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Longitudinal Declines in Event-Based, But Not Time-Based, Prospective Memory Among Community-Dwelling Older Adults

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Abstract

Objective: Older adults demonstrate poorer prospective memory (PM) performance compared to younger individuals, which may interfere with everyday activities such as remembering to take medications as prescribed. However, it is not known whether PM performance is stable over time or whether there are individual differences in trajectories.

Method: Participants included 271 community-dwelling older adults (50 to 91 years of age) who underwent a baseline evaluation and up to three follow-up visits, approximately 2.4 years apart. Participants completed the time-based and event-based PM tasks of the Memory for Intentions Test (MIsT), the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), clinical measures of executive functions, and self-report measures of everyday functioning. Changes in PM performance were analyzed using mixed effects linear longitudinal models.

Results: Analyses revealed small, but significant linear declines in event-based PM performance over time, as well as significant between-subjects variability in event-based PM changes. Participants also reported increased difficulty with activities of daily living over time. There were no changes in performance on measures of time-based PM, retrospective memory, or executive functions, and no changes in self-reported quality of life. Changes in event-based PM were not associated with age, retrospective memory, executive functions, or everyday functioning.

Conclusions: Among older adults, event-based PM appears to be more susceptible to linear declines than does time-based PM, which future research might examine with regard to the possible underlying cognitive mechanisms of cue encoding, monitoring, detection, and retrieval processes.

Keywords

aging; memory for intentions; cognition; neuropsychological tests; executive function; activities of daily living

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Conflicts of Interest: None.

Prospective memory (PM) is a form of declarative memory that involves the ability to remember and execute delayed intentions (McDaniel & Einstein, 2000). Also known as "remembering to remember," PM is relevant to everyday activities such as taking medication at the appropriate time, returning a telephone call, or remembering to buy groceries on the way home from work (Woods et al., 2012). According to the multiprocess model of PM (McDaniel & Einstein, 2000) and its dynamic extension (Shelton et al., 2019), PM cues place demands on varying degrees of strategic ("top-down") and/or automatic ("bottom-up") processing at different phases of the complex process of encoding, retaining, monitoring and retrieving, and deactivating an intention. For example, during PM tasks with high strategic processing demands (e.g., low salience cues), individuals must actively monitor the environment for the PM cue, although of course more spontaneous processes might also be important, particularly over long delay intervals (e.g., Doyle et al., 2013). In PM tasks that are more automatic, individuals are spontaneously reminded of the deferred intention upon processing the PM cue, although these processes are not necessarily fully automatic (Scullin et al., 2010). Time-based PM cues (e.g., remembering to take medication at 3:00 P.M.) tend to require more strategic processing than most external, event-based PM cues (e.g., remembering to deliver a message upon seeing a friend; d'Ydewalle et al., 2001), although this can vary depending on a variety of factors, including the focality of the PM cue (Kliegel et al., 2008). Highly strategic PM tasks are thought to rely largely on prefronto-parietal networks and executive functions, while more automatic PM tasks tend rely more heavily on the medial temporal lobes, ventral parietal cortex, and retrospective memory (e.g., Cona et al., 2016; Gordon et al., 2011; Kamat et al., 2014; McFarland & Glisky, 2009).

Older age is reliably associated with poorer performance on many aspects of strategically demanding PM (e.g., Henry et al., 2004), which in turn increases the risk of problems in everyday functioning. Among older adults, lower PM is associated with poorer medication management (Woods et al., 2014), dependence in manifest activities of daily living (ADLs; Tierney et al., 2016), reduced functional capacity (Hering et al., 2018), and lower quality of life (Woods et al., 2015). Therefore, it is important to understand how PM may change with advancing age and how these changes may impact everyday functioning and health outcomes. Evidence from neuroimaging studies suggests that aging impacts prefrontal regions (e.g., Taki et al., 2013), which is associated with poorer performance on tasks of executive functions (e.g., Yuan & Raz, 2014). The medial temporal lobes are also disrupted by aging (e.g., Fraser et al., 2015), and these neural changes can be associated with declines in episodic retrospective memory (e.g., Golomb et al., 1994). While cross-sectional studies have consistently found age-related differences in retrospective memory and executive functions beginning in early adulthood (see Salthouse, 2010b for a review), longitudinal studies have been less consistent (e.g., Rönnlund et al., 2005; Van Dijk et al., 2008; Zahodne et al., 2011; Zelinski & Burnight, 1997), perhaps due to practice effects, retention biases, and short follow-up periods in some aging studies (e.g., Salthouse, 2009). Given PM's associations with executive functions and retrospective memory, it is plausible that older adults would show declines in PM performance, with the greatest decrements occuring in PM tasks with high strategic processing demands.

Meta-analyses of PM and aging (e.g., Henry et al., 2004; Kliegel et al., 2008; Uttl, 2011) have consistently concluded that older adults demonstrate poorer performance on laboratory

PM tasks compared to younger individuals, and that these differences are greater for PM cues that require a higher degree of strategic processing (e.g., time-based or non-focal event-based PM cues). In particular, age-related changes in prefrontal neural systems (e.g., West, 1996) may make it more difficult for older adults to execute aspects of PM with higher strategic processing demands (e.g., time-based cues), whereas more automatic aspects of PM (e.g., focal, event-based cues) are less detrimentally impacted by aging. Additionally, among older adults, older age is associated with worse laboratory PM performance. Several cross-sectional studies (e.g., Kamat et al., 2014; Kvavilashvili et al., 2009; Uttl et al., 2001) have suggested that PM performance declines with increasing age, and that young-old adults (e.g., age 60) may demonstrate better laboratory PM than old-old adults (e.g., age 80). However, the trajectory of PM changes in older age is not well established. Although older adults demonstrate worse laboratory PM performance compared to younger adults, they often demonstrate comparable, or even better, performance on naturalistic PM tasks (e.g., Henry et al., 2004; Rendell & Thomson, 1999; Uttl, 2008). This “age-PM paradox” may be related to several factors, such as motivation, use of compensatory strategies, level of activity, and measurement differences (e.g., Rendell & Thomson, 1999). Among older adults, rates of PM change may also vary depending on individual characteristics, such as demographics and psychological distress.

The majority of studies on aging and PM have used cross-sectional designs, which can be confounded by cohort effects. We are aware of only two longitudinal investigations of PM among typically aging, nonclinical adults. Serrani (2010) studied 46 community-dwelling adults who were aged 65 to 67 at baseline. Participants were evaluated every two years over a 10-year period and were asked to complete four event-based and two time-based PM trials during ongoing numeric selection and semantic selection tasks. Specifically, participants were asked to tap the table when target words were presented in the ongoing task (i.e., focal, event-based cues) and after 10 and 15 minutes had passed (i.e., time-based cues). Participants declined in both event-based and time-based PM performance over the 10-year study period. Baseline working memory and attention were independent predictors of PM decline, while retrospective memory was not. Survival analyses showed a steep decline in event-based PM beginning around age 70, while declines in time-based PM were more gradual and began around age 73. Working memory and set-shifting demonstrated similar trajectories to time-based PM, with relatively gradual declines after age 73. This last finding is consistent with prior literature showing that aspects of PM with high strategic demands rely on prefrontal networks (e.g., Cona et al., 2015) and correlate with measures of executive functions (e.g., Kamat et al., 2014). However, it is surprising that participants were more likely to decline in event-based PM than time-based PM, since the strategic, time-based PM tasks would be expected to be more sensitive to aging than the focal, event-based PM tasks in this study. Notably, participants who had difficulty executing event-based or time-based PM tasks at baseline were excluded from this analysis; thus, it is possible that some participants had declined earlier on time-based compared to event-based PM. More recently, Kordovski et al. (2020) reported no significant changes (and small effect sizes) over a year in laboratory time- and event-based PM and naturalistic time-based PM among 77 HIV+ persons and 44 HIV- persons in their mid-50s. Given the small samples, variable

findings, and limited number of studies with multiple time points, further research on the trajectory of PM among older adults appears warranted.

The current study evaluates the hypothesis that both time-based and event-based PM would decline with advancing age among older community-dwelling adults. Secondly, it was hypothesized that older age and poorer baseline retrospective memory and executive functions would be associated with greater PM decline. Declines in retrospective memory and executive functions were also expected to be positively associated with PM declines. Finally, it was hypothesized that PM declines would be associated with corresponding changes in ADLs and quality of life among older adults.

Method

Participants

Participants included community-dwelling adults aged 50 years or older who were recruited via flyers and word of mouth into the Healthy Ageing Research Program at the University of Western Australia. Baseline data were collected from 271 participants (50 to 91 years of age) between August 2008 and September 2016. Descriptive data for the baseline sample are provided in Table 1. Participants were asked to return for up to three follow-up evaluations, approximately two years apart (M=2.4 years, SD=1.1, range=0.7–7.1). Of the initial 271 participants, 137 participants returned for at least one follow-up visit, 47 of whom returned for a second follow-up, and 12 for a third. All participants provided written, informed consent, and the study was approved by the University of Western Australia Human Research Ethics Office.

Participants were asked to complete a demographic and medical history questionnaire. In order to ensure that analyses reflected longitudinal changes in typically aging adults, participants were excluded if they reported a diagnosis of mild cognitive impairment (MCI) or dementia or scored less than 24 on the Mini-Mental State Examination (MMSE; Folstein et al., 1975) at baseline. Participants with a history of major psychiatric disorder (e.g., schizophrenia, bipolar disorder) or neurological condition (e.g., traumatic brain injury, stroke, seizure disorder) reported at the initial visit were also excluded. Participants with chronic medical conditions that are common among community-dwelling adults (e.g., hypertension, diabetes) were included in the study in order to maintain a representative sample of older adults.

PM Measures

Participants completed the research version (Woods et al., 2008) of the Memory for Intentions Test (MIsT; Raskin et al., 2010), which is a well-validated clinical measure of PM. The same version of the MIsT (i.e., Form A) was administered at each visit. This test requires participants to complete an ongoing word search task and interrupt the word search to complete eight PM tasks, four of which have cues that are time-based (e.g., “In 15 minutes, tell me that it is time to take a break”) and four that are event-based (e.g., “When I show you a postcard, self-address it”). The time- and event-based cues are not focal to the ongoing task and balanced in terms of their delays (i.e., either 2-min or 15-min

spans between the task instruction and execution). Participants are permitted to use a digital clock behind them to keep track of time, but they are not explicitly encouraged to do so (NB. clock checking was not recorded in this study). Participants earned 2 points per trial if they provided the correct response at the correct time or in response to the correct event. A score of 1 point was assigned if the participant made an error (e.g., responded at the incorrect time or to the incorrect event; responded at the correct time but provided the incorrect response). A score of 0 was assigned if no response was provided. Each participant received a score ranging from 0 to 8 for both the time-based and event-based PM scales of the MIsT, with higher scores representing better performance. Errors were classified as PM errors (i.e., omissions) if the participant did not respond to the time-based or event-based cue (ranges=0–4 for each scale).

Neuropsychological Assessment

Retrospective memory.—Participants completed the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998), which allowed for the assessment of verbal recognition and delayed recall of rote verbal material, contextual verbal material, and a complex visual figure within a brief, standardized clinical battery. The same version of the RBANS (i.e., Form A) was administered at each evaluation. Raw scores on the RBANS List Recall, List Recognition, Story Memory, and Figure Recall subtests were converted to sample-based *z*-scores derived from the *M* and *SD* of the baseline cohort and then averaged to create a delayed retrospective memory composite score (mean ρ=.34, α=.71 at baseline). Given the importance of age in our analyses and the absence of validated age-based normative standards for the research version of the MIsT, this approach was viewed as optimal in providing a common metric across follow-up visits and limiting our risk of Type II error (i.e., adjusting analyses of aging for age can be contra-indicated).

Executive functions.—Executive functions were assessed with four measures spanning different executive functions: the executive clock-drawing task (CLOX; Royall et al., 1998) to measure visual construction/planning, Trail Making Test (TMT) part B (Reitan & Wolfson, 1985) to measure set-shifting, letter C fluency (Benton et al., 1994) to measure phonemic generation, and action (verb) fluency (Woods et al., 2005) to measure semantic generation. A composite executive functions score was calculated by averaging the raw sample-based *z*-scores for the CLOX executive index (calculated as CLOX part 2 – CLOX part 1), TMT B time, letter C fluency, and action fluency, derived from the *M* and *SD* of the baseline cohort, such that higher *z*-scores reflected better executive functions (mean ρ=.24, α=.55 at baseline).

Everyday Functioning Measures

Activities of daily living.—Participants completed the Activities of Daily Living Questionnaire (ADLQ; Johnson et al., 2004) at each visit. This 28-item self-report questionnaire assesses six subscales of activities: self-care, household care, employment and recreation, shopping and money, travel, and communication. Each item has four response options representing differing levels of functional ability (e.g., “Employment” is rated from 0: “Continues to work as usual” to 3: “No longer works”). Each item also has a response option for questions that are not applicable (e.g., “Never worked OR retired before illness

OR don't know"). For this study, items rated as not applicable or unknown were scored as 0. The total score for the ADLQ was calculated as the sum of responses across the 28 items (range=0–84), with higher scores indicating more difficulties with ADLs.

Quality of life.—Participants were also asked to complete the World Health Organization Quality of Life 8-item questionnaire (WHOQOL-8; see Power, 2003) at each visit. The WHOQOL-8 includes questions about quality of life over the past two weeks, which are rated on a five-level scale (e.g., "How satisfied are you with your health?" is rated from "Very Dissatisfied" to "Very Satisfied"). The total score for WHOQOL-8 was summed across the eight items (range=8–40), such that higher scores reflect better quality of life.

Affective Distress

Due to a change in the study protocol, participants completed either the Patient Health Questionnaire-9 (n=189; PHQ-9; Kroenke et al., 2001) or the Geriatric Depression Scale 15-item Short Version (n=78; GDS-15; Sheikh & Yesavage, 1986) to measure depressive symptoms at each visit. Participants also completed either the Generalized Anxiety Disorder 7-item scale (n=189; GAD-7; Spitzer et al., 2006) or the 20-item Geriatric Anxiety Inventory (n=78; GAI; Pachana et al., 2007) at each visit. Participants were considered to have elevated affective distress if they obtained a score of 5 or greater on the PHQ-9, GDS-15, or GAD-7, or a score of 9 or greater on the GAI.

Data Analysis

Descriptive statistics.—Time-based PM scores were approximately normally distributed. Between-person event-based PM scores were negatively skewed, but examination of residuals indicated that specification of event-based PM as normally distributed provided a similar, or better, fit to the data compared to alternatives (e.g., negative binomial distribution). Additionally, within-subject scores on event-based PM were approximately normally distributed. Therefore, both time-based and event-based PM were considered to be normally distributed for all analyses.

Longitudinal analyses.—Mixed effects linear longitudinal analyses were conducted in Mplus version 8 (Muthén & Muthén, 1998–2007) using maximum likelihood estimation and full information maximum likelihood (FIML) to handle missing data. This method allowed for the estimation of both within-subject and between-subject effects and has been used in prior studies of cognitive aging (Fletcher et al., 2018). FIML allows for the use of all available data without imputing missing values, and the inclusion of partially complete cases improves model estimation (e.g., Enders & Bandalos, 2001). FIML is generally preferred over other missing data methods (including listwise deletion) for these reasons (e.g., Enders & Bandalos, 2001). In order to account for the unbalanced intervals between follow-up evaluations, study time (calculated as the number of years from the baseline visit, rounded to the nearest hundredth of a year) was used as the main variable rather than visit number.

First, an unconditional model tested the hypothesis that time-based and event-based PM would decline over time. Results for time-based and event-based PM were estimated within the same model, using two dependent variables. Time-based and event-based PM were

allowed to covary in both the within- and between-subjects parts of the models. In the within-subjects part of the model, time-based and event-based PM scores were regressed on study time, which generated within-person intercept and linear slope random effects for each PM variable. Next, to test the hypothesis that older age and poorer baseline PM would be associated with greater PM decline, these baseline variables were added to the model as fixed-effect predictors of PM slope.

A similar unconditional model was used to determine whether other neurocognitive functions declined over time, with retrospective memory and executive functions as the two dependent variables. Retrospective memory and executive functions were allowed to covary in both the within- and between-subjects parts of the models. These neurocognitive variables were regressed on study time in the within-subjects part of the model to generate intercept and linear slope random effects. Next, a model was run with baseline neurocognitive variables and any significant neurocognitive slopes as fixed-effect predictors of PM slope.

Additionally, an unconditional model was run to determine whether everyday functioning declined over time, with ADLQ and WHOQOL-8 as the two dependent variables. They were allowed to covary in the within- and between-subjects parts of the models. ADLQ and WHOQOL-8 were regressed on study time in the within-subjects part of the model to generate intercept and linear slope random effects. Next, a model was run with baseline values on these functional measures and any significant slopes in functional measures as fixed-effect predictors of PM slope.

Confound and post-hoc analyses.—In order to investigate the effects of attrition on the study results, chi-square and Wilcoxon rank-sum tests were used to analyze differences between participants who returned for follow-up versus those who did not. There were no *a priori* hypotheses about the effects of additional covariates or confounding factors on model results. However, in order to investigate potential modifying variables that may have influenced study results, sex, affective distress, and the number of chronic medical conditions were explored as possible covariates. None of these variables was related to time-based or event-based PM at baseline ($ps>.05$); therefore, no additional covariates were added to the analyses.

In terms of post-hoc analyses, we examined four specific factors that were deemed relevant to the findings during the review process. First, we conducted a post-hoc of our primary analysis, but excluded the baseline participants who had elevated affective distress ($n=49$). Second, we used mixed effects models to examine PM specific errors (i.e., omissions), since the scoring of the MIsT includes both prospective (i.e., remembering to respond appropriately) and retrospective (e.g., providing the correct response) memory components. Third, mixed effects models were run separately for participants age 50–69 years at baseline and those age 70 or older at baseline, since older age may influence the trajectory of PM declines. Finally, analyses excluding the third follow-up visits were conducted, due to the low number of participants who completed a third follow-up ($n=12$).

Results

Pearson's product-moment correlations for all primary variables at the baseline visit are presented in Table 2. A Wilcoxon signed-rank test showed that participants performed better on the event-based compared to the time-based PM tasks at baseline (S=15074.5, p<.001).

Longitudinal Analyses

Results of mixed effects models included unstandardized estimates. The unconditional model of PM indicated that there was a significant amount of between-subject variability in time-based (σ^2=0.72, p<.001) and event-based (σ^2=0.46, p=.001) PM. The intraclass correlation (ICC) from Mplus for time-based MIsT PM was .35, and the ICC for event-based MIsT PM was .26. There was a significant decline in event-based PM over time, such that event-based PM declined 0.08 points per year on average (SE=0.04, p=.032). There was also significant variability in the slope of event-based PM (b= −0.03, SE=0.02, p=.025). The slope of time-based PM was not significant (b= −0.03, SE=0.03, p=.364), and there was no between-person variability in time-based PM slopes (b=0.00, SE=0.02, p=.819). Therefore, no further analyses of time-based PM were conducted. When baseline event-based PM and age were added as predictors of event-based PM slope, results revealed that neither baseline event-based PM (b=0.04, SE=.08, p=.370) nor age (b= −0.01, SE=0.01, p=.160) was associated with event-based PM declines (residual σ^2=0.04, p=.029).

The unconditional model of retrospective memory (ICC=.68) and executive functions (ICC=.66) revealed that there were no significant changes in retrospective memory (b= −0.01, SE=0.01, p=.579) or executive functions (b=0.00, SE=0.01, p=.793). Additionally, there was no between-subjects variability in slopes of retrospective memory (b=0.00, SE=0.00, p=.748) or executive functions (b=0.00, SE=0.00, p=.694). Therefore, no further analyses were conducted with slopes of retrospective memory or executive functions. A model using baseline neurocognitive scores as predictors of event-based PM slope revealed no significant effects of either baseline retrospective memory (b=0.01, SE=.06, p=.838) or executive functions (b=.09, SE= −.06, p=.128) on event-based PM decline (residual σ^2=0.04, p=.025).

The unconditional model of ADLQ (ICC=.62) and WHOQOL-8 (ICC=.76) found significant increases in ADL difficulties over time (b=0.29, SE=0.12, p=.013), but no changes in quality of life on the WHOQOL-8 (b= −0.06, SE=0.09, p=.543). There was significant between-subjects variability in ADLQ slopes (b=0.67, SE=0.12, p=.001) but not in WHOQOL-8 slopes (b=0.04, SE=0.12, p=.776). In a model with ADLQ slope, baseline ADLQ, and baseline WHOQOL-8 as predictors of event-based PM slope, there were no significant effects of ADLQ slope (b= −0.28, SE=0.64, p=.666), baseline ADLQ (b= −0.01, SE=0.02, p=.398), or baseline WHOQOL-8 (b= −0.01, SE=0.02, p=.701) on event-based PM declines (residual σ^2=0.07, p=.381).

Post-Hoc Analyses

Affective distress.—After excluding participants with elevated affective distress at baseline (n=49), results of the unconditional model continued to show significant declines in

event-based PM (b= −0.08, SE=0.04, p=.041) and significant variability in event-based PM slopes (b=0.04, SE=0.01, p=.013), but no significant changes (b= −0.04, SE=0.03, p=.222) or slope variability (b=0.00, SE=0.01, p=.833) in time-based PM.

PM omission errors.—Results of the unconditional mixed effects model were largely similar when PM error scores were used instead of MIsT subscale scores. There was a modest increase in event-based PM errors (b=0.03, SE=0.02, p=.051) and significant variability in the slope of event-based PM errors (b=0.01, SE=0.00, p=.008). There was no significant increase in time-based PM errors (b=0.02, SE=0.02, p=.372) and no significant variability in the slope of time-based PM errors (b=0.00, SE=0.00, p=.551).

Age stratification.—The unconditional mixed effects model was also run separately for participants age 50–69 years at baseline and those age 70 or older at baseline. In the younger group (n=124), there were no significant declines in event-based PM (b= −0.06, SE=0.06, p=.296), and variability in event-based PM slopes was at the trend level (b=0.05, SE=0.03, p=.060). There was also no significant decline in time-based PM (b= −0.02, SE=0.05, p=.649) and no variability in time-based PM slopes (b=0.00, SE=0.03, p=.965). However, in the older group (n=147), there was a significant decline in event-based PM (b= −0.10, SE=0.05, p=.040), but no variability in event-based PM slopes (b=0.02, SE=0.02, p=.234). There was no significant decline in time-based PM (b= −0.03, SE=0.05, p=.576) and no significant variability in time-based PM slopes (b=0.01, SE=0.02, p=.590).

Third follow-up visit exclusions.—Of the 12 participants who completed three follow-up visits, 8 of them (67%) were age 70 years or older at baseline. When the third follow-up visits were excluded, declines in event-based PM were no longer significant (b= −0.06, SE=0.04, p=.134), although the size of this effect was within the 95% confidence interval (CI) of the original findings [−0.15, −0.01]. Similarly, the variability in event-based PM slopes was at the trend level (b=0.03, SE=0.01, p=.051), but the size of the effect was within the original 95% CI [−0.03, 0.03]. There was no significant decline in time-based PM (b= −0.05, SE=0.04, p=.132) and no significant variability in time-based PM slopes (b=0.01, SE=0.02, p=.480), and these findings, too, fell within the 95% CIs of the original analyses in the full sample.

Attrition.—Half of the participants who completed a baseline evaluation did not return for any follow-up visits (n=134, 49.4%). Wilcoxon rank-sum tests revealed that participants who only completed the baseline visit performed more poorly on the time-based PM tasks, $\chi^2(1)=9.95$, p=.002, and retrospective memory measures, $\chi^2(1)=4.01$, p=.045, compared to those who returned for at least one follow-up visit. However, there were no differences in event-based PM performance, $\chi^2(1)=2.36$, p=.124, or executive functions, $\chi^2(1)=3.25$, p=.072. Chi-square and Wilcoxon rank-sum tests revealed that participants who only completed the baseline visit had a higher prevalence of affective distress, $\chi^2(1)=7.19$, p=.007 than those who returned for follow-up visits; however, they did not differ in terms of sex, age, or the number of chronic medical conditions (ps>.10). Among participants who completed the first follow-up, there were no differences in baseline time-based PM,

event-based PM, retrospective memory, or executive functions between those who did or did not return for a second follow-up (*p*s>.10).

Discussion

Older adults commonly demonstrate worse PM than younger adults (e.g., Henry et al., 2004), which may put them at an increased risk of problems in everyday health behaviors. The current study was designed to investigate linear changes in PM among a sample of older adults. Participants demonstrated modest, but significant declines in event-based PM, but not time-based PM, over a period of several years. Older adults also demonstrated significant inter-individual variability in their trajectories of event-based PM, but not time-based PM, over time. The observed decline in event-based PM is consistent with a prior longitudinal study of PM in 46 older adults (Serrani, 2010), which found PM declines over periods of 5 and 10 years using a naturalistic event-based task with low retrospective memory load (i.e., remembering to tap the table in response to specific verbal stimuli). In the present study, we also found average declines in event-based PM using a larger sample of older adults, more rigorous statistical analyses, and a well-validated clinical measure of event-based PM (Kamat et al., 2014). Evidence from these two studies suggests that older adults are at risk of declining performance on event-based PM tasks as they age. Additionally, results of post-hoc analyses isolated to just the younger (age 50–69 years) or older (age 70 years or older) participants indicated that old-old adults may be at greater risk of declines in event-based PM compared to young-old adults. It should be noted, however, that the effect size of event-based PM decline was quite small overall, as participants declined only 0.08 points per year on average. Another study that investigated PM among HIV+ and HIV- adults found stability in PM performance over the course of one year (Kordovski et al., 2020). Taken together, findings suggest that declines in event-based PM may be small, especially over short follow-up intervals. Additional longitudinal research using older samples and longer follow-up periods would be helpful in further elucidating the trajectory of event-based PM.

In contrast to the observed declines in event-based PM, there was no overall pattern of linear decline in time-based PM over the course of the study and no significant variability between individuals. This finding seems to contrast with cross-sectional studies, which have found that older adults perform worse on time-based PM tasks than younger individuals (e.g., Henry et al., 2004), and with Serrani's (2010) longitudinal study, which found declines in time-based PM over longer periods of time than were measured here. This discrepancy could be due to differences in the study methods; for example, the four time-based trials of the MIsT had a higher retrospective memory load (e.g., "In 15 minutes, tell me that it is time to take a break") and monitoring demands than those used by Serrani (2010). A power analysis indicated that our study was adequately powered to detect small-to-moderate effects. However, observed changes in time-based PM were quite small, raising the possibility of a type II error. Baseline performance on the time-based and event-based PM trials of the MIsT may also have had an effect on the overall amount of decline observed in this study. Another possibility is that results may relate to the age-PM paradox, which finds that older adults perform relatively well on naturalistic PM tasks despite age-related deficits on laboratory PM measures (e.g., Rendell & Thomson, 1999). Time-based PM tasks may be more closely related to some naturalistic PM tasks (e.g., remembering to take medication at

a certain time) than event-based PM. However, event-based PM is also reliably associated with everyday functioning problems in older adults, including instrumental ADLs (Woods et al., 2012) and medication management (Woods et al., 2014). Longitudinal studies of naturalistic PM in older adults remain an important area for future study.

Prior studies reliably show that the time-based scale of the MIST is more difficult (e.g., Kamat et al., 2014; Woods et al., 2008), more strategically demanding (Doyle et al., 2013; Morgan et al., 2015), and more vulnerable to frontal systems pathology (e.g., Nicoll et al., 2014; Raskin et al., 2011) than is the event-based scale. Thus it is reasonable to speculate that the declines in event-cued, but not time-cued PM may have some important underlying cognitive differences worthy of examining, including the relatively automatic versus strategic processing involvement at encoding, monitoring, cue detection, and retrieval. That said, there is notable variability in the strategic versus automatic demands of event-based tasks, which are important to consider in interpreting these findings. In this case, the event-based scale of the research version of the MIsT is not a purely automatic/spontaneous PM measure (see McDaniel et al., 2015). Indeed, it contains some strategic processing elements at encoding (e.g., multiple different PM cues linked to different intentions), retention (e.g., two 15-min cues), and monitoring (e.g., non-focal cues). Although this allows for more direct comparisons to the relatively strategic demands of the time-based scale of the MIsT, it should not be interpreted as a highly automatic measure of PM (Shelton et al., 2019). While we measured PM with a well-validated clinical measure that shows good evidence of reliability, construct validity, and ecological relevance, it is not precise with regard to underlying cognitive processes, which await further study with more elegant experimental measures.

There was significant between-subjects variability in the amount of event-based PM decline; however, it is unclear which factors may put certain older adults at greater risk of declines. Surprisingly, baseline age, baseline event-based PM, and performance on measures of retrospective memory and executive functions were not associated with the rate of event-based PM decline. While our neurocognitive composite variables were based on well-validated, performance-based assessments, these measures have some limitations. Retrospective memory was measured with the delayed recall and recognition subtests of the RBANS, which is a brief neurocognitive assessment. While our retrospective memory composite included measures of rote verbal, contextual verbal, and visuospatial memory, the RBANS stimuli are relatively simple compared to more comprehensive memory measures. Additionally, our assessment of executive functions included measures of planning and organization, switching, and generativity; however, it did not assess all aspects of executive functions, such as novel problem-solving. Additionally, event-based PM declines were not associated with self-reported independence in ADLs or quality of life. Future studies using performance-based functional measures may provide additional information about the everyday correlates of PM declines. While our sample included 271 participants, only 47 of those participants returned for at least three visits. Thus, it is possible that our sample was too small to detect small effects that may explain individual differences in rates of event-based PM decline. Further longitudinal research that includes larger samples, neuroimaging, and more thorough assessments of retrospective memory and executive functions may be helpful in further examining the neuropsychological mechanisms responsible for age-related

PM declines. Additionally, our study only examined linear changes in PM; however, future studies may wish to examine other possible trajectories of change.

Of course, attrition represents one limitation of longitudinal studies and may have biased our results. For example, it is plausible that participants who experienced declines in PM may have had difficulty remembering to attend follow-up study appointments (Zogg et al., 2012). Indeed, post-hoc analyses revealed that participants with lower time-based PM performance were less likely to return for follow-up. Therefore, it is possible that participants from the baseline sample experienced time-based PM declines over the course of the study, but that they did not return for follow-up visits and thus created a possible type II error risk. Participants who were lost to follow-up also had higher rates of affective distress and poorer retrospective memory performance compared to those who returned for follow-up visits. Additionally, no age-related declines in retrospective memory, executive functions, or quality of life were observed. Taken together, these findings suggest that our sample may represent a high-functioning subset of community-dwelling older adults. Results suggest that even high-functioning older adults may experience subtle declines in certain aspects of PM with age; however, further research with participants with a greater diversity of neurocognitive abilities will be important.

In addition to attrition, several other limitations are worth noting. The exclusion of MCI and dementia at baseline does not ensure that an influential minority of participants did not exhibit subclinical declines in cognition that could have influenced the findings. One participant obtained an MMSE score of 23 during a follow-up visit, which represents a slight decline from the participant's score of 27 at baseline. However, no other participants scored <24 on the MMSE at any visit, and no participant was diagnosed with MCI during the study. It is certainly possible that some participants developed MCI which went undetected; nonetheless, we believe that our sample represents typically aging adults, and indeed may represent a relatively high-functioning sample as noted above. Additionally, our follow-up period was relatively short and may not have allowed for the development of declines in PM that might be observed over longer intervals. Similar to other longitudinal neuropsychological research, practice effects may have limited our ability to detect neurocognitive changes. However, prior research with a mean internal of 2.5 years between visits did not find substantial practice effects among older adults (Salthouse, 2010a), suggesting that practice effects may be less of a concern in this older adult sample.

Overall, this study represents one of the first longitudinal investigations of time-based and event-based PM performance among older adults. Further research with a larger sample and a longer period of follow-up time may provide additional information about how various types of PM change with age. In the present study, there was a large age range of participants (50 to 91 years old); future studies may wish to use an older sample (e.g., 65 years or older at baseline), in order to clarify how PM changes among older adults who are most vulnerable to neurocognitive decline. Finally, given that participants demonstrated significant declines in event-based laboratory PM performance, studies of intervention techniques and compensatory strategies would be an important next step. Nonetheless, the results of this study further our understanding of the effects of aging on both automatic and strategically demanding laboratory PM.

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Table 1

Characteristics of the older adults at the baseline visit (N = 271)

Variable	*M* (*SD*) or %
Demographic and medical	
Age (years)	70.3 (7.3)
Sex (% women)	67.5
Education (years)	13.9 (3.1)
Estimated premorbid IQ	108.2 (7.2)
Affective distress (% elevated)	18.4
Chronic medical conditions (no.)	1.4 (1.3)
Prospective memory	
Time-based MIsT (of 8)	5.3 (1.4)
Event-based MIsT (of 8)	6.8 (1.3)
Other neurocognitive	
RBANS Total Scale	102.8 (12.9)
Retrospective memory	
List Recall (of 10)	6.2 (2.4)
List Recognition (of 20)	19.4 (1.0)
Story Recall (of 12)	8.8 (2.4)
Figure Recall (of 20)	11.9 (4.0)
Executive functions	
Trail Making Test, Part B (sec)	82.3 (42.0)
Letter C fluency (no. of words)	16.5 (4.9)
Action (verb) fluency (no. of words)	18.3 (5.3)
CLOX executive index (of 15)	1.6 (2.2)
Everyday functioning	
Activities of Daily Living Questionnaire (of 84)	4.8 (4.9)
WHOQOL-8 Total (of 40)[^]	33.7 (4.6)

Note. MIsT = Memory for Intentions Test; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status; CLOX = executive clock-drawing task; WHOQOL-8 = World Health Organization Quality of Life 8-item questionnaire.

[^] *n* = 188.

Table 2

Pearson correlations of study variables at the baseline visit (N = 271)

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Age	–						
2. Retrospective memory	−.23*	–					
3. Executive functions	−.20*	.46*	–				
4. ADLQ	.14*	−.18*	−.13*	–			
5. WHOQOL-8^	.02	.08	.02	−.55*	–		
6. Time-based MIsT PM	−.34*	.38*	.32*	−.25*	.16*	–	
7. Event-based MIsT PM	−.07	.20*	.13*	−.16*	.21*	.25*	–

Note. ADLQ = Activities of Daily Living Questionnaire; WHOQOL-8 = World Health Organization Quality of Life 8-item questionnaire; MIsT = Memory for Intentions Test; PM = prospective memory.

^ $n = 188$.

* $p < .05$.