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Research Article

Time-Based prospective memory predicts insight into functional abilities among community-dwelling older adults

Michelle Gereau Mora, Libby A. DesRuisseaux and Yana Suchy
Department of Psychology, University of Utah, Salt Lake City, UT, USA

Abstract

Objective: Accurate appraisal of one's own abilities (i.e., insight) is necessary for appropriate compensatory behaviors and sustained independence during aging. Although insight is often purported to be related to executive functioning (EF), nuanced understanding of the cognitive correlates of insight for functional abilities among nondemented older adults is lacking. Because insight shares neuroanatomic underpinnings with time-based prospective memory (PM), the present study examined the contributions of time-based PM, beyond event-based PM and other potential cognitive confounds (i.e., episodic memory, time estimation, and EF), in predicting insight into one's own performance on instrumental activities of daily living (IADLs) among community-dwelling older adults. **Method:** A group of 88 nondemented, community-dwelling older adults completed performance-based measures of time- and event-based PM, episodic memory, time estimation, and EF, as well as IADL tasks followed by self-appraisals of their own IADL performance as indices of insight. **Results:** Time-based PM was moderately-to-strongly associated with insight, beyond event-based PM, time estimation, and episodic memory [$F(1,83) = 11.58$, $p = .001$, $\eta_p^2 = .122$], as well as beyond EF and demographic covariates [$F(1,79) = 10.72$, $p = .002$, $\eta_p^2 = .119$].Specifically, older adults who performed more poorly on a time-based PM task overestimated the efficiency of their own IADL performance to a greater extent. **Conclusions:** Findings suggest that nondemented older adults with poorer time-based PM may be more prone to inaccurately appraising their functional abilities and that this vulnerability may not be adequately captured by traditional EF measures.

Keywords: Metacognition; instrumental activities of daily living; prospective memory; aging; executive functioning; insight

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Introduction

In clinical neuropsychology, "insight"[1] typically refers to the ability to make accurate appraisals of one's own cognitive or functional performance. Insight is an important aspect of cognition, as accurate ongoing appraisal of one's own abilities is imperative to maintenance of independence (Devolder & Pressley, 1992; Hertzog & Jopp, 2010; Shaked et al., 2019) and is a prerequisite to appropriate compensation when faced with declines (Arora et al., 2021; Toglia, 2011). Among aging adults, instrumental activities of daily living (IADLs), which are complex activities central to functional independence (Borella et al., 2017; C. Graf, 2008; Lawton & Brody, 1969), arguably represent the most important object of self-appraisal. Poor insight into IADL declines raises concerns for significant errors (e.g., overdrawing account, missing appointments) and risks to health and safety (e.g., medication mismanagement, failure to turn stove off, falls, impaired driving) (Cosentino et al., 2011; De Souza et al., 2022; Hoffman et al., 2018; Liu & Lapane, 2009). These concerns are warranted even among seemingly cognitively intact older adults, given considerable variability in *both* functional abilities (Burton et al., 2006; Grigsby et al., 1998; Suchy et al., 2011, 2020a, 2020b; Ziemnik et al., 2020) *and* insight in this population. Indeed, much research has demonstrated the fallibility of IADL self-reports among community-dwelling older adults (Harty et al., 2013; McAlister & Schmitter-Edgecombe, 2016; Schmitter-Edgecombe et al., 2011; Suchy et al., 2011; Weakley et al., 2019). Thus, better understanding of the cognitive correlates of insight into IADLs would enhance the utility of neuropsychological evaluations with this population.

Executive functioning versus prospective memory

Executive functioning[2] (EF) has been consistently identified as a predictor of insight across a variety of populations (e.g., Fazeli et al., 2017; Mazancieux et al., 2021; Steward & Kretzmer, 2022), including community-dwelling older adults (Gereau Mora & Suchy, 2023). Prospective memory (PM), a component of EF defined as the ability to carry out previously planned actions at a specified later point, may be a stronger predictor of insight, given both theoretical (Kuhlmann, 2019) and empirical (Knight et al., 2005; Roche et al., 2002)

[1]In the literature, "insight" is used interchangeably with "self-awareness" and "metacognition." While *metacognition* is most typically used in cognitive psychology and neuroscience, other terms such as *insight* are more common within clinical contexts, particularly when pertaining to older adults (Chapman et al., 2020).

[2]EF refers to a set of cognitive processes that facilitate engagement in purposeful, goal-directed, and future-oriented behavior (Lezak et al., 2012; Stuss & Knight, 2002; Suchy, 2015a)

Corresponding author: Michelle Gereau Mora; Email: michelle.gereau@psych.utah.edu
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associations between “metacognition” (i.e., insight about one’s own abilities and performances; Chapman et al., 2020; Sunderaraman & Cosentino, 2017) and PM in daily life. However, past research has not examined whether PM performance can predict insight into *IADL performance.* This question is clinically relevant given that most traditional, well-validated EF measures fail to tap into PM (Burgess et al., 2006) due to their highly structured and examiner-prompted nature (Chaytor & Schmitter-Edgecombe, 2003; Rabin et al., 2016). As such, the ability to detect poor insight via traditional EF measures may be limited if PM is in fact a more sensitive indicator.

Time-based versus event-based prospective memory

There are two types of PM: event- and time-based. Event-based PM is the ability to retrieve relevant information when a specific event occurs (Suchy, 2015b) (e.g., remembering to stop for gas when returning from the store). Time-based PM is the ability to remember to do something following a certain amount of time or at a particular time (Suchy, 2015b) (e.g., removing a tea bag after the steeping time; taking medications at prescribed times). While both event- and time-based PM are crucial to successful IADL performance (Sheppard et al., 2020), time-based PM may additionally be distinctly associated with *insight* given neuroanatomical and conceptual overlap. Neuroanatomically, there is substantial evidence of overlap in brain regions subserving time-based PM and insight, including the right lateral prefrontal cortex (PFC) (namely, Broadman’s areas 10 and 45) and the right anterior insula (Baird et al., 2013; Burgess et al., 2008; Cona & Rothen, 2019; Hosseini et al., 2020; Morales et al., 2018; Picton et al., 2006; Rouault et al., 2018; Sunderaraman & Cosentino, 2017; Volle et al., 2011). Conceptually, time-based PM relies more heavily on self-monitoring capacity (McDaniel & Einstein, 2000), an aspect of insight, than event-based PM does. Additionally, unlike event-based PM tasks, time-based PM tasks lack explicit cues, making them generally more resource demanding (Zuber & Kliegel, 2020). It is unsurprising, then, that time-based PM is also generally more prone to error (Casaletto et al., 2014) and age-related declines[3] (Vanneste et al., 2016; Zuber & Kliegel, 2020) than event-based PM is. Thus, if time-based PM and insight are strongly associated, performance on time-based PM tasks may afford greater sensitivity to early/subclinical declines in insight and IADL abilities than traditional EF tests (Alzheimer’s Disease Neuroimaging Initiative et al., 2018), particularly among relatively high-functioning older adults (Karr et al., 2024).

Present study

Understanding of the cognitive correlates of insight among nondemented older adults is important given the critical role of accurate self-appraisal in the maintenance of independence during aging. While research has largely supported the contribution of EF to insight, PM may be more strongly associated with insight, as PM is more directly linked (conceptually and neuroanatomically) to the cognitive processes undergirding insight. Furthermore, time-based PM may be a more sensitive proxy of insight than event-based PM, especially among nondemented older adults, as it is generally considered more difficult. However, past research has not examined whether PM performance can predict insight into IADL performance, or whether time- and event-based PM differ in this regard.

Accordingly, this study aimed to examine the relationships between PM (time- and event-based) and the accuracy with which nondemented older adults appraise their own speed on IADL tasks. Participants completed (a) timed, performance-based IADLs, after each of which they judged their own speed relative to similarly aged peers, and (b) measures of time- and event-based PM and other potential cognitive confounds. We hypothesized that time- and event-based PM would each significantly predict insight (operationalized as discrepancies between actual IADL speed and subjective appraisals), but that only time-based PM would emerge as a unique predictor beyond event-based PM, EF assessed via traditional measures, and potential confounds.

Method

Participants

Participants were 100 nondemented community-dwelling older adults recruited for a larger study (see Brothers & Suchy, 2022). Inclusion criteria were being at least 60 years old; living independently/without significant assistance at home; having at least eight years of education; and self-reported ability to fluently understand, speak, and read English. Initial exclusion criteria were self-reported diagnosis of dementia or mild cognitive impairment; other significant neurological disorder (e.g., stroke, essential tremor); or severe/insufficiently controlled psychiatric disorder; uncorrected vision or hearing impairments; motor impairments precluding task performance; and color blindness. To ensure that participants with possible unreported dementia or severe depression were not inadvertently included in the sample, those participants who obtained a Dementia Rating Scale-Second Edition (DRS-2) raw score at or below 123[4] (N = 2) or obtained a Geriatric Depression Rating Scale-30 Item (GDS-30) raw score at or above 20 (N = 2) (Yesavage, 1988) were excluded from present analyses. Additionally, eight other participants were excluded from analyses due to missing data on primary variables. The final sample consisted of 88 participants (69.30% female, 30.70% male, 0% other) who were 92.04% non-Hispanic White, 3.41% Hispanic/Latino/a/e, 1.14% multiple races (White and Native American), and 3.41% of undisclosed race or ethnicity. See Table 1 for additional sample characteristics. These participants and sub-samples have been included in prior papers (Brothers & Suchy, 2021; Suchy et al., 2022, 2023), none of which examined PM or insight abilities.

Procedures

This study was approved by the University of Utah Institutional Review Board and was conducted in accordance with the Helsinki Declaration. Eligibility screening was completed via telephone. Eligible participants completed a four-to-six-hour battery of cognitive and psychological/self-report measures in the laboratory, during which they were offered at least three breaks, including 30 minutes for lunch/snack. The primary measures of interest for the present manuscript were administered approximately halfway through the study visit. Reimbursement was provided at

[3]For opposing findings, see a recent meta-analysis by Román-Caballero and Mioni (2023) in which results suggest no difference between PM types as a function of age; however, this is based on *clinical* samples (i.e., mild cognitive impairment, Alzheimer’s disease).

[4]Various DRS-2 raw score cutoff values have been proposed, ranging from 123 to 140 (e.g., Jurica et al., 2001; Lopez et al., 2023; Matteau et al., 2011; Springate et al., 2014). The DRS-2 was used in the present study to exclude possible overt dementia and as a supplementary covariate, rather than as a primary variable of interest. Thus, we chose the more lenient cutoff of 123, as done in our previous research (e.g., Gereau Mora & Suchy, 2023; Kraybill et al., 2013; Niermeyer & Suchy, 2020).

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Table 1. Characteristics of the sample

	Mean	SD	Minimum	Maximum	Possible range
Age (years)	69.38	5.76	60	85	–
Education (years)	16.33	2.53	11	24	–
DRS-2 (raw total score)	139.50	3.46	128	144	0 – 144
GDS (raw score)	4.41	4.13	0	18	0 – 30
TOPF (standard score)	111.26	10.89	86	131	40 – 160

Note: $N = 88$; DRS-2=Dementia Rating Scale-Second Edition, GDS = Geriatric Depression Scale, TOPF = Test of Premorbid Functioning, SD = Standard Deviation.

$10 per hour. Two-tailed p values of < .05 were considered statistically significant.

Measures

Characterizing the sample

General cognitive status was assessed using the DRS-2 (Jurica et al., 2001); premorbid functioning and general verbal ability using the Test of Premorbid Functioning (TOPF; Wechsler, 2011); and depressive symptoms using the 30-item Geriatric Depression Scale (GDS; Yesavage, 1988).

Insight

Insight was operationalized as the discrepancy between observed performance and the participant's self-appraisal. Specifically, judgments about performance speed relative to others of similar age were compared against observed performance speed adjusted for age. We focused on speed rather than accuracy given evidence that IADL completion time provides unique predictive (e.g., of future cognitive decline) and discriminative (e.g., mild cognitive impairment *vs.* cognitively intact) information *beyond* number of errors alone (Borella et al., 2017; Lassen-Greene et al., 2017; Wadley et al., 2008). Additionally, nondemented older adults may commit few, if any, errors on IADLs performed in the laboratory (Owsley et al., 2002; Suchy et al., 2011). We chose judgments of speed *relative to others of similar age* to set a common reference to which all participants would compare themselves, representative of how self-appraisals are typically made in day-to-day life (i.e., relative to similar peers; Mussweiler et al., 2005). To these ends, we first measured IADL task speed and then asked participants to judge their own speed relative to similarly aged peers, in accordance with methodology used in our prior research (Gereau Mora & Suchy, 2023).

Specifically, the Timed Instrumental Activities of Daily Living (TIADL; Owsley et al., 2002) was used and includes five tasks in communication, finance, food, shopping, and medication management. In the present sample, Cronbach's Alpha was .77. Test-retest reliability has previously been reported as .85 (Owsley et al., 2002). A composite "IADL performance" variable was created by regressing age onto individual task completion times, saving the standardized residuals (thus inherently placing them on a Z-score scale) for each of the five tasks, and then averaging these five residuals. Values were then reversed such that negative values represented completion times slower than predicted given the participant's age, zero represented times equivalent to prediction, and positive values represented times faster than predicted.

Upon completing each task, participants judged their speed as slower than (−1), the same as (0), or faster than (+1) that of similarly aged peers. The "average self-appraisal" variable is the average of these five judgments, transformed to match the score range and standard deviation of the *IADL performance* variable (to facilitate direct comparison between the two). In the present sample, Cronbach's Alpha was .68. In analyses, "insight" refers to the discrepancy between average self-appraisal and average IADL performance.

Prospective memory

Time- and event- based PM were assessed using two event-based and two time-based tasks modeled after prior research (Huppert et al., 2000; Koivula, 1996).

Time-based Prospective Memory. The time-based PM tasks consisted of alerting the examiner when 90 and 30 s (items 3a and 3c in supplementary materials) had passed while simultaneously completing distractor tasks (i.e., completion of written arithmetic problems and playing tic-tac-toe with the examiner). Total elapsed time from the beginning of the item to when the participant alerted the examiner was recorded. The discrepancy between the actual elapsed and instructed time was computed. Negative values were converted to zero, as they were deemed to likely reflect poor time estimation (i.e., under-estimation), rather than a lapse in PM itself. Importantly, we selected this method of calculation over incorrect/correct scoring using a predefined time window[5] given evidence that continuous time values provide additional sensitive information about accuracy and precision of ongoing time-based PM monitoring without severely reducing score variance (Maylor et al., 2002; West & Craik, 1999). While positive values could also in part reflect poor time estimation (i.e., time over-estimation), this was controlled for in analyses (see potential cognitive confounds below). This adjusted discrepancy score represents the "time-based PM" variable.

Event-based Prospective Memory. The event-based PM tasks consisted of remembering to write previously specified information on an envelope and on an index card during the testing session, with event-based cues being questionnaire completion and reception of an index card (items 1 and 2 in supplementary materials). The sum of points on the two event-based tasks, ranging from 0 to 5 points (see supplementary materials for scoring), represents the "event-based PM" variable.

Potential cognitive confounds

Time Estimation. Given that time-based PM inherently relies on time estimation as a prerequisite, albeit distinct, cognitive process (Cona & Rothen, 2019; P. Graf & Grondin, 2006), we also assessed time estimation to better isolate the time-based PM construct. Participants were asked to alert the examiner when 60 s had passed (item 3b in supplementary materials), *without* engaging in an attention-demanding distractor (modeled after the non-activity condition in Koivula (1996))[6]. The absolute value of the discrepancy between estimated time and instructed time (absolute value of time centered around 60 s) served as "time estimation" in analyses. Thus, time estimation represents the number of seconds by which a participant was *off* in making their estimate.

[5]There is considerable heterogeneity in selection of and rationale for time-based PM cutoff(s) when dichotomizing performance as correct *versus* incorrect (e.g., anywhere from plus/minus 1% to 50% of the instructed time; Lecouvey et al., 2019; Massa et al., 2020; Maylor et al., 2002; Mioni et al., 2020; Troyer & Murphy, 2007; Zhuang et al., 2021).

[6]We chose a prospective time production paradigm, as production task performance is believed to reflect individual internal clock processes (Mioni, 2018). The target estimation time was similar to those of the time-based PM tasks, as much shorter or longer temporal interval production may rely on different cognitive processes (Mioni, 2018).

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Episodic Memory. Similarly, given that event-based PM inherently relies on the capacity for encoding and retrieval of relevant information from episodic memory (Ball et al., 2018; Brewer & Marsh, 2010), we assessed episodic memory to isolate event-based PM. The raw delayed recall total from Form 3 of the Hopkins Verbal Learning Test–Revised (HVLT-R) represents "episodic memory."

Executive Functioning. The D-KEFS battery was used to generate a well-validated EF composite, consistent with our prior research (e.g., Brothers & Suchy, 2021; DesRuisseaux et al., 2023; Franchow & Suchy, 2017; Suchy et al., 2022). Participants were administered four D-KEFS subtests, Trail Making Test (TMT), Verbal Fluency (VF), Design Fluency (DF), and Color-Word Interference Test (CWIT) (Delis et al., 2001). Those subtest conditions designated as "primary" in the test manual were then used to generate the EF composite. Raw scores were converted to scaled scores[7] (Delis et al., 2001), then averaged within subtests. Subtest scores were then averaged to create the "EF" composite variable. Cronbach's alpha in this sample was .81. Test-retest reliabilities have previously been reported at .90 (Suchy & Brothers, 2022).

Analytic plan

Missing Data. Regression-based single imputation[8] with appropriate auxiliary variables[9] was used to generate missing data on secondary/covariate variables with low proportion of missingness. Missing GDS scores ($n = 3$; 3.41%) were imputed using neuroticism and extraversion scores from the NEO Five-Factor Inventory, third edition (NEO-FFI-3) as auxiliary variables given theoretical relevance (Hayward et al., 2013; Koorevaar et al., 2013; Kotov et al., 2010; Weber et al., 2012) and observed sample correlations with GDS (r=.496 and -.409, respectively). Missing episodic memory scores ($n = 8$; 9.09%) were imputed using the DRS-2 memory scale raw score as the auxiliary variable given theoretical relevance (Lopez et al., 2023) and observed sample correlation with HVLT-R (r=.439).

Primary Analyses. Statistical analyses were conducted using IBM SPSS Statistics (Version 29.0.2). For all principal analyses, mixed model repeated measures ANOVAs were run using self-appraisal and IADL performance as the dependent variables, which together represent the within-group factor of "insight." The primary results of interest are the interactions between each predictor and the within-group factor, indicating whether insight is a function of that predictor. Significance level was set at $p < .05$. To test the hypothesis that time-based PM would emerge as a unique predictor of insight beyond event-based PM and potential cognitive confounds, time- and event-based PM, time estimation, and episodic memory were included as predictors. To test the hypothesis that time-based PM would also emerge as a unique predictor of insight beyond EF assessed via traditional measures, a model was run including time-based PM, time estimation, and EF as predictors. Finally, the prior model was run again, including relevant demographic and psychiatric variables, to ensure that results held beyond additional possible confounds.

Results

Preliminary analyses

All variables were normally distributed (skewness = −1.24–1.35), apart from IADL performance (skewness = −2.70), which was resolved via Winsorization (skewness = −.805). No consistent outliers were identified upon examining leverage, discrepancy, and influence statistics. Q-Q plots indicated adequate normality of residuals. Descriptive statistics of participant characteristics, primary independent and dependent variables, and the raw amount of time in seconds to complete the TIADL tasks can be found in Tables 1–3, respectively.

Zero-order correlations between primary dependent and independent variables and sample characteristics (demographics, cognitive status, depression) are presented in Table 4. As seen in the table, individuals with higher TOPF scores had better (faster than predicted) IADL performance. Older age, lower DRS-2 scores, and lower TOPF scores were all weakly-to-moderately associated with poorer time-based PM performance. Interestingly, higher GDS scores were weakly associated with better event-based PM performance. Episodic memory was associated with age and DRS-2 score, and EF was associated with age, education, and DRS-2 and TOPF scores, all in the expected direction. As such, age, education, DRS-2, TOPF, and GDS were included in the final model. Correlations among dependent and independent variables are presented in Table 5, showing that those with faster IADL performance had better time-based PM scores and higher episodic memory and EF performance. Self-appraisals[10] were not themselves correlated with any primary variables. In line with expectations, poorer time-based PM was moderately associated with lower EF performance. Unexpectedly, event-based PM was not significantly associated with EF, although episodic memory was.

Principal analyses

Time- versus Event-Based Prospective Memory. When examined independently, time-based PM did [$F(1,86) = 16.03$, $p < .001$, $\eta_p^2 = .157$] and event-based PM did not ($p = .090$) interact with insight. Specifically, poorer time-based PM was associated with greater discrepancy between one's self-appraisal and actual performance. Time-based PM continued to interact with insight [$F(1,85) = 15.81$, $p < .001, \eta_p^2 = .157$] after accounting for time estimation, which itself was not associated with insight ($p = .997$). As hypothesized, upon including both PM types and their respective potential confounds in a single model, time-based PM emerged as the only variable to interact significantly with insight [$F(1,83) = 11.58$, $p = .001, \eta_p^2 = .122$], while event-based PM ($p = .456$), time estimation ($p = .985$), and episodic memory ($p = .299$) did not. The interaction between time-based PM and insight is represented in Figure 1, showing that those who had poorer time-based PM scores (i.e., took longer than the sample median of 29.00 s) also more greatly overestimated their own IADL performance speed.

Time-Based Prospective Memory versus Executive Functioning. We next ran a model including time-based PM, time estimation, and EF as independent variables. In line with our hypothesis, time-

[7]D-KEFS raw scores were converted to scaled scores using the normative reference group for adults aged 60–69 years. This allowed for combination of standardized scores into a single composite *without* correcting for age, as other primary variables (insight, IADL performance, prospective memory) did not have age-based normative data. The 60–69-year-old age band was selected because scores within this age band encompass the widest range of raw scores (compared to other age bands) and therefore have the highest probability of avoiding floor or ceiling effects (Delis et al., 2001).

[8]For evidence that regression-based single and multiple imputation methods perform similarly under low missingness conditions, see Javanbakht et al. (2022).

[9]For review of auxiliary variable selection guidelines, see Enders (2022); Hardt et al. (2012); Javanbakht et al. (2022).

[10]Self-appraisals are distinct from insight. Specifically, self-appraisals reflect how participants appraised their performance, whereas insight reflects the discrepancy between self-appraisals and performance.

Table 2. Descriptive statistics of primary dependent and independent variables used in analyses

Variable name	Mean	SD	Minimum	Maximum	Possible range
IADL performance (Winsorized) (*z*-score)	.029	.534	−2.97	1.44	−3 – 3
Average self-appraisal (raw score)	.167	.533	−1.93	1.93	−3 – 3
Time-based PM (seconds)	37.72	34.30	0	167	0 – 180
Event-based PM (raw score)	4.10	1.05	0	5	0 – 5
Time estimation (seconds)	12.38	9.89	0	39	0 – 90
Episodic memory (raw score)	8.90	2.47	0	12	0 – 12
Executive functioning (scaled score)	12.11	1.69	5.63	16.50	0 – 19

Note. $N = 88$. For variables that were normalized via transformation, the transformed scores are presented in the table, as indicated in variable names. IADL = Instrumental activities of daily living, PM = Prospective memory, SD = standard deviation. IADL Performance is the average of *age-corrected* Z-score-transformed completion times (for each of the five Timed Instrumental Activities of Daily Living tasks). Time-based PM is the sum of positive value differences between the amounts of time elapsed when the participant alerted the examiner and the amounts of time at which they were instructed to alert the examiner (i.e., 30 and 90 s), thus representing total *overestimation* (in seconds) across the two tasks. Time Estimation is the absolute value of the difference between the amount of time estimated by the participant and the amount of time they were instructed to estimate (i.e., 60 s).

Table 3. Descriptive statistics of the timed instrumental activities of daily living scores (in seconds)

Variable Name	Mean	SD	Minimum	Maximum	Time limit
TIADL Communication	41.50	27.53	9	180	180
TIADL Finances	11.24	4.36	4	23	120
TIADL Food	22.26	11.98	4	71	360
TIADL Shopping	5.44	5.92	1	55	120
TIADL Medicine	10.43	6.35	2	58	240
TIADL Raw Total	90.67	40.03	27.79	335	1020

Note. $N = 88$. TIADL = Timed Instrumental Activities of Daily Living.

based PM continued to significantly interact with insight [$F(1,84) = 8.94, p = .004, \eta_p^2 = .096$] beyond time estimation and EF, neither of which contributed significantly ($p = .913$ and $p = .464$, respectively). Finally, we ran the prior analysis with the addition of age, education, DRS-2, TOPF, and GDS as covariates. Time-based PM continued to interact significantly with insight [$F(1,79) = 10.72, p = .002, \eta_p^2 = .119$] beyond additional possible confounds, which themselves were non-significant (see Table 6).

Discussion

The present study examined the contributions of time- and event-based prospective memory (PM) to the accuracy with which nondemented older adults appraised their own speed when performing a series of IADL tasks. The chief finding is that poorer performance on time-based PM tasks was robustly and uniquely associated with overestimation of IADL performance speed, beyond event-based PM and beyond executive functioning (EF) assessed via traditional measures. The present study addressed a gap in neuropsychological literature, namely, the lack of empirical evidence for the theorized association between PM and insight for functional abilities. Findings support the ability of time-based PM performance to aid in detection of subtle deficits in insight about functional abilities, which may otherwise go undetected among seemingly cognitively healthy and independent older adults.

Time- versus event-based prospective memory

This study is the first to demonstrate a unique association between PM and insight into IADL performance among nondemented older adults. Specifically, time-based, but *not* event-based, PM emerged as a robust predictor of insight. Notably, event- and time-based PM are partly dissociable constructs that are subserved by slightly different brain regions (Picton et al., 2006; Román-Caballero & Mioni, 2023). Additionally, some studies have described impairments (Cheung et al., 2015; Katai, 2003; Raskin et al., 2011) and overconfidence (Casaletto et al., 2014) in one but not the other. Of note, just as time-based PM may be more vulnerable than event-based PM to non-pathological aging-related declines (Casaletto et al., 2014; Suchy, 2015b; Vanneste et al., 2016; Zuber & Kliegel, 2020), speed on functional tasks is also more prone to decline during aging than is accuracy (Gregory et al., 2009; Lassen-Greene et al., 2017; Wadley et al., 2008). Taken together, findings suggest that time-based PM may be a more sensitive indicator of subtle insight *and* functional declines (as evidence by speed-, rather than accuracy-, based IADL paradigms) than event-based PM among nondemented older adults.

Alternatively, significant time-based PM effects could be explained by time estimation abilities, particularly given mixed findings from prior attempts to decouple time estimation and time-based PM (P. Graf & Grondin, 2006; Labelle et al., 2009; Mioni et al., 2020; Park et al., 1997). However, to facilitate isolation of time-based PM, our tasks involved sufficient distraction to avoid simultaneous counting; and times falling below the target were set to zero, retaining only overestimates, believed to reflect true PM failure. Additionally, performance on a separate "pure" time estimation task was included in analyses.

Lastly, the fact that time-based PM was more strongly associated with insight than was event-based PM could be a function of the two measures' psychometric properties, which are not fully known. More concretely, we did not collect data for examination of test-retest reliabilities, and the two measures do not lend themselves to valid examination of internal consistency due to being two-item scales (Eisinga et al., 2013; Pallant, 2020). Future research should examine the differential associations of event- and time-based PM with insight using more extensively validated performance-based PM measures.

Time-based prospective memory versus executive functioning

Consistent with our hypothesis, time-based PM was associated with insight after accounting for a highly reliable EF composite, which itself was not associated with insight. Even though PM is considered a component of EF (Rummel & McDaniel, 2019; Suchy, 2015b), and time-based PM was correlated with EF here, time-based PM tasks may be better poised than traditional EF measures to detect *subtle* declines in insight. Indeed, traditional EF measures have been criticized for not tapping into PM abilities (Burgess et al., 2006; Chaytor & Schmitter-Edgecombe, 2003; Rabin et al., 2016).

Notably, the failure of EF to predict accuracy of self-appraisals in the present study sample is inconsistent with our prior research

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Table 4. Zero-order correlations of the primary dependent and independent variables with sample characteristics

	IADL performance (Winsorized)	Average Self-appraisal	Time-based PM	Event-based PM	Time estimation	Episodic memory	Executive functioning
Age	.044	.039	.365***	−.120	−.160	−.255*	−.348***
Education	.195	.090	−.135	−.091	−.123	.086	.313**
Sex	−.110	−.118	.078	.020	.197	.207	−.055
GDS	−.011	−.157	.061	.217*	−.001	.109	−.103
DRS-2	.131	−.069	−.280**	.163	.044	.255*	.426***
TOPF	.332**	−.029	−.240*	.027	−.167	.131	.349***

Note. $N = 88$; $^{*}p < .05$; $^{**}p < .01$, $^{***}p < .001$. For variables that were normalized via transformation or log-transformation, the normalized scores were used in analyses, as indicated in variable names. DRS-2=Dementia Rating Scale, Second Edition, raw score; GDS = Geriatric Depression Scale, TOPF = Test of Premorbid Functioning, IADL = Instrumental activities of daily living, PM = Prospective memory. Sex was coded 1=female, 0=male. IADL Performance is the average of *age-corrected* Z-score-transformed completion times (for each of the five Timed Instrumental Activities of Daily Living tasks). Time-based PM is the sum of positive value differences between the amounts of time elapsed when the participant alerted the examiner and the amounts of time at which they were instructed to alert the examiner (i.e., 30 and 90 s), thus representing total *overestimation* (in seconds) across the two tasks. Time Estimation is the absolute value of the difference between the amount of time estimated by the participant and the amount of time they were instructed to estimate (i.e., 60 s).

Table 5. Zero-order correlations between the primary dependent and independent variables

	Time-based PM	Event-based PM	Time estimation	Episodic memory	Executive functioning	Average self-appraisal
IADL Performance (Winsorized)	−.371***	.097	−.095	.273*	.461***	−.018
Average self-appraisal	.195	−.163	−.070	−.008	.076	–
Executive functioning	−.525***	.103	−.146	.361***	–	–
Episodic memory	−.210	.179	−.114	–	–	–
Time estimation	−.112	.112	–	–	–	–
Event-based PM	.176	–	–	–	–	–

Note. $N = 88$. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$. For variables that were normalized via transformation, the normalized scores were used in analyses, as indicated in variable names. IADL = Instrumental activities of daily living, PM = Prospective memory. IADL Performance is the average of *age-corrected* Z-score-transformed completion times (for each of the five Timed Instrumental Activities of Daily Living tasks). Time-based PM is the sum of positive value differences between the amounts of time elapsed when the participant alerted the examiner and the amounts of time at which they were instructed to alert the examiner (i.e., 30 and 90 s), thus representing total *overestimation* (in seconds) across the two tasks. Time Estimation is the absolute value of the difference between the amount of time estimated by the participant and the amount of time they were instructed to estimate (i.e., 60 s).

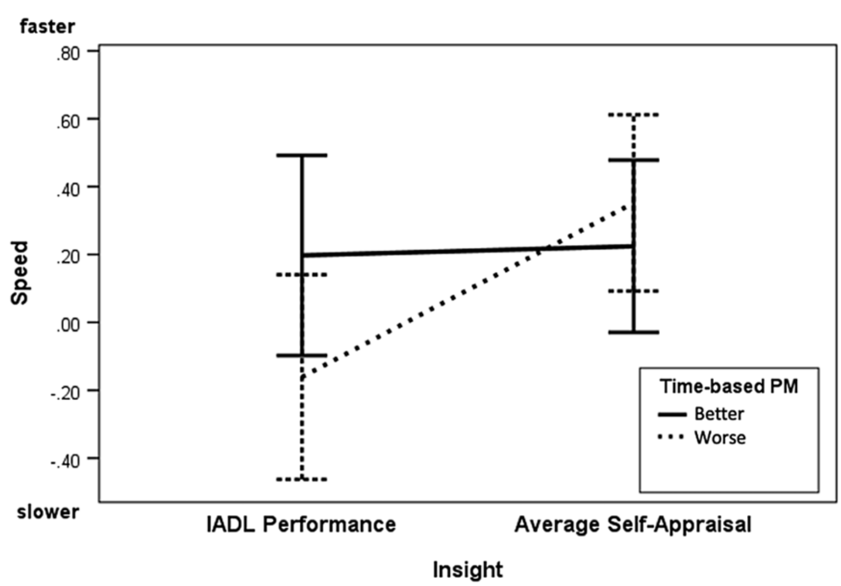

Figure 1. Interaction effect between insight and time-based prospective memory. *note:* $N = 88$. IADL = instrumental activities of daily living. PM = prospective memory. Time-based PM is the sum of positive value differences between the amounts of time elapsed when the participant alerted the examiner and the amounts of time at which they were instructed to alert the examiner (i.e., 30 and 90 s), thus representing total *overestimation* (in seconds) across the two tasks. Better and worse/poorer time-based PM scores are those above and below the median overestimation (29.00 s), respectively. The insight factor (discrepancy between objective performance speed relative to similarly aged peers and subjective appraisals of speed relative to peers) interacts with time-based PM, such that those with poorer time-based PM scores overestimated their IADL performance speed more than those with lower/more accurate time-based PM scores. Error bars represent 95% confidence intervals.

utilizing the same paradigm in a different, albeit demographically similar, sample of older adults (i.e., comparable age, education, and cognitive status; Gereau Mora & Suchy, 2023). Importantly, the range of EF scores was similar in the two samples (prior *range* = 5.63–16.50 *vs.* current *range* = 5.63–16.50). However, the previous study's sample size was larger ($N = 150$) than that of the present (N=88). Upon examining correlations between the EF composite and insight in both studies, effect sizes were found to be similar between the Gereau Mora and Suchy (2023) ($r = -.264$, $p < .001$) and present ($r = -.270$, $p = .011$) paper, suggesting two conclusions: first, differences in sample size may in part explain discrepant findings; and second, time-based PM may be *more sensitive* than traditionally assessed EF in the detection of subtle insight deficits among nondemented older adults.

Clinical implications

Accurate awareness of one's own functional abilities is a prerequisite for appropriate use of compensatory strategies (Arora et al., 2021; Toglia, 2011) and is thus integral to continued

Table 6. Mixed model repeated measures ANOVA of insight, controlling for covariates

Source	*Mean Square* (1,79)	*F*	*p*	η_p^2
Within-group factor (insight)	.219	.900	.346	.011
Time-based PM*	**2.613**	**10.718**	**.002**	**.119**
Time estimation*	.120	.491	.486	.006
Executive functioning*	.254	1.042	.310	.013
DRS-2*	0	.001	.970	0
Age*	.888	3.642	.060	.044
Education*	.049	.202	.654	.003
TOPF*	.309	1.269	.263	.016
GDS*	.471	1.934	.168	.024
Error (Discrepancies)	.244	–	–	–

Note. *N*=88. Within-group factor (insight) is comprised of Average Self-Appraisal and IADL Performance (Winsorized). *Predictor interaction with insight. PM = Prospective memory, EF = Executive functioning, TOPF = Test of Premorbid Functioning, GDS = Geriatric Depression Scale. Time-based PM is the sum of positive value differences between the amounts of time elapsed when the participant alerted the examiner and the amounts of time at which they were instructed to alert the examiner (i.e., 30 and 90 s), thus representing total *overestimation* (in seconds) across the two tasks. Time estimation is the absolute value of the difference between the amount of time estimated by the participant and the amount of time they were instructed to estimate (i.e., 60 s).

functional independence during aging (Hertzog & Jopp, 2010; Shaked et al., 2019). Additionally, accurate insight is a prerequisite for valid completion of self-report measures of IADL capacity that are commonly used in clinical settings. The present findings indicate a unique role for time-based PM tasks in detecting subtle cognitive declines among nondemented older adults. Specifically, inclusion of quite brief time-based PM tasks in assessments of independent older adults may provide valuable information about insight into functional abilities that would not be captured by self- or informant- report and, importantly, *without* the need for often long PM batteries. Therefore, it may be beneficial to include short time-based PM tasks in clinical evaluations to assess both the likelihood of PM failures and the ability to maintain accurate insight into functional abilities, thus further informing characterization of daily functioning and decisions regarding functional independence.

Limitations

There are several limitations to consider. First, we acknowledge that, while our method for operationalizing insight has been used in our prior research (Gereau Mora & Suchy, 2023), it is not a validated measure per se. While efforts have been made to develop and validate comparative (self- *vs.* -rater) questionnaires examining insight for IADLs in brain injury populations (e.g., Salazar-Frías et al., 2024; Winkens et al., 2019), such validation studies in non-clinical populations using comparative (self- *vs.* -performance) behavioral methods are lacking. Second, our sample consisted of primarily White, well-educated (i.e., most completed at least 4 years of college), non-Hispanic/Latino/a/e older adults. As a result, age-adjusted IADL performance estimates were anchored within our homogenous sample rather than the broader population. Although this approach has strengths relative to much prior research, it allows for the possibility of differing findings in samples with a broader range of IADL performances. Similarly, it is possible that participants made appraisals in relation to peers with poorer-than-average IADL abilities. However, a meta-analysis by Heine and Hamamura (2007) indicates that individuals from western cultures tend to compare themselves more "fairly" against the true average, rather than opting for self-enhancement by comparing against lower-than-average peers. Additionally, confidence in one's performance (Ardila, 2005; Lechuga & Wiebe, 2011; Lundeberg & Mohan, 2009; Rachmatullah & Ha, 2019), as well as relative value of speed over accuracy (Ardila, 2005), also vary by culture. Thus, it will be important for future research to sample a more diverse population, especially in light of the growing diversity of the United States' population (U.S. Census Bureau, 2020). It is also unclear if and to what extent PM and insight may be related in young-to-middle-aged adults, particularly given that PM abilities may begin (albeit slowly) declining as early as age 20 (Zuber & Kliegel, 2020).

Additionally, although our time-based PM assessment addressed limitations of many previously employed measures by not allowing for monitoring assistance (e.g., presence of a clock), it is not without its own limitations. Specifically, time-based PM items were relatively brief (30 and 90 s), thus possibly not tapping into the full range of time-based PM abilities implemented in daily life. However, robust findings suggest that quite brief time-based PM assessments may sufficiently capture subtle deficits, although it would be necessary to pit these against a more comprehensive measure to ascertain this. Further, methodological similarities between our insight and time-based PM measures (i.e., require appraisal of one's own speed and estimation of elapsed time, respectively) could partially account for their observed relationship. While this possibility cannot be fully discounted, it is rendered less likely given that findings remained robust upon including time estimation (presumably accounting for some of the overlap in prerequisite cognitive processes) in analyses. Lastly, both event and time-based PM composites were based on two items each. While this number of items may strain the reliability of our composites, it is not dissimilar from existing, validated PM measures (Blondelle et al., 2020).

Conclusions

This study was the first to directly investigate the previously theorized association between PM and insight into functional abilities among nondemented older adults. Results showed that poorer time-based PM was uniquely and robustly associated with overestimation of speed of performance-based IADL tasks, beyond event-based PM and overall EF. Overall, findings suggest that nondemented older adults with poorer time-based PM may be more prone to overestimating their functional abilities, consequently increasing the possibility of failing to engage in compensatory strategies when faced with functional declines.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355617724000614.

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