Title

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Abstract

Aging is associated with task-specific changes in eye movements, and thus eye movements during mind wandering (MW) in older adults may differ from young adults. We showed that changes in number of fixations or fixation duration were associated with MW in young adults when searching for information but not older adults, possibly due to aging-related changes in these measures. Similarly, larger variance in pupil diameter change was associated with MW when imagining a scenario in young but not older adults, possibly related to aging-related affect stability. In contrast, lower eye movement consistency was associated with MW when implementing well-learned visual routines in older but not young adults, possibly related to their higher susceptibility to MW interferences. Reduced joint attention with another participant was associated with MW for tasks involving clearly defined strategies for both young and older adults. These results have important implications for monitoring task engagement through eye tracking.

Keywords: mind wandering, eye tracking, EMHMM, learning

Introduction

As the world population ages, there has been a significant rise in older Internet users, increasing from 12% in 2000 to 67% in 2016 (Anderson & Perrin, 2017). The Internet provides numerous educational and intervention opportunities, and it is crucial to evaluate whether older adults are attentive to the provided content. This consideration brings attention to the concept of mind wandering (MW), defined as the shift of attention from task-related information to task-irrelevant thoughts (American Psychological Association, 2018). MW disrupts learning, making the identification of MW episodes essential for optimizing training outcomes in older adults.

Most existing studies have focused on using eye movement measures to identify MW episodes in younger adults. For instance, longer fixation duration was associated with MW during video lectures (Zhang et al., 2020) and scene viewing (Faber et al., 2020). However, inconsistent results have been reported. For example, shorter rather than longer fixation duration was identified as MW indicators when participants looked at the screen during audiobook listening (Faber et al., 2020). A smaller number of fixations was associated with MW in scene encoding task (Zhang et al., 2021) but not in the audiobook listening task (Faber et al., 2020). These findings suggest that eye movement markers of MW may be task specific. Indeed, recent research has suggested that eye movements during a visual task is driven by task demands (Kanan et al., 2015; Hsiao & Chan, 2023). To address this issue, Teng et al. (2024) tested the hypothesis that different eye movement measures, including number of fixations, average fixation duration, pupil diameter change, eye movement consistency and joint attention (JA), may be associated with MW in tasks involving different task demands, including tasks involving "clearly defined strategies", "imagining a scenario", "well-learned visual routines", and "searching for information". Consistent with their hypothesis, they found that a reduced number of fixations was associated with MW in tasks involving "searching for information", whereas a larger variance in pupil diameter and reduced eye movement consistency was associated with MW in tasks involving "imagining a scenario". Also, reduced eye movement consistency and JA with another participant were associated with MW in tasks involving "clearly defined strategies". However, none of the eye movement measures tested was associated with MW in tasks involving "well-learned visual routines" such as face identification. This may be because a well-learned visual routine requires minimal attentional resources to implement in young adults, rendering the tested eye movement measures ineffective in capturing MW episodes.

While Teng et al.'s (2024) findings are informative for young adults, it remains unclear whether those indicators apply to older adults as well. Previous studies have shown that older adults exhibited lower MW frequency than young adults (Maillet & Schacter, 2016a), and their thoughts during MW are generally more pleasant (Maillet et al., 2018), stimulus-dependent, and past-oriented (Maillet & Schacter, 2016b; Irish et al., 2019). Thus, eye movements during MW in older adults may differ from young adults. In addition, age-related differences in eye movements during cognitive tasks have been commonly reported (Whitehead et al., 2018; Wynn et al., 2020) and shown to be associated with cognitive decline in older adults (Chan et al., 2018). For example, older adults had longer fixation duration than young adults when searching for information on smartphones or in real-world photographs, suggesting difficulties in local processing (Al-Showarah et al., 2014; Williams et al., 2009). They also had a larger number of fixations at the central part of the screen in web-based information-search tasks than younger adults due to their reduced size of useful field of view (Romano et al., 2013). Similarly, Ho et al. (2001) found that older adults had a larger number of fixations during visual search for traffic signs. Therefore, while a smaller number of fixations or longer fixation duration were good MW indicators for young adults for tasks involving searching for information, they may not be good indicators for older adults.

In addition, emotional stability has been shown to increase with age (Burr et al., 2020), with older adults experiencing lower affect variability (Carstensen et al., 2000; Röcke et al., 2009) due to better emotion regulation capabilities than young adults (Gross et al., 1997; Blanchard-Fields, 2007; Shiota & Levenson, 2009), making them require less cognitive efforts to regulate emotions. For instance, young adults showed impaired cognitive performance after regulating emotions during a distressing film, whereas older adults did not (Scheibe & Blanchard-Fields, 2009). In young adults, MW during tasks requiring imagining scenarios was associated with larger variance in pupil diameter changes (Teng et al., 2024; Partala & Surakka, 2003). Pupil dilation is reported to be associated with emotional arousal, with an increased pupil size observed while viewing or imagining emotional images (Bradley et al., 2008; Whipple et al., 1992). Thus, larger variance in pupil size changes in young adults may reflect fluctuating internal emotional states. In contrast, emotional stability in older adults may reduce their emotional state changes during imagining a scenario, making variance in pupil diameter changes not a good MW indicator for them.

Older adults also differ from young adults in where they attend to during cognitive tasks. For example, Chaby et al. (2017) showed that older adults were more likely to focus on the lower part of a face during emotion recognition whereas young adults showed more exploratory gaze behavior. A similar phenomenon was observed in face recognition, where eye movement patterns in older adults were more focused at the face center, in contrast to young adults, who focused more on the eyes (Chan et al., 2018). Since eyes are the most diagnostic feature for face recognition, this finding suggests that aging leads to reduced cognitive abilities in implementing the well-learned visual routine due to cognitive decline (Chan et al., 2018; Hsiao et al., 2022). Thus, as compared with young adults, older adults' eye movements during tasks involving implementing a well-learned visual routine may be affected more by MW, leading to reduced eye movement consistency. In other words, reduced eye movement consistency may be a good MW indicator for older adults, in contrast to young adults (Teng et al., 2024).

For JA, Teng et al. (2024) found that reduced JA with another participant was associated with MW in tasks involving clearly defined strategies, since participants typically followed similar strategies and thus reduced JA may indicate reduced task engagement. Consistent with this finding, previous studies have reported that higher percentage of JA was associated with better collaboration quality (Schneider & Pea, 2013) as well as improved task performance/learning outcomes (Schneider et al., 2016, 2018). As for older adults, since previous research has reported a similar JA effect in older adults to young adults, although with a slower time course (Deroche et al., 2016), we speculated that a similar MW effect may be observed in older adults, where reduced JA would be associated with MW in tasks involving clearly defined strategies.

Accordingly, to examine eye movement markers associated with MW episodes in older adults here we adopted the same tasks from Teng et al. (2024), which could be categorized into four task types: tasks involving (1) "clearly defined strategies"; (2) "imagining a scenario"; (3) "well-learned visual routines"; and (4) "searching for information". We hypothesized that in contrast to young adults, 1) fixation behaviors including number of fixations and fixation duration may not be good MW indicators for tasks involving "searching for information" due to their increased number of fixations and fixation duration in general during cognitive tasks; 2) A larger variance in pupil diameter change may not be a good MW indicator for tasks involving "imagining a scenario" due to their enhanced emotional stability; 3) Lower eye movement consistency may be a good MW indicator for tasks involving "well-learned visual routines" due to their declined cognitive abilities for implementing the visual routine, making their eye movement behavior more easily affected by MW; 4) Reduced JA may be a good MW indicator for tasks involving "clearly defined strategies", which is similar to young adults.

Methods

Participants

We recruited 34 participants (22 females and 12 males) aged 60 to 82 (M = 67.2, SD = 6.2) from the local population. They had normal or corrected to normal vision with glasses. To ensure the robustness of the linear mixed-effects models (LMM) analysis, we conducted a power analysis using R with the simr package (Green, 2016). To examine the MW effect in each task type, y ~ MWCondition + (1 | SubjectID) + (1 | SubTaskType) was used as the model equation to simulate data with fixed and random effect parameters based on previous studies (Faber et al., 2020), indicating that 30 participants would achieve 80% power. To examine whether a behavioral MW indicator is specific to a particular task type, the equation y ~ MWCondition * TaskType + (1 | SubjectID) + (1 | SubTaskType:TaskType) was used, indicating that 25 participants would achieve 81% power. Thus, the sample size provided sufficient power for the current study.

Materials

We replicated tasks from Teng et al. (2024), designed based on "recall", "interpret" and "evaluate" criteria according to the National Assessment of Educational Progress (National Assessment governing board, 2022). Each participant performed 10 tasks which were further categorized into four types of tasks by answering the host's questions verbally.

(1) Tasks involving a clearly defined strategy ("clearly defined strategy")

(1.1) Sound judgment between two alternative choices This task consisted of 30 trials. During each trial, participants listened to a 5-second sound while fixating on a central sound icon (1.26° x 0.97° visual angle). They were then instructed to choose one of two images (9.58° x 6.45°) displayed on the left and right sides of the screen that corresponded to the sound. All sounds and images were from everyday scenarios.

(1.2) Preference of a place between two different times This task consisted of 10 trials. During each trial, participants viewed two side-by-side images of local scenes (9.58° x 6.45°), with the left one depicting an earlier time period of the place. Participants were asked to indicate their preference.

(2) Tasks involving imagining a scenario while maintaining a central fixation ("imagining a scenario")

(2.1) Imagining playing with toys This task consisted of 20 trials, with each trial displaying a toy image at the center of the screen (16.11° x 9.69°). Participants were asked to evaluate its level of interest and provide their explanation.

(2.2) Imagining working with celebrities This task included 10 trials, each showing an image of a local celebrity (9.88° x 9.98°). Participants were asked to decide if they would like to shoot a movie or sing with the celebrity.

(3) Tasks involving well-learned visual routines/diagnostic features ("well-learned visual routines")

(3.1) Person Identification This task consisted of 10 trials. During each trial, participants saw a photograph of a local celebrity (9.88° x 9.98°). They were instructed to identify the person and engage in a brief discussion.

(3.2) Scene Identification This task consisted of 20 trials, each presenting a scene image (12.86° x 7.61°) at the top center of the screen. Participants were instructed to identify the scene and list common objects found in that setting.

(3.3) Preference of a person This task consisted of 10 trials. In each trial, participants viewed a photo of a local celebrity (9.88° x 9.98°). They were asked to express their preference for the individual and provide reasons during the discussion.

(4) Tasks involving searching for information without a clearly defined strategy ("searching for information")

(4.1) Video viewing This task consisted of five trials. In each trial, participants watched a 30-second video of current affairs (13.77° x 7.81°).

(4.2) Place Comparison This task consisted of 10 trials, each featuring two images of local scenes (9.58° x 6.45°). The image on the left depicted the location during an earlier time period, while the image on the right showed the same place in a more recent era. Participants were instructed to identify the differences of the place between two periods.

(4.3) Tic-Tac-Toe This task included 10 trials. Participants played the game against the host five times by drawing on a chessboard (9.74° x 9.74°) displayed on the screen. The other participant was asked to view the whole process.

Design

In our experimental protocol, each interactive learning session was conducted via Zoom with three individuals: a host (the investigator) and two participants. The investigation of MW episodes employed the thought probe method (Risko et al., 2012). Specifically, during the experiment, participants responded to a post-trial probe inquiring about their attentional state (i.e. the thought probe) during the trial. Trials were then classified into MW or No-MW trials based on these responses for subsequent data analysis. The thought probe method has been commonly used in the literature on MW and shown to have similar results to the self-report method (Varao-Sousa & Kingstone, 2019).

Our analysis focused on several eye movement behavioral parameters as potential indicators of MW. These metrics included average number of fixations per second, average fixation duration, variance of pupil diameter change, eye movement consistency (measured by overall entropy and marginal entropy of the first fixation), and percentage of JA (participants' shared attention with both the other participant and the host; see the Eye Movement Data Analysis section for further details).

To examine whether these eye movement behavioral measures could indicate MW across task types, we employed LMMs to do the analyses. These analyses were conducted using the *lme4* package (Bates et al., 2015) in R (version 4.2.3; R Core Team, 2023), with p-values calculated using the *lmerTest* package (Kuznetsova et al., 2017). For each dependent variable (i.e. eye movement behavioral measures outlined in our hypotheses), we first examined whether MW had a significant effect within each task type using the formula Dependent variable ~ MW condition + (1| Subject) + (1| Sub Task Type). Here, MW condition was included as the fixed effect, while subject and sub-task type were treated as random effects. If a significant MW effect was detected for a specific task type, this type was treated as the reference category to further examine whether the dependent variable was a unique indicator of MW for that specific task type. The subsequent formula was specified as Dependent variable ~ MW condition * Task Type + (1| Subject) + (1| Sub Task Type : Task Type), which incorporated MW condition, task type, and their interaction as fixed effects, while subject and sub-task types (nested within task type) were included as random effects. For both formulas, MW condition was coded using treatment contrasts, with the no-MW condition chosen as the reference category for MW condition.

Apparatus

Each participant completed the online learning tasks using a 10.4-inch tablet (2000 x 1200 pixels in resolution) to join Zoom. Eye movement data were captured with an EyeLink eye tracker (EyeLink 1000, EyeLink 1000 Plus, or EyeLink Portable Duo) integrated with WebLink software for tablet-based data collection. A chin rest was employed to minimize head movement, maintaining a fixed viewing distance of 59 cm. All eye trackers operated in pupil and corneal reflection tracking mode at a 1000 Hz sampling rate. The EyeLink default cognitive research parameters were applied for data acquisition, including a saccade motion threshold of 0.1° of visual angle, a saccade acceleration threshold of 8000°/s², and a saccade velocity threshold of 30°/s.

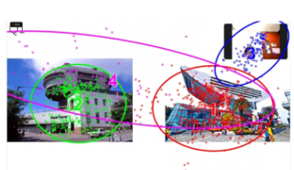
Procedure

Before the experiment, participants were first provided with instructions defining MW as engaging in thoughts irrelevant to the task. To ensure accurate eye-tracking data, a nine-point calibration was carried out at the beginning of each task. Each participant then completed ten tasks presented in a randomized order alongside another participant and the host. During the tasks, participants engaged with stimuli, responded to questions raised by the host, and participated in discussions when necessary. A small window was positioned in the upper-right corner of the screen, displaying either the other participant or the host, replicating the typical Zoom interaction setup. Following each trial, a thought probe appeared on the screen, asking participants to indicate whether they had experienced MW during the trial. They responded by pressing "Y" for yes or "N" for no.

Eye movement data analysis

Entropy

To evaluate participants' eye movement consistency while exposing them to the stimuli, we employed the EMHMM method (Chuk et al., 2014; Hsiao, Lan et al., 2021). For each trial, a Hidden Markov Model (HMM) was generated to represent the participant's eye movement patterns. The hidden states of the HMM represented each person's ROIs, with gaze transitions summarized in a transition matrix (see Figure 1). We set the potential number of ROIs from 1 to 8, determined using a variational Bayesian approach. with each model being trained 300 times. The model with the highest log-likelihood was selected for further analysis. Eye movement consistency was quantified by calculating the entropy of participants' HMMs (Hsiao et al., 2020; Hsiao, Chan et al., 2021; Hsiao, Liao et al., 2022). Entropy reflects the predictability of eye movement patterns, with higher entropy indicating less predictable and less consistent patterns. In addition, we examined the marginal entropy of the first fixation in each trial. This measure captures the variance in initial fixation distribution, showing how first fixations influenced overall eye movement patterns.



	1	2	3	4
Prior	.41	.35	.07	.17
1	.77	.16	.07	.00
2	.31	.63	.06	.00
3	.30	.19	.51	.00
4	.00	.00	.01	.99

Figure 1. Representative model example of the "Preference of a place between two different times" task generated using EMHMM. Ellipses represented ROIs, and dots indicated raw fixations within these areas. Eye gaze transition probabilities among different ROIs were summarized in a transition matrix. The prior showed the probability of the first fixation in a trial landing in each ROI.

Joint Attention (JA)

To define a JA event, following Teng et al. (2024), both spatial and temporal thresholds were considered. The spatial threshold was based on the average size of prominent objects in each video frame, set at 150 pixels. A JA fixation was identified if one participant's fixation fell within 150 pixels of the other participant's fixation.

For the temporal threshold, fixation duration overlap was used to measure how long two participants' fixations aligned at the same location. To calculate this overlap, we started with a fixation from participant A (duration: a_1) and then identified the overlapping fixation durations from participant B (denoted as b_{11} and b_{12}). The overlap percentage relative to A's fixation duration was calculated as $(b_{11}+b_{12})/a_1$. The mean overlap percentage across all of A's fixations was then used as the JA measurement (i.e. JA_AB_DP in Figure 2).

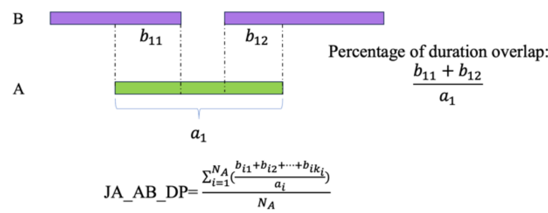


Figure 2. Demonstration of JA calculation. The long strips represent fixation durations.

Results

Fixation behavior

In average number of fixations per second, we observed a significant effect of MW condition in task type "clearly defined strategies", $\chi^2(1, N = 34) = 5.037$, $p = .025$, where participants had a smaller number of fixations per second in MW condition than no-MW condition, $\beta = -0.000$, SE = 0.000, $t = -2.244$, $p = .025$. No significant MW effect was observed in any other task types. We further examined whether a smaller number of fixations per second was a unique indicator of MW for the task type "clearly defined strategies" when compared with the other task types. The LMM results indicated that there was no significant interaction effect between MW condition and task type, $\chi^2(3, N = 34) = 4.067$, $p = .254$, suggesting the MW effect did not vary across tasks. Thus, although a significant MW condition effect was only observed in task type "clearly defined strategies" but not in the other task types, it did not appear to be a unique MW indicator for this task type when compared with the others.

In average fixation duration, we did not observe a significant effect of MW condition in any task types. Therefore, a longer average fixation duration did not appear to be a good MW indicator for older adults. This result was in contrast to the findings from young adults in a previous study (Teng et al., 2024), where a longer fixation duration was a good MW indicator for task type "searching for information".

Pupil diameter change

In pupil diameter change, we did not observe a significant effect of MW condition in any task types. Therefore, a larger pupil diameter change did not appear to be a good MW indicator for older adults. This result was in contrast to the findings from young adults in a previous study (Teng et al., 2024), where a larger variance in pupil diameter change was a good MW indicator for task type "imagining a scenario".

Entropy

In overall entropy, we did not observe a significant effect of MW condition in any task types.

In marginal entropy of the first fixation, we observed a significant effect of MW condition in task type "well-learned visual routines", $\chi^2(1, N = 34) = 5.117$, $p = .024$, where participants had lower consistency in the first fixation (i.e. higher marginal entropy of the first fixation) in the MW condition than no-MW condition, $\beta = 0.135$, SE = 0.060, $t = 2.262$, $p = .024$. No significant MW effect was observed in any other task types. We further examined whether lower consistency in the first fixation was a unique indicator of MW for the task type and "well-learned visual routines" when compared with the other task types. The results indicated that there was a marginally significant interaction between MW condition and task type, $\chi^2(3, N = 34) = 6.322$, $p = .097$, suggesting lower consistency in the first fixation could potentially be an indicator of MW uniquely for task type "well-learned visual routines": compared with "well-learned visual routines", participants had a significantly smaller MW condition effect in task type "searching for information", $\beta = -0.217$, $SE = 0.098$, $t = -2.210$, $p = .027$, but this effect was not significant when compared with task types "imagining a scenario" and "clearly defined strategies" (Table 1).

JA

In JA with another participant, we observed a significant effect of MW condition in task type "clearly defined strategies", $\chi^2(1, N = 34) = 6.230$, $p = .013$, where participants had less JA with another participant in the MW condition than no-MW condition, $\beta = -0.022$, SE = 0.009, $t = -2.496$, $p = .013$. No significant MW condition effect was observed in any other task types. This result was consistent with findings from young adults (Teng et al., 2024), suggesting that JA may be a good MW indicator for tasks involving clearly defined strategies across the age groups.

We further examined whether JA with another participant was a unique indicator of MW for task type "clearly defined strategies" as compared with the other task types. The results showed a marginally significant interaction between MW condition and task type, $\chi^2(3, N = 34) = 7.601$, $p = .055$, suggesting JA with another participant could potentially be an indicator of MW uniquely for task type "clearly defined strategies": compared with "clearly defined strategy", participants had a significantly smaller MW condition effect in "imagining a scenario", $\beta = 0.032$, $SE = 0.013$, $t = 2.415$, $p = .016$, and in "well-learned visual routines", $\beta = 0.029$, $SE = 0.012$, $t = 2.371$, $p = .018$; this effect was not significant in "searching for information" (Table 2).

In JA with the host, we did not observe a significant effect of MW condition in any task types. Therefore, it did not appear to be a good MW indicator for older adults.

In summary, our results generally supported our hypothesis that young and old adults showed differences in eye movement behavioral MW indicators. Specifically, a smaller number of fixations and longer fixation duration and a larger variance in pupil diameter were not good MW indicators for any type of tasks for old people. Lower eye movement consistency could be a good indicator of MW in task type "well-learned visual routines". In addition, JA with another participant could be a good indicator of MW in task type "clearly defined strategy", and this finding was consistent with that from young adults.

Table 1. Fixed effects estimates from the LMM results for marginal entropy of the first fixation (***$p < .001$, *$p < .05$, ^$p < .10$).

Fixed Effects Omnibus test					
Effect	*df*	χ^2	*p*		
MW condition	1	4.323	0.064^		
Task Type	3	8.499	0.037*		
MW condition X Task Type	3	6.322	0.097^		
Fixed Effects					
Effect	*β*	*SE*	*95%CI*	*t*	*p*
(Intercept)	12.300	0.194	[12.602,13.255]	63.557	< .001***
MW condition	0.139	0.067	[-0.057,0.156]	2.079	0.038*
"clearly defined strategy" vs "well-learned visual routines"	0.523	0.276	[-1.049,-0.068]	1.907	0.105
"imagining a scenario" vs "well-learned visual routines"	0.374	0.276	[-0.996,-0.015]	1.354	0.225
"searching for information" vs "well-learned visual routines"	0.700	0.248	[-1.268,-0.389]	2.823	0.030*
MW condition: Task Type ("clearly defined strategy" vs "well-learned visual routines")	0.009	0.104	[-0.052,0.215]	0.082	0.935
MW condition: Task Type ("imagining a scenario" vs "well-learned visual routines")	-0.045	0.107	[-0.023,0.282]	-0.421	0.674
MW condition: Task Type ("searching for information" vs "well-learned visual routines")	-0.217	0.098	[-0.087,0.185]	-2.210	0.027*

Table 2. Fixed effects estimates from the LMM results for JA with another participant (*$p < .05$, ^$p < .10$).

Fixed Effects Omnibus test					
Effect	*df*	χ^2	*p*		
MW condition	1	5.712	0.017*		
Task Type	3	2.458	0.483		
MW condition X Task Type	3	7.601	0.055^		
Fixed Effects					
Effect	*β*	*SE*	*95%CI*	*t*	*p*
(Intercept)	0.115	0.038	[0.050,0.181]	2.996	0.021*
MW condition	-0.022	0.009	[-0.040,-0.004]	-2.390	0.017*
"imagining a scenario" vs "clearly defined strategy"	-0.005	0.053	[-0.095,0.085]	-0.097	0.926
"well-learned visual routines" vs "clearly defined strategy"	0.060	0.048	[-0.023,0.142]	1.232	0.264
"searching for information" vs "clearly defined strategy"	0.013	0.048	[-0.069,0.096]	0.270	0.796
MW condition: Task Type ("imagining a scenario" vs "clearly defined strategy")	0.032	0.013	[0.006,0.059]	2.415	0.016*
MW condition: Task Type ("well-learned visual routines" vs "clearly defined strategy")	0.029	0.012	[0.005,0.052]	2.371	0.018*
MW condition: Task Type ("searching for information" vs "clearly defined strategy")	0.018	0.012	[-0.006,0.043]	1.424	0.154

Discussion

In this study, we examined eye movement behavior during MW in older adults. when they performed different types of cognitive tasks in an online learning scenario. We hypothesized that since older adults are shown to exhibit different eye movement behavior from young adults in these cognitive tasks, they may also have different MW indicators. Specifically, in contrast to young adults, number of fixations and fixation duration may not be good MW indicators for tasks involving "searching for information" in older adults since they tend to make more fixations with longer fixation durations even without MW. Similarly, a larger variance in pupil diameter change may not be a good MW indicator for tasks involving "imagining a scenario" in older adults due to their relatively stable emotional states as compared with young adults. However, in older adults' lower eye movement consistency may turn out to be a good MW indicator for tasks involving "well-learned visual routines" in contrast to young adults, because their cognitive decline may make these well-learned visual routines more easily affected by MW. Finally, similar to young adults, reduced JA may be a good MW indicator for tasks involving "clearly defined strategies".

Consistent with our hypotheses, we discovered that fixation behaviors, including either number of fixations or fixation duration, were not reliable indicators of MW for older adults in the task type "searching for information". This phenomenon may be related to aging-related increase in number of fixations and fixation duration when searching for information typically observed in the literature. Indeed, as compared with young adults reported in Teng et al. (2024), older adults in the current study had a larger number of fixations in the "Tic-Tac-Toe" task, $U = 863$, $p < .001$. This finding was consistent with a previous study, which suggested that the increased number of fixations may be related to age-related decline in visual working memory (Laberge & Scialfa, 2005). We also found that older adults had shorter average fixation duration than younger adults in the "video viewing" task, $U = 1047$, $p = .024$ and the "Tic-Tac-Toe" task, $U = 772$, $p < .001$, which may be related to older adults' higher familiarity with the stimuli than young adults, which facilitated their processing (Meyer et al., 2014). Although age differences in fixation behavior in tasks involving searching for information did not appear to be consistently found, in general our results suggest that these summary statistics measures of fixation behavior may not be a good MW indicator in older adults as in young adults since they can be affected by multiple factors including cognitive decline and stimulus familiarity.

Similarly, in contrast to young adults, larger variance in pupil diameter changes was not a reliable MW indicator in older adults during the task type "imagining a scenario", consistent with our hypothesis. Indeed, as compared with young adults in Teng et al. (2024), our older adults had a marginally smaller variance in pupil diameter change in the task "Imagining playing with toys", $U = 1148$, $p = .097$. This result was consistent with previous research showing that older adults had more effective emotion regulation (Blanchard-Fields, 2007) and experienced lower affect variability (Röcke et al., 2009) than younger adults. This age difference may have rendered variance in pupil diameter change an ineffective MW indicator for older adults.

As for eye movement consistency, consistent with our hypothesis, we found that in older adults' lower eye movement consistency (measured in the marginal entropy of the first fixation) was a unique MW indicator for task type "well-learned visual routines" but not for any other task types. This result was in contrast to young adults, where eye movement consistency during MW and no-MW episodes in this task type did not differ significantly. We speculated that this age difference may be related to older adults' cognitive decline, making their eye movement during tasks involving implementing a well-learned visual routine affected more by MW. In contrast, young adults were able to implement a well-learned visual routine even during MW. Consistent with this speculation, we found that older adults had higher marginal entropy of the first fixation (i.e. lower eye movement consistency) in this task type (e.g., in task "scene identification", $U = 1034$, $p = .019$) than younger adults. Previous research has suggested that older adults are more susceptible to interference due to cognitive decline (Hasher & Zacks, 1988). Thus, older adults' visual routines may be more easily interfered by MW than young adults', making reduced eye movement consistency a good MW indicator for tasks involving well-learned visual routines for older adults.

Finally, in older adults, reduced JA with another participant was identified as a unique MW indicator for the task type "clearly defined strategies" but not for any other task types. This phenomenon was also observed in young adults (Teng et al., 2024). For this task type, participants were expected to pay attention to similar regions using similar strategies, which would result in higher JA when they focused on the task. Thus, reduced JA may indicate that participants had shifted their attention away from the task. The finding that this effect could be observed in both young and older adults suggested that this MW indicator for tasks involving clearly defined strategies is not affected by aging.

In conclusion, our findings revealed fundamental differences in how MW manifests in eye movement behavior between older and younger adults, highlighting the significant impact of aging on attentional processes. Specifically, fixation behaviors, including a smaller number of fixations and longer average fixation duration, were good indicators of MW for younger adults for "searching for information". However, this effect was not observed in older adults, possibly due to multiple factors that could have influenced older adults' fixation behavior in addition to MW including cognitive decline and stimulus familiarity. Similarly, larger variance in pupil diameter changes was a good MW indicator for "imagining a scenario" for younger adults but not for older adults, possibly due to their enhanced affect stability or emotion regulation ability. In contrast, lower eye movement consistency was a unique MW indicator for "well-learned visual routines" for older adults but not for young adults, possibly due to their higher susceptibility to interference such as MW when implementing these well-learned visual routines. We also found that some MW indicators, such as reduced JA with another participant, was a good MW indicator for tasks involving "clearly defined strategies" for both young and older adults. Our findings thus suggested that aging leads to task-specific changes in eye movement behavior, which can in turn lead to differential impact on behavioral indicators of MW across different tasks in older adults. These findings have important implications for ways to facilitate learning or cognitive stimulation therapies in older adults through monitoring task engagement with eye tracking.

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