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RESEARCH

AGING EFFECT IN PROSPECTIVE MEMORY MONITORING: AN EYE-TRACKING STUDY

Abstract

Introduction: Prospective memory is a robust predictor of functional capacity among older adults. Studies examining prospective memory and aging have suggested that prospective memory deficits are associated with aging. Although the impairment of prospective memory processes is mostly attributed to the impairment of the monitoring process, contradictory findings have been reported in the literature. This study aimed to determine the main factors underlying the negative effects of aging on prospective memory. To this end, we compared the monitoring performances of older and younger adults in time- and event-based prospective memory tasks using the eye-tracking method.

Materials and Method: A total of 88 healthy and voluntary participants participated in the experiment. The time- and event-based prospective memory tasks were presented on a computer-screen. Participants were instructed to count the living/non-living objects, and when they saw the prospective memory target on the right corner of the screen, they were asked to press the spacebar on the keyboard.

Results: A 2×2 analysis of variance was conducted. We found an age-related decline in event-and time-based prospective memory. In addition, the aging effect was greater in the time-based prospective Memory task, which requires more executive function than the event-based prospective memory task. The eye-tracking findings suggest that there is no monitoring deficit among older adults in either prospective memory task.

Conclusion: We conclude that aging deficits in prospective memory tasks may not be due to monitoring deficits. Instead, executive functions other than monitoring are discussed as possible mechanisms underlying older adults' reduced prospective memory performance.

Keywords: Memory; Aged; Young Adult; Executive Function; Eye-Tracking Technology.

INTRODUCTION

Prospective memory (PM) is to remember to perform a planned action at the necessary time or place (1,2). Remembering a dentist appointment at 14.00 on Saturday is an example of a PM task. Existing literature suggests that there are two types of PM tasks: time-based and event-based PM (1). Time-based PM involves performing a pre-planned action at the appropriate time by retrieving that actual action, whereas event-based PM refers to performing a pre-planned action after detecting an environmental cue and retrieving that action. Recently, with changing age demographics worldwide, more attention has focused on the effect of aging on PM (3). One reason for this is that PM is a vital cognitive function for older adults in terms of health needs (e.g., remembering medication). Moreover, PM deficit is an early marker of Alzheimer's disease (4).

Among older adults, PM is a robust predictor of functional capacity (5). Most laboratory studies examining PM and aging have revealed aging-related deficits (3). However, contradictory results exist in the studies focusing on PM task types (Event-based PM or Time-based PM) that have demonstrated that the elderly perform poorer in time-based PM tasks compared to event-based PM tasks. (6). Compared to event-based PM tasks, time-based PM tasks involve self-initiated processes and are based more on executive functions, especially strategic monitoring processes (7,8). These results suggest that the poorer performance of older adults compared with younger adults in time-based PM tasks is due to their limited strategic monitoring resources (7). According to the executive framework of PM, several core executive functions (including inhibition, working memory, set-shifting, and strategic monitoring) play a crucial role during certain PM stages (9). In particular, strategic monitoring, which is defined as shifting attention from the ongoing task to the PM task at the appropriate moment, is essential for PM (10). One reason for this is that individuals monitor the external environment for the appearance of PM cues. Given the essential role of executive functions attributed to PM, this framework predicts that age-related differences in executive functions mediate age-related differences in PM performance (9).

Although the age-related impairment of PM processes is mostly attributed to the impairment of the strategic monitoring process (10), more recent literature has emerged that offers contradictory findings on the effect of aging on strategic monitoring (11,12). These studies suggest that strategic monitoring is not affected by aging (11,12). These controversial results may be related to methodological limitations, however. A commonly used behavioral indicator for strategic monitoring is the so-called "ongoing task cost". Ongoing task cost is the decrease in the performance of an ongoing task while performing a PM task (13). However, it has been suggested that the ongoing task cost is associated with short-term relief experienced, rather than strategic monitoring after completing a PM task (12). Studies that compare older adults and younger adults in terms of ongoing task cost have shown that regarding the balance between speed and accuracy, older adults take a lot longer to deliver an accurate PM reaction (14,15). In this respect, the need to measure strategic monitoring using a direct method rather than an indirect one, such as ongoing task cost, is a contentious issue (13).

Strategic monitoring can be measured directly, especially by providing a target outside the ongoing task area and taking eye-tracking records. Physiological data based on eye-tracking records provide detailed information to understand and explain the mechanisms underlying many complex cognitive processes such as attention (16), visual perception (17), and memory (11,13). For this reason, it is frequently used in the fields of "Psychology" and "Neuroscience". In the PM research area, although only a few studies have investigated strategic monitoring using the eye-tracking method (11,13), these studies have shown that eye-tracking methods are ideal instruments to measure strategic monitoring directly. One study compared the strategic monitoring performances of older and younger participants in event-based PM tasks using the eye-tracking method and demonstrated that there was no difference between older and younger participants in terms of strategic monitoring, unlike behavioral measurements (11). In this study, the researchers did not utilize the time-based PM task. Although strategic monitoring has mostly been investigated in event-based PM tasks, it is well-known that there is a greater need for strategic monitoring in time-based PM tasks (18). In this context, the effect of aging on strategic monitoring in time-based PM tasks should be investigated using an eye-tracking method.

The main aim of this study was to compare the strategic monitoring performance of older and younger adults in time-based PM and event-based PM tasks using the eye-tracking method. To our knowledge, this study is the first study to compare event and time-based PM monitoring in older adults. If older adults have poorer strategic monitoring abilities, then their strategic monitoring performance will be lower in both PM tasks than that of younger individuals. In this case, we can conclude that older adults' reduced PM performance may stem from impaired monitoring. Furthermore, considering that time-based PM requires higher strategic monitoring processes, participants would perform more strategic monitoring on a time-based PM task than on an event-based PM task. On the other hand, if there is no difference between younger and older adults regarding their strategic monitoring abilities, we can conclude that the poor PM performance of older adults might not be directly linked to the strategic monitoring process. In either case, this study will contribute to exploring how strategic monitoring affects the decline in PM among older adults. This study examines the effect of aging on strategic monitoring in event-based PM and time-based PM tasks using eye-tracking and provides new insights into aging and PM research.

METHOD

Participants

A total of 88 healthy individuals, comprising 46 younger adults (32 females; M_{age}= 20.74; SD=1.23) and 42 older adults (14 females; M_{age}= 68.82; SD= 4.17) voluntarily participated in the study. The younger adult participants were studying at Hacettepe University, while the older adult participants were living in Ankara, Turkey. All participants had normal or corrected-to-normal vision, no history of neuropsychological or psychiatric disorders, and had not been taking medications that affected the nervous system in the past six months. Table 1 presents the demographic characteristics.

To select "healthy" participants, the Montreal Cognitive Assessment (19) and the Geriatric Depression Scale (20) was used for older adult participants, whereas the Beck Depression Inventory (21) was used for younger adult participants. Nine individuals' data of those who took the above score from the cut-off score in Depression Inventories were excluded from the behavioral analyses. Thus, we conducted behavioral analyses with 79 participants. Also, the eye-tracking data of 13 participants, whose eye-tracking data quality was lower than 70% were excluded from the eye-tracking data analyses. Thus, we conducted eye-tracking analyses with 66 participants. Table 1 lists the test results. Informed consent was obtained from all the participants.

MATERIALS

Prospective Memory Tasks

In this study, we used the eye-tracking method to obtain a more objective and direct measurement of strategic monitoring in PM tasks. In light of this, we used a slightly modified version of the PM task developed by Shelton and Cristopher (13).

Event-based PM and time-based PM tasks included an ongoing task and a PM task that was presented simultaneously. In both PM tasks, the

Table 1. Demographic characteristics and screening test scores of participants

	Event-Based PM		Time-Based PM	
	Younger Adults	Older Adults	Younger Adults	Older Adults
Age (M* ± SD*)	20.90 ± 1.55	68.67 ± 3.62	20.56 ± 0.70	69.00 ± 4.81
Sex (%)	Male (%28.6) / Female (%71.4)	Male (%23.8) Female (%76.2)	Male (%27.8) Female (%72.2)	Male (%31.6) Female (%68.4)
Education (M ± SD)	13.33± .26	14.66 ± .45	13.55± .28	13.79± .44
Depression Scales** Score (M ± SD)	5.26±3.92	3.39±.42	4.96±3.91	3.45±.45
Working Memory Score***	10.14± 1.24	6.71±1.35	10.01±1.05	6.26±1.45
MoCA* Score (M ± SD)		24.5±0.42		25.4±0.3

Note:*M: Mean, SD: Standard deviation, MoCA: Montreal Cognitive Assessment. ** Depression scales represent the Beck Depression Inventory for young adults and Geriatric Depression Scale for older adults. *** Working Memory Scores represent the Wechsler Adult Intelligence Scale-Revised (WAIS-R) Backward Digit Span subtest.

PM target and ongoing task area were positioned at different locations on the screen. The ongoing task region was located at the center of the screen, whereas the PM target region was located in the top right-hand corner (Figure 1 A and B).

In the ongoing task trials for both event-based PM and time-based PM, there were a total of 12 black and white images at the center of the screen, including living objects and non-living objects in every trial. In the event-based PM condition, the ongoing task of the participants was to count the living objects presented as black and white image collages, whereas in the time-based PM condition, they were asked to count non-living objects.

In PM tasks, hand-drawn black and white images (fruit and vegetables in event-based PM and a digital clock starting at 8 a.m. and running until 9.59 a.m. in time-based PM) were shown in the PM target

Figure 1. Example of sub-trail in event-based PM (A) and time-based PM (B) tasks.

A

B

area in the top right corner of the screen. In the PM task, participants were asked to press the space bar on the keyboard whenever they saw the PM target stimuli (when they see an "apple" for instance, or every 25 minutes according to the "digital clock") while performing the ongoing task. The PM target in event-based PM was an "apple" whereas in time-based PM the PM targets were "08.25," "08.50," "09.15," and "09.40". The screen time for each PM trial was 2 s. The PM targets were displayed in only four trials in random order.

The images used in each trial were different. To select the images to be used in the ongoing task, we used the Google search engine to search for non-commercial and royalty-free images that could be reused. The collages comprised images that had high external validity and that were neutral living and non-living objects.

Both PM tasks consisted of 40 ongoing task trials. The screen time for each ongoing task (living/non-living object task) trial was 6 s, and the screen time for each PM task trial was 2 s (see Appendix 1). The purpose of changing images in the PM target region was to encourage overt strategic monitoring for targets, which is often required in more dynamic real-world visual scenes (13). Each task (event-based PM and time-based PM tasks) lasted approximately 5 min.

Eye Movement Recording

Tobii T120 eye tracker was used to collect the eye movement data of participants in the study. Tobii T120 is equipped with a buried eye-tracking server and a 17" TFT monitor with a resolution of 1280 × 1024.

Eye movements were recorded throughout the experiment, and the PM task area was defined in Tobii Studio for each task trial as the area of interest (AOI).

Procedure

Participants who voluntarily responded to the (study) announcement were given individual appointments. Before the experiment commenced, participants were given detailed information about the study. Written informed consent was obtained from all participants for voluntary participation. Younger adults completed the Demographic Information Form and Beck Depression Inventory, and the Geriatric Depression Scale and Montreal Cognitive Assessment were administered to older adult participants. After the screening tests, the younger and older participants were randomly assigned to the event-based PM and time-based PM task groups. The task type (event-based PM and time-based PM task) variables of this study were designed as "between-group," which differed between these two groups. Participants were requested to count the living objects on the screen in event-based PM or the non-living objects in time-based PM (an ongoing task) and to say the number out loud. Ongoing task responses were recorded by the researcher on a scoring form. While performing the ongoing task, participants were asked to press the space bar on the keyboard whenever they saw the PM target stimuli (when they see an "apple", for instance, or every 25 minutes according to the "digital clock"). After the instructions were issued, participants were positioned 55–65 cm away from the screen of the eye-tracking device, and a practice session consisting of five ongoing task trials was conducted. After the practice trials, a 2 min distractor phase, which included listing the male or female names starting with the letter A, was applied. The main experimental session was conducted after the distractor phase. After completion of the experimental phase, the Wechsler Adult Intelligence Scale-Revised (WAIS-R) Digit Span subtest (22) was administered to all participants to measure their working memory performance. The experiment lasted approximately 20 min.

This study was approved by the Hacettepe University Ethics Committee (letter no. 12908312-300).

Statistical Analysis

Behavioral analyses were conducted with 79 participants (39 younger and 40 older adults) and eye-tracking analyses with 66 participants (34 younger and 32 older adults). All analyses were performed using Statistical Package for the Social Sciences (IBM®, SPSS 22). The data were analyzed using a 2 (age: younger and older adult) × 2 (task type: event-based PM and time-based PM) analysis of variance (ANOVA). Both the independent variables "age" and "task type" were manipulated between groups.

RESULTS

Strategic Monitoring

Strategic monitoring was measured with both ongoing task accuracy rate (behavioral data) and the number of PM target checks, which were "apple" check-in event-based PM tasks and "clock" check-in time-based PM tasks (eye-tracking data).

Ongoing Task Accuracy Rate

Ongoing task accuracy, which is the behavioral measurement of strategic monitoring, was measured by the number of correct living (event-based PM) or non-living (time-based PM) stimuli specified by the participants in each trial. The ongoing task accuracy rate was calculated by dividing the total number of accurate responses by the number of trials. In line with previous studies (14), ongoing task trials involving the PM target were removed from the ongoing task analysis to avoid any limitation resulting from only the performance of the PM task.

According to the results of the 2 (age: older adult vs. younger adult) × 2 (task type: event-based PM vs. time-based PM) ANOVA, the main effect of age group on the ongoing task accuracy rate was significant ($F_{(1,75)}$=78.721, p <.000, η_p^2= .512). Younger adults (M = .81, SE = .01) performed better in the ongoing task than older adults (M = .69, SE=.01). The main effect of task type ($F_{(1,75)}$= .209, p= .649, η_p^2= .003) and the interaction effect of age group and task type ($F_{(1,75)}$=.156, p = .694, η_p^2= .002) were not significant.

Number of PM Target Checks

The number of PM target checks was the total number of participants fixated on the PM target area (top right-hand corner of the screen) to detect PM targets ("apple" and "clocks") across all task trials.

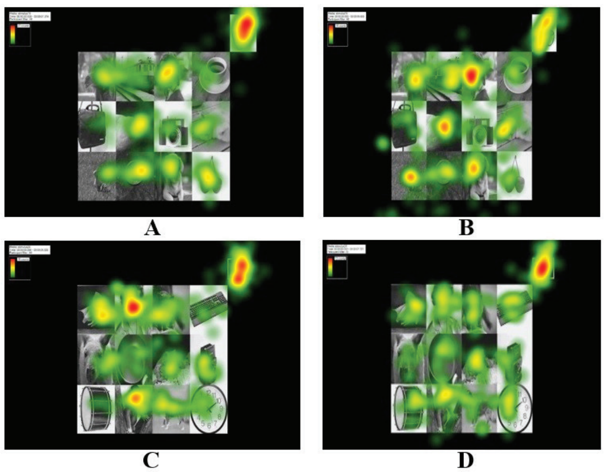
According to the results of the 2 (age: older and younger adults) × 2 (task type: event-based PM and time-based PM) ANOVA, the main effect of age group ($F_{(1,62)}$=2.3, p =.134, η_p^2= .036), task type ($F_{(1,62)}$= 2.2, p= .143, η_p^2= 003.) and the interaction effect of age group and task type ($F_{(1,62)}$=.002, p = .96, η_p^2= .000) were not significant (see Figure 2).

Prospective Memory Performance

PM Accuracy Rate

Regarding PM performance, this was operationalized as the rate at which participants hit the space bar after a PM target appeared. According to the results of the 2 (age: old vs. young) × 2 (task type:

Figure 2. Heatmaps of event-based PM and time-based PM tasks.



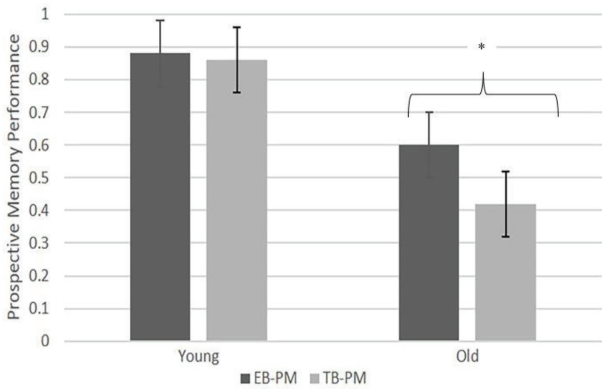
Note: Figure A represents the younger participants' event-based PM task, Figure B represents the older participant's event-based PM task, Figure C represents the younger participant's time-based PM task, and Figure D represents the older participants' time-based PM task.

event-based PM vs. time-based PM) ANOVA, the main effects of age ($F_{(1,75)}$=72.04, p <.001, η_p^2= .491) and task type($F_{(1,75)}$=4.27, p<.05, η_p^2= .054) were significant. Younger adults (M = .88, SE = .03) were more successful in PM accuracy than older adults (M = .51, SE=.03). On the other hand, both age groups were more successful in the event-based PM task (M = .74, SE = .03) than in the time-based PM task (M = .65, SE = .03). In addition, the interaction effect of age and task type ($F_{(1,75)}$=3.73, *p*<.05, η_p^2= .047) was significant; the simple effect test was examined and the results were as expected, indicating that older adult participants were more successful in the event-based PM task (M=.59, SE= .04) than in the time-based PM task (M=.42, SE= .04) ($F_{(1, 75)}$ = 8.11, p<.01, η_p^2 = .61). However, in terms of PM accuracy in younger adult participants, there was no difference between event-based PM (M=.88, SE= .04) and time-based PM (M=.86, SE= .05) tasks ($F_{(1, 75)}$ = .000, *p*=.924, η_p^2 = .000) (see Figure 3). Descriptive analysis of results is summarized in Table 2.

Further Correlation Analysis

The PM accuracy rate was found to be positively correlated to working memory performance in both young and older adults (respectively, r = .42, p < .05; r = .61, p < .001) (Table 1).

Figure 3. PM accuracy rate as a function of task type and age group.



Note: Error bars represent standard errors per conditions

DISCUSSION

This study examined the effect of aging on the monitoring process in event-based and time-based PM tasks. We hypothesized that the main reason for the decline in PM tasks that require more attentional control in older adults is impaired monitoring. In this context, we compared older and younger adult participants in different PM tasks (time-based PM event-based PM tasks). Apart from the behavioral measures of monitoring, we utilized the eye-tracking task used by Shelton and Cristopher (13) to measure monitoring directly.

Table 2. Descriptive statistics for ongoing task accuracy, PM check number, and prospective memory performance

	Young Aduts				Older Adults			
Task Type	EB-PM*		TB-PM*		EB-PM		TB-PM	
	M*	SD*	M	SD	M	SD	M	SD
OTAR*	.80	.06	.81	.04	.68	.06	.69	.06
PMAR*	.88	.15	.86	.18	.59	.27	.42	.15
NPMC*	196.16	34.72	186.62	24.35	186.41	18.51	176.31	26.82

Note: *EB-PM: Event-based PM, TB-PM: Time-based PM, M: Mean, SD: Standard Deviation, OTAR: Ongoing task accuracy rate, PMAR: Prospective memory accuracy rate, NPMC: Number of PM checks.

The findings of the PM performance showed that there was an age-related decline in both PM tasks. Furthermore, we found greater age differences in time-based PM than in event-based PM, as expected (23,24). This finding supports studies suggesting that time-based PM is more affected by aging because of its greater reliance on self-initiated processes and executive functions (25,26). The observed increased age-related decline in time-based PM can be explained by the multi-process framework, which states that older adults are less able to perform resource-demanding tasks that involve preparatory attentional processes required to detect prospective cues.

The main purpose of this study was to determine whether there is an age-related decline in strategic monitoring in different PM tasks (event-based PM and time-based PM) to find out how monitoring patterns might be related to differences in PM performance. Therefore, we operationalized strategic monitoring as the number of PM target checks (eye-tracking measurement) and ongoing task accuracy rate. We found no age-related decline in the number of PM checks; however, an age-related decline in the ongoing task accuracy rate was observed. How do we explain the discrepancy between the behavioral and eye-tracking measures of strategic monitoring? As mentioned in the introduction section, the behavioral indicator of monitoring is the decrease in ongoing task accuracy while performing a PM task (ongoing task cost). That cost may represent short-term relief experienced, rather than strategic monitoring after completing a PM task. Therefore, one can argue that the eye-tracking measurement of strategic monitoring measures the monitoring process directly and is more accurate than behavioral measurement. In this context, the findings of the current study are significant in revealing the importance of direct measurements in the measurement of strategic monitoring.

The results of the number of PM target checks indicate that the decline in PM performance of older adults cannot solely be attributed to their monitoring processes. Similarly, Ballhausen, Lauffs, Herzog, and Kliegel (11) examined the event-based PM task and found no age-related decline in strategic monitoring. These findings suggested that older participants may not realize the importance of the PM cues when they appear in the PM target area, even when participants follow PM cues. Furthermore, these findings can be explained by the executive framework, which suggests that monitoring, as well as several core EFs (including, *working memory*, *inhibition*, and *set-shifting*), play crucial roles during certain PM stages. For example, *working memory* serves to maintain or refresh the prospective intention that needs to be recalled each time a prospective cue appears. *Inhibition* is needed to end the ongoing task (the prepotent response) and activate the novel PM response. *Set shifting* is also required in PM because participants need to switch continuously between ongoing and PM tasks as a function of the presence of the PM cue (9,26). Supporting this conclusion, we found a moderate positive correlation between working memory measurement (WAIS-R Digit Span test performance) and PM accuracy rate both in young and older adults. To clarify this issue, future studies should examine whether other executive functions, such as inhibition, set-switching, and working memory contribute to PM performance in older adult participants.

It is essential to note that, the present study compared directly event-based and time-based PM monitoring behavior using eye-tracking methods, for the first time, in older adults. From this point, we consider the results of this study to be very valuable and believe future studies should focus on designing new eye-tracking paradigms to shed light on the above topics and inform theoretical discussions in the PM literature.

The limitation of the present study includes the clock in the time-based PM task, which did not work in real-time. Previous studies have shown a positive relationship between time perception and time-based PM performance (27). Even though the participants were informed that the clock was not working in real-time, this may have created an inconsistency in their time perception, which in turn may have led to a decrease in strategic monitoring performance in time-based PM performance. Clock manipulation in the time-based PM is another limitation of this study that should be addressed in future research.

In conclusion, the current study suggests that older adults showed lower PM performance in time-based PM tasks than in event-based PM tasks. The results suggest that the strategic monitoring process supports but is not sufficient for successful PM performance. It is important to determine the mechanism underlying the age-related decline in PM to find appropriate solutions that will increase PM performance among older adults. Based on this, it is suggested that future studies should examine the contribution of inhibition, set-shifting, and working memory to PM to identify the underlying mechanism of age-related decline in PM.

Declaration of Conflicting Interests

We declare that there is no conflict of interest.

Appendix 1. Pilot Study

We have conducted a pilot study separately in age groups (10 young, M_{age} = 21.35, SD= .7; 10 old, M_{age}= 63.12, SD=1.1) to determine screen time of ongoing and PM tasks. In the pilot study, participants conducted 5 trials of the ongoing task. For each trial, the reaction time was measured. As a result of the pilot study, the mean of the counting task (ongoing task) time of the young participants in each trial was 5.87 s (SD=.63), and the mean of the counting task time of the older participants was 6.79 s (SD=.57). As a result of the independent t-test analysis, it was shown that there was no statistically significant difference between the young and older adults in terms of counting task time ($t(18) = .03$, $p > .05$). The descriptive analysis results of the pilot study are shown in Table A1. Based on the results of this analysis, the screen time of ongoing tasks was determined as 6 s for both age groups.

Based on the 1/3 ratio (PM task trial/Ongoing task trial= 1/3) in Shelton and Cristopher's study (13), the screen time of the PM trials for young participants was 2.10 s (5.87/3); it was calculated as 2.37 s (6.79/3) for the older participants. Therefore, for both young and older participants, the screen time of the PM trial was 2 s in each trial, while the screen time for the ongoing task was 6 s.

Table A1. Descriptive Statistics of Pilot Study

N=20	The shortest reaction time	The longest reaction time	Mean (M)	Standart Deviation (SD)	t-test value
Younger Adults	4.83	8.76	5.87	.63	.03
Older Adults	5.05	9.49	6.79	.57	

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