3m; Near Visual Acuity (NVA) was measured at reading distance of 40cm. All measurements were taken with participants' presenting optical corrections and converted to LogMar equivalents (Holladay, 1997).

Auditory Acuity. Air-conducted auditory pure-tone thresholds (dB) were obtained for five different frequencies: 250, 500, 1000, 2000, and 4000 Hz.

Processing Capacity. Processing capacity was measured by the A/B card sorting task (Uttl, Graf, & Cosentino, 2000).

Vocabulary. Participants' vocabulary knowledge was assessed using a shorter version of the North American Adult Reading Test called NAART35 (Uttl, 2002) that requires participants to pronounce 35 English words with irregular spelling.

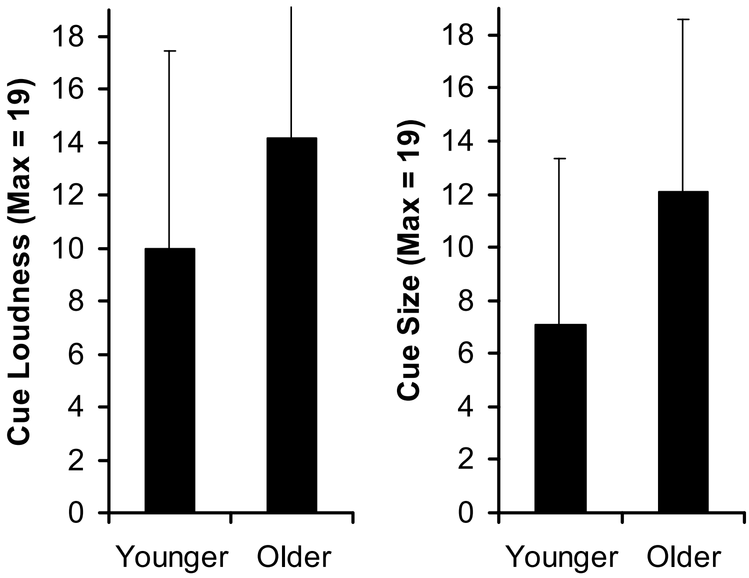

Fig. 6. Mean cue loudness required for ProMP response on Auditory ProMP (left panel) and mean cue size for Visual ProMP (right panel). Error bars represent one standard deviation.

Results and Discussion

Two sets of analyses were conducted. The first set of analyses compares performance of younger and older adults (between-groups analyses). The second set of analyses focuses on correlational analyses within the older adult group that take advantage of more reliable measurement of ProMP due to multiple assessments of both Auditory and Visual ProM within the older adult group (within older-group analyses).

Between Group Analyses

Consistent with extant results from prior RetM research, older adults recalled fewer words than younger adults on all trials; older adults also recalled fewer words (M = 6.1, SD = 3.6) than younger adults (M = 8.7, SD = 2.8) after a 20-minute delay, $t(63) = 3.24$, $p = 0.002$. More importantly, Figure 6 shows participants' performance on the two indexes of ProMP.

Table 4. Correlations within older adults.

	1. Age	3. FVA	4. NVA	5. Hear	6. Aud ProM	7. Vis ProM	8. VLT/U LDR
1. Age							
3. FVA	0.29						
4. NVA	**0.40**	**0.57**					
5. Hear	**0.62**	0.29	0.21				
6. Aud. ProM	**0.62**	**0.44**	0.33	**0.39**			
7. Vis. ProM	**0.57**	**0.47**	0.31	0.16	**0.63**		
8. VLT/U LDR	**-0.47**	**-0.36**	**-0.53**	**-0.42**	**-0.59**	**-0.39**	
10. CS	**0.65**	**0.40**	**0.43**	**0.49**	**0.61**	**0.49**	**-0.52**

Note: FVA = Far Vision Acuity (logMar); NVA = Near Vision Acuity (logMar); Hear = better ear Hearing Level (dB); VLT/U LDR = Verbal Learning Test with unrelated words, 20-min. Long Delay Recall (#correct); CS = A/B Card Sorting (ms). Correlations printed in bold are significant with $p < 0.05$.

Compared to younger adults, older adults required larger cues on the Visual ProMP tests, $t(63) = 3.26$, $p = 0.002$, and louder cues on the Auditory ProM test, $t(63) = 2.59$, $p = 0.012$.

Within older-group analyses

Visual ProMP, Auditory ProMP, RetM, and Aging. Table 4 shows correlations between age, visual and auditory acuity, Visual and Auditory ProMP, RetM, and processing resources. Consistent with well-established prior research findings, free recall of unrelated words after a 20-minute delay was negatively correlated with age, $r = -.47$. This age-related decline in retrospective memory was obtained on all recall trials. More importantly, the analyses of ProMP performance revealed strong age-related declines in both Visual and Auditory ProMP, $r = 0.57$, $p < 0.05$, and $r = 0.62$, $p < 0.05$, respectively. In combination, these findings suggest that age-related declines on the indexes of ProMP are larger than age-related declines on free recall retrospective memory tests.

ProMP, RetM, and Processing Resources. Table 5 shows the results of hierarchical regression analyses aimed to elucidate the relative contribution of processing resources to age declines on ProMP indexes vs RetM. The data in the table show that A/B Card Sorting, an index of processing resources, explained similar proportions of overall variability in RetM and Visual ProMP but a larger proportion of variability in Auditory ProMP.

Table 5. Hierarchical regression analyses.

	Visual ProM		Auditory ProM		RetM	
	Δr^2	R^2	Δr^2	R^2	Δr^2	R^2
Age only						
Age	**.32**	**.32**	**.39**	**.39**	**.23**	**.23**
Resources + Age						
1. A/B Card Sorting	**.24**	**.24**	**.37**	**.37**	**.27**	**.27**
2. Age	**.11**	**.35**	**.09**	**.46**	.03	**--**
% Age	66		77		87	
Sensory systems + Age						
1. Vision	**.23**	**.23**				
2. Hearing	**--**	**.23**				
1. Hearing			**.16**	**.16**	**.17**	**.17**
2. Vision			**.12**	**.28**	**.20**	**.37**
3. Age	**.21**	**.43**	**.19**	**.47**	.02	**--**
% Age	34		51		91	

Note: Values printed in bold are significant with $p < 0.05$.

More importantly, A/B card sorting explained the largest amount of age-related variability on RetM and smaller amounts on Auditory ProMP and Visual ProMP.

ProM, RetM, and Sensory Functions. The next set of analyses was designed to elucidate the contribution of sensory functioning to performance on ProM Proper and RetM. Consistent with extant prior research (Botwinick, 1967; Fozard, 1990), the hearing data revealed substantial age-related declines in pure tone auditory acuity; the tones had to be louder for older adults than for younger adults, $r = 0.62$. Similarly, the visual acuity data showed large age-related declines in both Near and Far Visual Acuity, with older adults requiring larger print than younger adults, $r = 0.29$, and r = 0.40, respectively (see Table 4).

Table 5 shows the results of hierarchical regression analyses aimed at determining whether these age-related declines in sensory functions mediated age declines in Visual and Auditory ProMP as well as in RetM. These analyses show that although sensory functions explained all or almost all age-related variability in RetM, they explained only 34% and 51% of age-related variability in Visual ProMP and Auditory ProMP, respectively.

Section Summary

The findings from this study demonstrate that both Visual and Auditory ProMP decline with age and suggest that the magnitude of age-related declines in Visual and Auditory ProM Proper are larger than declines in RetM. Although processing resources explain all or almost all age-related declines in RetM, they explain only a part of age declines in ProMP. Similarly, whereas age-related declines in sensory functions account for all or almost all of age-related declines in RetM, they account for only 34% of age declines in Visual ProM and only about 51% of age declines in Auditory ProM.

Conclusions

Graf and Uttl (2001) have argued that ProM is best divided into several subdomains, with ProMP, vigilance, and habitual ProM as parallels to episodic, short-term, and semantic memory in the RetM domain. The quantitative review of prior research shows substantial age-related declines on both ProMP and vigilance/monitoring tasks. Moreover, the review reveals more pronounced age declines on ProMP than on vigilance/monitoring tasks, supporting the distinction between these two subdomains of ProM and illuminating one possible source of confusion regarding the magnitude of age-related declines on ProM. Consistent with the dynamic competition for limited processing resources between ProM and ongoing task demands, the research review also revealed that age declines were smaller when the ongoing task was made easier for older vs younger adults or when studies compared much more intelligent older vs younger adults. These findings are similar to those observed in the RetM domain showing that age declines in RetM can be minimized when older vs younger adults are given more study time or when more intelligent older adults are compared to less intelligent younger adults.

Perhaps the most striking new finding showed that the best predictor of age declines in ProM is researchers' success in avoiding ceiling effects. Of course, this finding tells us little about processes involved in ProM but it calls (or should call) our attention to the methods we are using in this relatively new research field. The finding underscores the necessity to develop better methods for assessing ProM.

The new research findings showed large age-related declines on Visual ProMP and extended the previous research by showing large age-related declines in Auditory ProMP. Moreover, similar to the RetM domain, portions of these age declines in ProMP can be explained by processing resources and by sensory functions. In contrast to RetM, however, a substantial portion of age declines in ProMP remains unexplained by processing resources or by sensory functions. In combination, the review of prior research and the new research findings are consistent with Craik's (1983, 1986) prediction of substantial age declines on ProMP tasks, and they highlight the importance of processing resources and degradation in sensory functions in mediating age declines in ProMP.

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