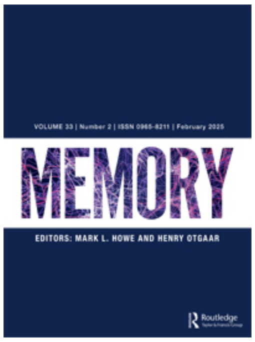

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Executive control contributes little to prospective memory function in older age: evidence from more ecologically valid paradigms

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ABSTRACT

Age-related losses in executive control are widely assumed to contribute to prospective memory (PM) lapses in late adulthood, but to date, this assumption has gained only inconsistent support from lab-based studies. The present study tested whether age indirectly affects PM via (1) individual differences in specific executive control operations (a parallel mediated model), or (2) a serially mediated model, with processing speed as the first mediator. Older adults ($n = 166$) completed four measures of PM that had higher ecological validity than standard lab-based paradigms, as well as measures of executive function and other cognitive abilities. The results showed that, although age was a significant predictor of reduced performance on three of the PM measures, particularly time-based tasks, these negative age associations were only slightly diminished when executive functions were controlled for. Performance on the PM task with the greatest ecological validity (MEMO) was independent of age and measures of executive function but positively related to both learning and retention. Processing speed was a poor predictor of PM performance on all measures (accounting for between 0% and 4% of variance). Taken together, these results highlight the need for circumspection in generalising the role of executive control in age-related prospective memory performance.

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Prospective memory; ecological validity; cognitive ageing; executive control

Prospective memory (PM), or "remembering to remember", is a core cognitive skill that is critical for independent living (Henry, 2021). PM lapses are a common complaint for older adults and predict their ability to perform many functional activities of daily living, such as remembering to pay bills or to take medicine (Hering et al., 2018). PM function also predicts future cognitive decline and incident dementia even after controlling for broader cognitive function (Browning et al., 2023). However, although PM function also declines in healthy aging, it does so in a manner that is distinct from the losses that best predict abnormal adult aging. While difficulties on PM tasks supported by spontaneous (as opposed to more effortful) retrieval most strongly predict future abnormal cognitive decline (Browning et al., 2023), normal age-related difficulties are typically greatest for PM tasks that impose the highest demands on strategic control processes such as working memory (Craik & Henry, 2023). Yet important questions remain about whether, and if so how, strategic control processes contribute to healthy older adults' PM performance, especially on ecologically valid tasks. The current study was designed to address these questions.

PM tasks in daily life can be broadly categorised as *event-based* (e.g., passing on a message to a colleague when seeing them) or *time-based* (e.g., attending a medical appointment or moving the car in 15 min; McDaniel & Einstein, 2007). These PM task types can also be conceptualised on a continuum from low-to-high in cognitive demands depending on their associated cues (McDaniel & Einstein, 2000). Event-based tasks with cues that are either salient or focal (i.e., cognitively related) to ongoing task demands tend to elicit spontaneous retrieval of the PM task, requiring less strategic processing than event-based tasks with perceptually peripheral or non-focal (i.e., cognitively unrelated) cues. Time-based tasks which are associated with a daily routine or time-relevant cues (e.g., changes in sunlight or traffic) may similarly prompt spontaneous recall (Haines et al., 2020) and make fewer demands on executive control than unscheduled or unexpected short interval time-based PM tasks.

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Consistent with the notion that more effortful PM tasks are most vulnerable to age-related effects, in their meta-analysis, Henry et al. (2004) found that older adults' PM performance showed greater decline on time-based tasks than event-based tasks that imposed higher levels of controlled strategic demand, but that there was no difference between time-based tasks and event-based tasks that were supported by relatively more automatic processes.

However, previous studies that have directly tested whether performance on tests of executive control contributes to age-related difficulties in PM have shown mixed results. For instance, while Kamat et al. (2014) found that executive functioning predicted better time (but not event-based) PM task performance, Wilson et al. (2004) found executive functioning was related to event but not time-based tasks. It should be noted that in addition to using different types of PM tasks, both Kamat et al. (2014) and Wilson et al. (2004) used global measures of executive functioning, and it therefore remains unclear which specific aspect(s) of executive control were associated with PM performance in their studies.

Executive control consists of at least three related but separable components (Miyake et al., 2000): mental-set shifting or the ability to maintain two or more qualitatively different goals or intentions in working memory (*shifting*); manipulation and updating of the contents of working memory (*updating*); and the ability to avoid distractions and inhibit habitual responses (*inhibition*). It is unlikely that aging will influence each of these functions in the same way (Phillips et al., 2008), or that their relationship to PM is equivalent, but it has often been suggested that decreases in one or more of these functions in normal aging may mediate the negative relationship between PM and age.

Only three studies to date have directly tested this question. In the first, Gonneaud et al. (2011) found no evidence to support the mediational role of shifting, updating, or inhibition in the association between PM and age. Instead, measures of retrospective memory and verbal learning fully mediated age-related effects on PM performance on both low and high demand event-based PM tasks (but not on time-based tasks). In a later study, Schnitzspahn et al. (2013) found that age effects on a high demand event-based PM task were fully mediated in a model including all the components of executive control, but only shifting and inhibition, along with processing speed, emerged as significant unique predictors of performance. More recently, Zuber et al. (2016) identified weak relationships between performance on a high demand (non-focal cue) PM task and all three components of executive control, but only updating and inhibition were related to performance on a low demand (focal cue), event-based PM task.

Collectively, these studies with their different findings suggest that the relationships between these cognitive abilities might be smaller and more complex than previously believed, and/or possibly restricted to specific types of PM and/or aspects of executive control. It is also possible that any relationship between PM and executive control might differ as a function of the PM tasks' level of ecological validity. In this regard, it is useful to consider the taxonomy proposed by Phillips et al. (2008). Here, there are five types of ecological validity ranging from: Type 1 (very high), in which the PM task is natural, familiar and in the context of daily life (e.g., taking medication); Type 2 (high), in which an experimental (artificial) PM task is embedded in daily life (e.g., calling the experimenter at an agreed upon time); Type 3 (moderate), PM task is experimenter given and setting is controlled but simulated to resemble "everyday" life (e.g., computer based tasks simulating preparing a meal); Type 4 (low), artificial PM task in laboratory context but with some familiarity (e.g., reminding experimenter to check keys at set time); and Type 5 (very low), in which the PM task is artificial, novel, and in a laboratory context (e.g., pressing a button when seeing a word on a screen).

A consideration in interpreting the studies by Gonneaud et al. (2011), Schnitzspahn et al. (2013), and Zuber et al. (2016), is that they all relied on PM tasks with very low (Type 5) ecological validity; that is, all used a lab setting in combination with an artificial task (Phillips et al., 2008). Specific tasks included being asked to press the space bar whenever a word shown during a semantic-matching task was presented in blue font (Schnitzspahn et al., 2013); press the space bar whenever the letter in a working memory task was an "A" or a "D" (Zuber et al., 2016); or press the D key whenever an arithmetic answer was over 100 (Gonneaud et al., 2011). To understand the relationship between executive function and PM in older adults' day to day lives accurately, it is critical that people be assessed on measures of PM that more closely approximate how PM operates in actual, daily life, particularly since PM function in late adulthood has been shown to vary markedly as a function of the social environment, contextual demands, and the perceived importance of the PM task (Craik & Henry, 2023).

The present study

This study was designed to understand whether, and if so how, executive control contributes to older adults' PM function on tasks that have a higher degree of ecological validity than traditional lab-based assessments. This objective was achieved by assessing older adults' performance on four diverse measures of PM function that met criteria for Type 4, Type 3, and Type 2 ecological validity (a realistic task set in a laboratory setting; a familiar task in a complex virtual environment; and an experimental task embedded in an everyday setting, respectively). Because we were interested in understanding whether any relations with executive control were general or specific, we also included tests of all three components of executive control (shifting, inhibition, and updating). To establish the specificity of any observed relationships, measures of broader cognitive function (episodic memory and processing speed) were also included.

This study was also designed to test predictions from two competing theoretical frameworks about the nature of any association between PM and executive control, should one be observed. Thus, a central tenet of the dynamic multiprocess framework is that high cognitive load will be associated with age-related difficulties, whereas low cognitive load should be associated with negligible age effects, and possibly even age-related improvement (Scullin et al., 2013). This model therefore predicts that aging should indirectly affect PM via individual differences in facets of executive control (see Figure 1(a)). By contrast, in Salthouse's processing speed model (Salthouse, 1996), age-related cognitive difficulties are assumed to reflect the core underlying process of reduced processing speed, and therefore changes in PM performance should be due either to direct effects of slower speed or to the indirect effects of slower speed operating via deleterious effects on components of executive functioning (see Figure 1(b)). In the present study, a further key aim was therefore to test which of these models provided the best fit to our data.

Method

Transparency and openness and data availability

We determined minimum sample size for each indirect effect in the mediation model using the Monte Carlo Power Analysis for Indirect Effects R package (Schoemann et al., 2017), with a target power of .80, estimated standardised coefficients for each variable path of .30 (e.g., a1, a2, a3 …) and direct effect of .10 (c′), each variable in the covariance matrix had a standard deviation set at 1.00, and mediation covariances (e.g., rM1M2) was set at .40. This gave the following required *N*s: a1b1: 154; a2b2: 78; a3b3: 88. The de-identified data on which the study conclusions are based is not publicly accessible to adhere with ethics but will be made available upon reasonable request by contacting the corresponding author. The study design, hypotheses and analytic plan were not preregistered. The precise analytic approach and statistical package used is specified and so analyses can easily be reproduced. All measures are validated, and most are standardised and publicly available. Those that we developed ourselves (Virtual Week and MEMO) are too large to be made publicly available, but we are happy to share these upon reasonable request.

Participants

A total of 166 healthy older adults ($M_{age} = 72.4$, $SD = 6.2$, range 60–88; 56% female; racial characteristic were not recorded) participated in this study between 2017 and 2020, recruited through independent living units, church and community newsletters, and word-of-mouth in Melbourne, Australia. Participants all had English as their first language and were screened using either the Mini Mental State Exam with cut-off score of ≥ 24, or the Telephone Interview for Cognitive Status modified test (TICS-M) with an education adjusted cut-off score of ≥ 33 required for inclusion. All participants provided written informed consent prior to completing any of the assessments and were reimbursed with $50 vouchers upon completion of the study. Ethics approval was provided by ACU-Melbourne Human Research Ethics Committee (#52413). One hundred and four of the participants in this study also contributed data on Virtual Week and MEMO to a separate study (Haines et al., 2020).

Materials and procedure

Participants were tested individually in two sessions of 2–3-hours duration. In Session 1, one of the measures of PM (the Memory for Intentions Screening Test or MIST; Raskin, 2009) and measures of executive control were administered. Instructions for a second measure of PM that needed to be completed in participants' actual everyday lives (the MEMO; Haines et al., 2020) were also provided, with participants then completing this measure over the following three days. In Session 2, the final two measures of PM were administered: Virtual Week (Rendell & Craik, 2000) and the Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2004). To minimise fatigue, breaks were provided as needed throughout the testing sessions.

Type 4 ecological validity PM task: laboratory setting but realistic task

Two type 4 measures were included. The first was the MIST (Raskin, 2009), which qualifies as a Type 4 PM task as it is a validated non-computerised measure of PM that includes the types of real-world tasks that one might have to perform in daily life (e.g., "in 15 minutes tell me to check my mail"). Participants are asked to perform eight PM tasks over a period of approximately 20 minutes whilst engaged in an ongoing word search task. The MIST assesses both time-based and event-based PM and varies the delay interval (2-minute or 15-minute delay) and response type (verbal or action response). Time-based tasks are rated on a 3-point scale ranging from 0 to 2, where 0 equals an omission, 1 equals a correct response at the incorrect time, and 2 indicates a completely correct response. Event-based tasks are rated on a 3-point scale between 0 and 2, where 0 is an omission error and 2 is a correct response. The key dependent measures of interest in the present study were the total scores for event-based PM and time-based PM tasks. Cronbach's alpha for the MIST in the current study was estimated to be .50 for the total score.

The CAMPROMPT (Wilson et al., 2004) is a clinical measure of PM that also includes more true-to-life PM tasks (e.g., "in seven minutes time I would like you to stop whichever task you are on and change to another

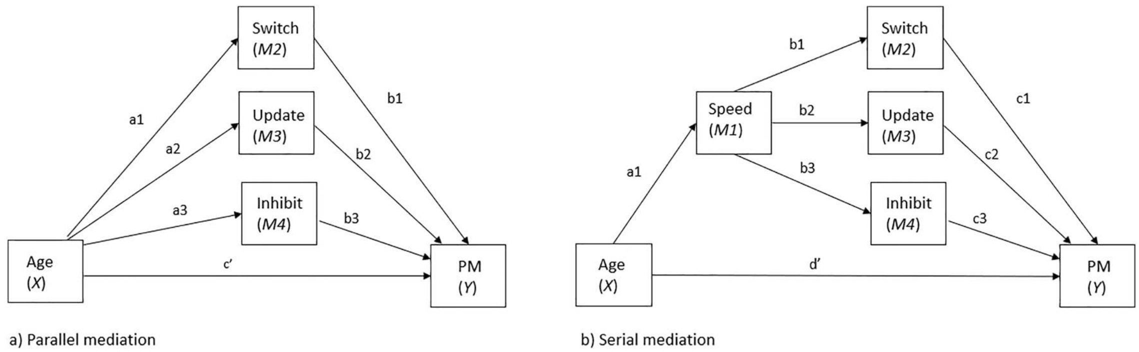

Figure 1. Path diagram showing (a) parallel mediation model; and (b) a serial mediation model of indirect age-related effects on PM.

task") and the more everyday life scenario where notes to make reminders are permitted. It includes a total of six PM tasks: three time-based and three event-based PM tasks. The required retention of PM tasks ranges from 7–20 minutes, with delays balanced across task type. Both a kitchen countdown timer and an analogue clock are used as reference points for time-based tasks. The ongoing/distractor task involves a range of puzzles and trivia questions. The dependent measures of interest in this study were again total scores for the time-based and event-based tasks. For the CAMPROMPT, estimates of Cronbach's alpha were .49 for the total score.

Type 3 ecological validity PM task: complex virtual environment with familiar tasks

Virtual Week (VW) is a task designed to represent PM in daily life (Rendell & Craik, 2000). Presented in a board game format, and recently adapted for a computerised version (which was used in the current study), participants use a computer mouse to move a token around the VW board after each "roll" (click) of a virtual die, with each circuit of the board representing a virtual (waking) day. The selection of activity options (e.g., what to have for breakfast), rolling the die, and moving the token (e.g., two squares which equals "15 minutes") constitute the ongoing activity for the PM tasks (e.g., "return library books when at the library") embedded in each virtual day (i.e., "7am" till "10pm"). Each day includes regular, irregular, and time-interval PM tasks. Regular PM tasks (e.g., "take medication at breakfast and dinner") are tasks that need to be completed on multiple occasions; an equal number of these are event-based (triggered by specific event cards; e.g., "you go to the library") or time-based (triggered by specific virtual times of day; e.g., "11am" showing on the virtual time of day clock). Irregular PM tasks are not repeated (e.g., choosing "return library books", by clicking on a "perform task" menu, when event "at the library" occurs); these also consist of an equal number of event-based and time-based tasks. Time-interval tasks are regular tasks that require the participant to "break set" from the board game activity and monitor real time on the stop-clock that is displayed prominently. Participants perform each PM task by clicking on the "perform task" button on the screen and selecting the appropriate action from the drop-down menu consisting of a list of target and distractor actions. In the present study, scores for event, virtual time of day, and short time-intervals were calculated. Cronbach's alpha was estimated to be .71 for the total score.

Type 2 ecological validity PM task: experimental task embedded in an everyday setting

The MEMO (Haines et al., 2020) was provided to participants as an app uploaded on a dedicated Android OS LG smart phone, with participants asked to complete MEMO tasks over a three-day period. There were four time-based PM tasks each day: two scheduled quizzes at set times chosen by the participant (i.e., either 10:30am or 11am; and either 3pm or 4pm); and two "random" quizzes which required the participant to open the app to do a quiz after a specified short-time interval delay (e.g., 15 min), which varied over the three days (i.e., between 10 and 20 min delays), with the task given at an unknown to the participant time via a visual and auditory notification from the MEMO app. Event based measures required participants to take four photos each day when they encountered particular events (e.g., each day when having lunch-take a photo of lunch; or on day 2 when watching evening news-take a photo of news on TV). The scheduled time-based tasks were set up each morning by the participant, and a list of the photos for events occurring that day was presented once, using a morning notification on the app (e.g., at 7am or 8am). For the present study, the three key dependent measures were total scores for event-based PM, time-based time-of-day PM, and time-based time-interval PM. Cronbach's alpha for the total score on MEMO was estimated to be .67.

Executive function measures

To index inhibitory cognitive control, the Go-no-Go task was used. For this task, a series of letters were briefly presented one at a time on a computer screen, and participants were asked to press a space bar on the computer keyboard as quickly as possible for all letters (75% of all trials), *except* the letter X (appearing on 25% of all trials), for which no response was to be made. The dependent measure for Go-no-Go task were the number of commission errors, i.e., the number of times participants pressed the space bar when the letter X appeared. To measure the updating component of executive control, the *N*-back task was used; this task required participants to watch a series of letters presented briefly one at a time on a screen, and to classify each one as either the same or different to the letter shown two letters prior to the current letter in the sequence (i.e., two-back). The proportion of correct categorizations over all trials was used to index working memory. To index the shifting component of executive control, the task switching task was used (Miyake et al., 2000), which involves classifying stimuli according to one of two rules. The stimuli presented are bivalent (i.e., consistent with either of the two rules) and remain on the screen until the participant responds with an arrow button press corresponding to one of the two rules. Participants are requested to respond as fast as possible and only use the rule of classification indicated at the top of the screen on each trial. Smaller global and local temporal switch costs indicate better mental set shifting capacity. The dependent variable for the task switching task was the average global switch cost, i.e., the average delay in categorising the stimuli on all trials.

Processing speed

Processing speed was measured using a computerised Choice Reaction Task (CRT). This task was grouped in four blocks, with two simple stimulus presentations (a blue and a red square) alternating pseudo-randomly across 25 trials within each block, with a variable interstimulus interval (range 1000 to 2000ms, mean 1508 ms) to prevent anticipatory response. Participants had to click on one side of the mouse if they saw a red square (left side – marked with a red sticker) and on the other right side (marked with a blue sticker) if they saw a blue square, as quickly as possible. The square would remain on the screen until the participant made a response. A practice block of 25 trials was provided to ensure that all participants understood the task requirements. The dependent measure for this task was mean latency for all correctly classified stimuli.

Learning and episodic memory

To index learning and episodic memory, the Hopkins Verbal Learning Test Revised (HVLT-R; Benedict et al., 1998) was used. Participants were asked to recall as many words as possible across three separate learning trials from a word list. The total number of words recalled provided an index of verbal learning. To measure delayed recall, participants were asked (25–30 min later) to recall these words again. Key dependent measures were the Delayed Recall, Total Recall (i.e., score across all three learning trials), and the Retention score (i.e., Delayed Recall score divided by the highest number of words recalled from any of the first three recall trials, multiplied by 100).

Statistical analyses

The skew and kurtosis for all variables were checked and transformed where skew was excessive (>1.000; see Table 1), except in the case of the MEMO event-cued proportion correct where transformations did not substantially reduce the negative skew. The N-back and the Go-no-Go were square root (sqrt) transformed; the CRT was log10 (lg10) transformed; and the HVLT Ret used the inverse formula (Inv). Choice of transformation was based on best reduction of skew. The parallel mediation model was investigated with two stage hierarchical linear regressions. A separate model was tested for each dependent variable, with age, retrospective memory, and processing-speed measures entered in the first stage, and the executive function measures entered in the second stage. The mediated models were also assessed using path analysis with SPSS version 25, using the process macro, model 4 (parallel mediation) and model 6 (serial mediation) (Hayes, 2022). Each PM measure and their subscores were used separately as an outcome measure (Y variable), with age (X variable) as the predictor mediated (M variables) by the transformed n-back accuracy score, the transformed go no-go commission error score, and the untransformed global switch cost from task-switch task used as mediating variables. For the serial mediation model the transformed CRT average latency was entered as the first mediator variable after age, and before the previously mentioned executive function variables.

For all analyses, an alpha level of .05 was used to interpret the statistical significance of inferential tests. Data, analytic methods, and study materials will be made available upon reasonable request by contacting the corresponding author via email.

Results

The descriptive statistics for all measures is shown in Table 1, including the variables which were transformed to reduce skew. Due to the assumption of normality being violated for a number of measures the correlation matrix in Table 2 shows the Spearman rho correlation (below the diagonal) and the Spearman rho partial correlations, controlling for age, above the diagonal. Age was correlated in the expected direction (i.e., greater age was associated with worse performance) with most measures. Processing speed was not meaningfully associated with any of the PM measures. The lab PM measures generally correlated with one another and age in theoretically meaningful directions, while correlations of the lab measures with the naturalistic PM measures were generally weak, apart from the MEMO time-interval task (most like lab TB

Table 1. Descriptive statistics of PM, EF and other cognitive test scores.

PM measures	N	Min	Max	M	SD	Rel.	Skew.	Kurt.	Trans.
CAMP total	134	6	36	25.28	5.74	.491	−.725	.624	–
CAMP EB	134	0	18	12.43	3.29	.312	−0.904	1.401	–
CAMP TB	134	3	18	12.85	3.64	.272	−0.386	−0.375	–
MIST total	123	6	48	32.74	8.11	.500	−.477	−.177	
MIST EB	163	0	8	6.15	1.89	.324	−.743	−.219	–
MIST TB	163	0	8	4.74	1.57	.476	−.393	.226	–
VW total	83	0	.88	.294	.203	.709	.697	−.187	
VW EB	133	0	1.00	.432	.258	.670	.316	−.815	–
VW TB	133	0	.88	.220	.196	.575	.959	.635	–
VW TI	133	0	1.00	.273	.312	.683	1.010	.037	–
MEMO total	42	.22	1.00	.682	.169	.674	−.429	−.422	
MEMO EB	151	.25	1.00	.867	.155	.501	−1.374[a]	1.671	
MEMO TB	151	0	1.00	.594	.256	.501	−.277	−.631	–
MEMO TI	144	0	1.00	.573	.285	.618	−.398	−.660	–
EF measures									
	N	Min	Max	M	SD	Rel.	Skew.	Kurt.	Trans Skew
TST global	148	−2215	0	−955	461	–	−.326	−.158	–
N-back	149	.37	.99	.78	.11	–	−1.141	1.765	Sqrt: −.605
GoNoGo	143	0	25	5.4	4.2	–	1.595	3.816	Sqrt: .026
Other cognitive measures									
	N	Min	Max	M	SD	Rel.	Skew.	Kurt.	Trans Skew
CRT	158	379	1037	533	106	–	1.818	5.555	Lg10: .921
HVLT Tot	163	6	12	10	1.5	–	−0.649	−.120	–
HVLT Ret	162	25	100	90	14	–	−2.007	4.806	Inv: −.136

[a]Transformations did not decrease skew.

tasks), with the VW time-interval task and the MIST TB task. Only the measure of inhibition showed a substantive correlation with time-interval tasks in VW and the EB naturalistic task. While EB naturalistic performance also showed a small association with retrospective memory (retention).

Parallel mediation models

The parallel mediation path estimates are shown in Table 3. Age invariably had a significant impact on task-switch cost (with increasing age there was increasing average global latency), M_1, but this facet of EF was only a significant predictor of total MIST score, and in an unexpected direction (increasing average latency was associated with better total MIST scores). While all other EF measures did not mediate the effect of age on PM performance for high or low demand PM tasks, better inhibition (less commission errors on the go-no go task) was associated with higher performance on Virtual Week total proportion correct scores, and for the theoretically highest demand task within Virtual Week, the time-check task (with decreasing commission errors in the go-no go task associated with higher proportions correct). Better updating (higher accuracy on the N-back task) was also associated with better performance on the MEMO time-interval task (e.g., remembering to open the app and complete a quiz after 10 min had elapsed). However, neither of these components of EF mediated age effects, which can be seen to consistently have a direct, negative effect on PM performance (with increasing age lower PM performance) for putatively higher demand PM tasks.

An exception of age effects varying by task demands appeared for the MEMO PM tasks (which were performed in a naturalistic setting and permitted external aids). MEMO proportion correct scores were unaffected by age. Direct age effects were *not* present for the CAMPROMT event-based score, nor the Virtual Week event-based proportion correct score, though these were present for the higher demand PM tasks within these measures (see Figure 2 for an example).

Serial mediation models

The mediation analyses were carried out to test whether parallel indirect effects of the variables of interest (processing speed, learning, and retention, inhibition, switching, and updating) might account for the association between age and PM. These analyses revealed a significant indirect effect for the MEMO total proportion correct score through learning (i.e., highest recall of words on first three immediate recall trials of HVLT), (−.057) (.030) = −.002 (bootstrap SE = .001; bootstrap CIs −.005, −.000). The completely standardised indirect effect was −.072 (SE = .042; CI −.181, −.003). A second significant indirect effect was also found for the MEMO event-based proportion score with learning, (−.057) (.027) = .003 (bootstrap SE = .001; bootstrap CIs −.004, .000). The completely standardised indirect effect was −.067 (SE = .044; CI −.185, −.002). None of the other indirect effects were significant. Some direct effects of age were significant in the serial mediation model only for the putatively higher demand PM tasks, as shown in Figure 3, with Virtual Week time-scheduled and time-interval tasks showing a significant negative effect of age but not event-cued (low demand) tasks.

Table 2. Spearman rho correlations between age and key variables (below diagonal); and partial correlations of key variables controlling for age (above diagonal).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Age	1																				
2. CAMP tot	−.18*	1	.85**	.70**	−.00	.03	−.04	.19	.11	.17	.24*	.13	.03	.17	.09	−.14	−.10	.17	.06	.15	−.10
3. CAMP TB	−.19*	.84**	1	.25*	−.06	.07	−.14	.15	.07	.16	.18	.14	−.08	.19	.10	−.13	−.07	.05	.08	.17	−.01
4. CAMP EB	−.09	.75**	.30**	1	.06	−.07	.12	.19	.17	.15	.19	.03	.13	.02	.02	−.04	−.08	.25*	−.01	.06	−.13
5. MIST tot	−.30**	.17	.18*	.11	1	.68**	.80**	.15	.09	−.03	.20	.21*	−.01	.11	.29**	−.05	.06	.02	.25*	.18	−.06
6. MIST TB	−.27**	.18*	.21*	.08	.75**	1	.15	.09	.04	.02	.10	.27**	.11	.10	.32**	−.05	.11	.02	.20	.21*	−.02
7. MIST EB	−.21*	.10	.07	.12	.81**	.26**	1	.13	.08	−.09	.20	.04	−.08	.04	.10	−.03	.04	−.02	.18	.05	−.04
8. VW tot	−.33**	.35**	.28*	.30**	.34**	.26**	.27**	1	.84**	.54**	.75**	.11	.21*	.07	.07	−.04	.26*	.27**	.15	.17	−.31**
9. VW EB	−.19*	.25**	.19*	.24**	.25**	.19*	.20*	.84**	1	.40**	.42**	.06	.15	.02	.03	−.11	.19	.24*	.18	.21*	−.17
10. VW TB	−.17*	.35**	.30**	.29**	.18*	.16	.11	.62**	.49**	1	.09	.12	.17	.09	.02	−.10	.28	.23*	.11	.19	−.07
11. VW TI	−.30**	.29**	.20*	.25**	.35**	.25**	.30**	.78**	.45**	.24**	1	.15	.17	.09	.15	.07	.15	.20	.04	.03	−.40**
12. MEMO tot	.00	.15	.15	.05	.24**	.29**	.08	.14	.08	.12	.16	1	.39**	.80**	.84**	−.19	−.08	.04	.07	.08	−.15
13. MEMOEB	.02	.11	.01	.15	.04	.07	.04	.21*	.15	.16	.17	.41**	1	.17	.14	−.12	.11	.13	−.05	−.14	−.22*
14. MEMO TB	.07	.06	.11	−.03	.11	.11	.07	.09	.06	.06	.10	.82**	.21**	1	.45**	−.09	−.18	.05	.01	−.02	−.11
15. MEMO TI	−.07	.11	.12	.03	.29**	.34**	.07	.12	.06	.06	.18*	.83**	.12	.46**	1	−.17	−.03	−.00	.11	.18	−.09
16. CRT	.07	−.10	−.08	−.08	−.00	−.05	.01	−.10	−.12	−.03	−.03	−.13	−.09	−.12	−.11	1	−.14	.14	−.28**	−.36**	.03
17. HVLT-Tot	−.19*	.12	.09	.10	.22**	.23**	.16*	.34**	.29**	.30**	.20**	.00	.05	−.09	.03	−.10	1	.16	.06	.16	−.09
18. HVLT Ret	−.09	.10	.02	.19*	.15	.13	.12	.22**	.12	.20*	.22**	.12	.09	.12	.07	.12	.18*	1	.00	−.06	−.10
19. TST global	−.41**	.15	.14	.11	.27**	.23**	.19*	.27**	.21*	.14	.19	−0.01	−.11	−.06	.08	−.31**	.15	.09	1	.48**	−.07
20. N-Back	−.23*	−.12	.20*	.00	−.23**	.23**	.13	−.20*	.19*	.17	.10	−.12	−.07	.11	.21*	−.39**	.16	.07	.43**	1	.11
21. GNG errors	.06	−.17	−.10	−.17	−.09	−.00	−.12	−.24**	−.10	−.06	−.32**	−.13	−.23**	−.08	−.10	.01	−.10	−.07	−.12	.04	1

Note: Spearman Rho Correlations between Age, PM Measures, Processing speed, Retrospective memory, and Facets of Executive Functioning below the diagonal; Spearman Rho partial correlations, controlling for age, above the diagonal. *$p < .05$; ** $p < .01$.

Table 3. Parallel mediation path estimates separately for the three indicators of executive control (switching, updating and inhibition).

X (Age)		M_1 (Switch)				M_2 (Update)				M_3 (Inhibit)				Y (PM)		
		Coeff	*SE*	*p*		*Coeff*	*SE*	*p*		*Coeff*	*SE*	*p*		*Coeff*	*SE*	*p*
CAMP Tot	a_1	−25.7	6.84	<.001	a_2	−.002	.002	.261	a_3	.019	.015	.202	c'	−.242	.090	.008
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.035	b_1	.002	.001	.152
M_2 (Update)		–	–	–		–	–	–	d_{32}	.619	.963	.522	b_2	4.81	6.05	.429
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.784	.558	.163
CAMP EB	a_1	−25.7	6.84	<.001	a_2	−.002	.002	.261	a_3	.019	.015	.202	c'	−.100	.052	.067
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.035	b_1	.001	.001	.278
M_2 (Update)		–	–	–		–	–	–	d_{32}	.619	.963	.522	b_2	1.16	3.44	.735
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.475	.322	.143
CAMP TB	a_1	−25.7	6.84	<.001	a_2	−.002	.002	.261	a_3	.019	.015	.202	c'	−.143	.059	.017
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.035	b_1	−.011	.001	.626
M_2 (Update)		–	–	–		–	–	–	d_{32}	.619	.963	.522	b_2	3.64	3.94	.358
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.309	.366	.400
MIST Tot	a_1	−29.2	6.12	<.001	a_2	−.003	.001	.055	a_3	.018	.014	.194	c'	−.401	.120	.001
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.087	b_1	.004	.002	.047
M_2 (Update)		–	–	–		–	–	–	d_{32}				b_2	8.50	8.11	.297
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.419	.746	.575
MIST EB	a_1	−29.2	6.12	<.001	a_2	−.003	.001	.055	a_3	.018	.014	.194	c'	−.063	.030	.036
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.091	b_1	.001	.000	.095
M_2 (Update)		–	–	–		–	–	–	d_{32}	.512	.915	.577	b_2	.769	2.03	.705
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.100	.187	.593
MIST TB	a_1	−29.1	5.99	<.001	a_2	−.003	.001	.062	a_3	.016	.013	.224	c'	−.075	.025	.003
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.091	b_1	.000	.000	.359
M_2 (Update)		–	–	–		–	–	–	d_{32}	.512	.915	.577	b_2	2.07	1.66	.215
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.034	.153	.825
VW Tot	a_1	−24.7	6.67	<.001	a_2	−.002	.001	.150	a_3	.012	.014	.387	c'	−.010	.003	<.001
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.126	b_1	.000	.000	.208
M_2 (Update)		–	–	–		–	–	–	d_{32}	.683	.934	.466	b_2	.344	.202	.091
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.065	.019	.001
VW EB	a_1	−26.4	6.35	<.001	a_2	−.002	.001	.096	a_3	.015	.014	.276	c'	−.008	.004	.077
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.106	b_1	.000	.000	.259
M_2 (Update)		–	–	–		–	–	–	d_{32}	.697	.897	.439	b_2	.422	.300	.163
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.038	.029	.195
VW TB	a_1	−26.4	6.35	<.001	a_2	−.002	.001	.096	a_3	.015	.013	.276	c'	−.008	.003	.007
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.106	b_1	.000	.000	.659
M_2 (Update)		–	–	–		–	–	–	d_{32}	.697	.897	.439	b_2	.193	.210	.362
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.032	.020	.116
VW TI	a_1	−24.7	6.67	<.001	a_2	−.002	.001	.150	a_3	.012	.014	.387	c'	−.013	.005	.004
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.126	b_1	.000	.000	.618
M_2 (Update)		–	–	–		–	–	–	d_{32}	.683	.935	.466	b_2	.387	.309	.213
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.125	.029	<.001
MEMO Tot	a_1	−26.8	6.77	.001	a_2	−.002	.001	.173	a_3	.018	.016	.261	c'	.002	.003	.587
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.088	b_1	.000	.000	.899
M_2 (Update)		–	–	–		–	–	–	d_{32}	.653	1.03	.527	b_2	.235	.199	.240
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.034	.017	.054
MEMO EB	a_1	−.27.2	6.30	<.001	a_2	−.002	.001	.110	a_3	.016	.014	.271	c'	.001	.002	.829
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.095	b_1	.000	.000	.139
M_2 (Update)		–	–	–		–	–	–	d_{32}	.608	.945	.521	b_2	−.155	.147	.295
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.029	.014	.034
MEMO TB	a_1	−.27.8	6.43	<.001	a_2	−.002	.001	.120	a_3	.016	.015	.274	c'	.004	.005	.440

M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.097	b_1	.000	.000	.946
M_2 (Update)		–	–	–		–	–	–	d_{32}	.613	.950	.520	b_2	.262	.293	.374
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.027	.027	.316
MEMO TI	a_1	−.26.2	6.61	<.001	a_2	−.002	.001	.157	a_3	.017	.015	.258	c′	−.001	.005	.835
M_1 (Switch)		–	–	–	d_{21}	.000	.000	<.01	d_{31}	−.000	.000	.086	b_1	.000	.000	.556
M_2 (Update)		–	–	–		–	–	–	d_{32}	.647	1.02	.528	b_2	.810	.334	.017
M_3 (Inhibit)		–	–	–		–	–	–		–	–	–	b_3	−.040	.029	.177

Note: CAMP refers to Cambridge Prospective Memory Test; Tot to Total; Switch to Switching; Update to Updating; Inhibit to Inhibition; EB to Event-Based; TB to Time-Based; TI to Time-Interval. MIST to Memory for Intentions Screening Task; VW to Virtual Week.

Table 4. Hierarchical regressions with prospective memory accuracy as the dependent measure.

	Stage 1		Stage 2	
Variable	Squared semi-partial correlation	Standardised regression coefficient	Squared semi-partial correlation	Standardised regression coefficient
CAMPT EB				
Age	.013	−.072	.016	−.081
CRT [Inv]	.019	.073	.029	.127
HVLT-Tot Rec	.000	.042	.001	.047
HVLT-Ret [Sqrt]	.029	.166	.029	.171
TST [Sqrt]	–	–	.000	.006
N-back	–	–	.025	−.157
Go-no-go [lg10]	–	–	.013	−.061
	$R^2 = .042$		R^2 Change = .026 $R^2 = .068$	
CAMP TB				
Age	.012	−.112	.011	−.106
CRT [Inv]	.004	−.069	.008	−.107
HVLT-Tot Rec	.015	.126	.017	.133
HVLT-Ret [Sqrt]	.000	−.019	.001	−.033
TST [Sqrt]	–	–	.001	.057
N-back	–	–	.003	.026
Go-no-go [lg10]	–	–	.008	−.091
	$R^2 = .032$		R^2 Change = .010 $R^2 = .042$	
MIST EB				
Age	.021	−.072	.016	−.081
CRT [Inv]	.012	.073	.029	.127
HVLT-Tot Rec	.017	.042	.001	.047
HVLT-Ret [Sqrt]	.023	.166	.029	.171
TST [Sqrt]	–	–	.000	.006
N-back	–	–	.025	−.157
Go-no-go [lg10]	–	–	.013	−.061
	$R^2 = .092$		R^2 Change = .036 $R^2 = .128$	
MIST TB				
Age	.041	−.147	.017	−.134
CRT [Inv]	.036	.113	.000	.004
HVLT-Tot Rec	.000	.135	.021	.149
HVLT-Ret [Sqrt]	.006	.151	.017	.134
TST [Sqrt]	–	–	.016	.139
N-back	–	–	.012	.124
Go-no-go [lg10]	–	–	.015	−.124
	$R^2 = .099$		R^2 Change = .021 $R^2 = .120$	
VW EB				
Age	.025	−.208	.037	−.198
CRT [Inv]	.011	.196	.007	.102
HVLT-Tot Rec	.057	.006	.000	.010
HVLT-Ret [Sqrt]	.016	.076	.005	.071
TST [Sqrt]	–	–	.015	.113
N-back	–	–	.010	.134
Go-no-go [lg10]	–	–	.000	−.005
	$R^2 = .142$*		R^2 Change = .013 $R^2 = .156$	
VW TB				
Age	.048	−.283*	.067	−.266*
CRT [Inv]	.003	.134	.000	.023
HVLT-Tot Rec	.000	.173	.033	.186
HVLT-Ret [Sqrt]	.017	.207	.031	−.179
TST [Sqrt]	–	–	.004	.190
N-back	–	–	.029	.069
Go-no-go [lg10]	–	–	.022	−.151
	$R^2 = .077$		R^2 Change = .021 $R^2 = .097$	
VW TI				
Age	.008	−.160	.022	−.151

(*Continued*)

Table 4. Continued.

CAMPT EB	Stage 1		Stage 2	
Variable	Squared semi-partial correlation	Standardised regression coefficient	Squared semi-partial correlation	Standardised regression coefficient
CRT [Inv]	.009	.110	.002	.052
HVLT-Tot Rec	.008	.245*	.057	.246*
HVLT-Ret [Sqrt]	.001	.128	.014	.119
TST [Sqrt]	–	–	.000	.019
N-back	–	–	.013	.130
Go-no-go [lg10]	–	–	.000	−.005
	$R^2 = .036$		R^2 Change = .048 $R^2 = .085$	
MEMO EB [Sq]				
Age	0.013	−.224	.043	−.212
CRT [Inv]	0.028	.059	.001	−.029
HVLT-Tot Rec	0.068	.013	.000	.020
HVLT-Ret [Sqrt]	0.110	.131	.013	.116
TST [Sqrt]	–	–	.005	.079
N-back	–	–	.015	.136
Go-no-go [lg10]	–	–	.005	−.071
	$R^2 = .203$**		R^2 Change = .091[t] $R^2 = .295$**	
MEMO TB				
Age	.000	.093	.005	.076
CRT [Inv]	.004	−.098	.001	.028
HVLT-Tot Rec	.013	−.090	.010	−.103
HVLT-Ret [Sqrt]	.012	.038	.000	−.012
TST [Sqrt]	–	–	.009	−.198
N-back	–	–	.031	−.106
Go-no-go [lg10]	–	–	.017	.133
	$R^2 = .025$		R^2 Change = .010 $R^2 = .035$	
MEMO TI				
Age	.006	.224	.040	.210
CRT [Inv]	.014	.188	.018	.159
HVLT-Tot Rec	.000	.331**	.118	.356**
HVLT-Ret [Sqrt]	.007	.269*	.043	.220
TST [Sqrt]	–	–	.000	.005
N-back	–	–	.002	.041
Go-no-go [lg10]	–	–	.046	−.205[t]
	$R^2 = .024$		R^2 Change = .033 $R^2 = .057$	

Note: CAMPT refers to Cambridge Prospective Memory Test; EB to Event-Based; TB to Time-Based; CRT to Choice Reaction Time, HVLT-Tot Rec to Hopkins Verbal Learning Test Revised Total Recall; HVLT-Ret to Hopkins Verbal Learning Test Revised Retention score; TST to Task Switching Task; MIST to Memory for Intentions Screening Task; VW to Virtual Week; TI to time-interval. *$p < .05$, **$p < .01$ (two tailed), *t* (trend) $p < .10$.

Unique variance accounted for when controlling other cognitive variables

To further investigate the unique contributions of each EF variable after controlling for other cognitive functions, such as perceptual processing speed and learning, a series of two stage hierarchical regression analyses were conducted to test the parallel mediation model, with each PM measure used as a separate dependent variable. In the first step age, scores on the measure of perceptual processing speed (CRT) and learning (HVLT total recall and percentage of items retained) were entered. In stage two the three components of executive control (switching, updating, and inhibition) were entered. Detailed results of hierarchical regression analyses for each dependent variable are reported in Table 4.

For CAMROMPT, regression analyses revealed no significant predictors for any of the PM measures. For the time-based score, the standardised beta value for age decreased from stage 1 (−.157) to stage 2 (−.151) when the facets of executive functioning were entered into the model. In contrast, for the event-based score the detrimental influence of age actually increased from stage 1 (−.119) to stage 2 (−.129), as did the contribution of processing speed (from .142 to .206) and learning (from .022 to .031). For all CAMPROMT measures, age accounted for a consistent 1% to 2% of variation in both stages 1 and 2; while learning, retention, and facets of executive functioning jointly accounted for between 0% and 3% of variation.

For MIST, a different pattern of results was observed. The R^2 value (.168) for stage 1 of the model predicting the Total MIST raw score was significant, $F(4, 75) = 3.78$, $p = .007$. When considering the individual predictors, increasing age was a significant predictor of lower total score on the MIST, accounting for 7% and 6% of variance in Stages 1 and 2 respectively. Although the standardised beta value of age was reduced when facets of executive functioning were entered in Stage 2 of the model, age continued to be a significant predictor. For the total score on MIST, processing speed, learning, retention, and facets of executive functioning accounted for only between 0% and 3% of variance. There were no significant predictors in the model for the event-based MIST score, though again the standardised beta value for age was reduced when facets of executive functioning were entered in Stage 2 of the model. The combined predictors for Stage 1 of the model with time-based MIST score as the outcome was marginally significant, $F(4, 75) = 2.3$, $p = .062$, with age accounting for approximately 5% of variance in outcome in Stages 1 and 2 of the model. The executive functioning measures accounted for 0–2% of variance with updating and shifting accounting for approximately 1% and 2% of variance respectively.

For Virtual Week, the regression model for the total proportion correct was significant at Stage 1, $F(4, 75) = 4.72$, $p = .002$, and Stage 2, $F(7, 70) = 3.14$, $p = .006$. Increasing age significantly predicted lower Virtual Week total proportion correct at both stages (age accounted for 8% and 7% of variance at Stages 1 and 2, respectively). However, the standardised beta value for age was reduced when the facets of executive functioning were entered in stage 2. For event-based proportion correct in Virtual Week, individual differences in learning or encoding efficiency (highest number of items recalled on any of the three HVLT immediate recall trials) was a significant predictor, accounting for 6% of variance consistently in both Stage 1 and 2. The standardised beta value for age was slightly reduced in Stage 2 of this model, but only accounted for approximately 2% of variance in event-based proportion correct in Virtual Week. Neither the models nor individual predictors of the proportions correct on the time-of-day or time-interval Virtual Week measure were significant. For time-of-day, age consistently accounted for approximately 4% of variance in outcome, while age accounted for less than 1% of the variance when time-interval in Virtual Week was the outcome variable. After age, updating accounted for most variance on time-of-day and time-interval proportion correct in Virtual Week (approximately 2–3% in both cases).

For MEMO the regression model for the total proportion correct was significant at Stage 1, $F(4, 58) = 4.02$, $p = .006$, and Stage 2, $F(7, 55) = 2.70$, $p = .018$. The only variables that predicted PM performance overall on the MEMO paradigm were learning and retention. Learning was a robust predictor that explained between 10% and 11% of variance in overall performance. Inhibition and age were both marginally significant ($p < .10$) and accounted for 4–5% of variance in overall performance (the other measures of facets of executive functioning accounted for less than 1%). For overall PM performance on the MEMO, the amount of variance accounted for by the model with executive functions (25.6%) did not account for significantly more variance compared to the model with only age, processing speed, learning, and retention (21.7%). For the MEMO event-based proportion correct, learning, retention, and inhibition were all significant predictors. The inclusion of executive functions in the model was marginally significant and accounted for the greatest amount of variance in the dependent variable (20.3% with only age, processing speed, learning, and retention; 29.5% with shifting, updating, and inhibition included). Notably, facets of executive functioning partially mediated the effects of age and processing speed, though not learning and retention.

Discussion

Lapses of PM represent the most common cognitive failure at all stages of the adult lifespan but have the potential to be particularly devastating in late adulthood because of the key role PM plays in many daily activities that are critical to maintaining independence. Understanding the mechanisms that contribute to age-related difficulties on different types of PM tasks is therefore critical if we are to develop targeted support for older adults at different stages of late life development (Henry, 2021).

The present study was designed to meaningfully extend previous research focused on understanding whether, and if so how, executive control and other cognitive functions might mediate the relationship between age and PM performance. A particular strength of the study was the inclusion of four PM tasks with greater ecological validity than the tasks used in previous studies focused on this question. Because MEMO represents the one of the most ecologically valid, standardised measure of this construct available to date, this study had the opportunity to provide a truly unique window into the broader cognitive correlates of PM function in actual, daily life.

The first key finding to emerge was that, contrary to predictions from the multiprocess framework, there was no evidence that performance on tests of executive function mediated age effects more on putatively high demand PM tasks (i.e., time-based PM measures) relative to putatively low demand ones (i.e., event-based tasks). The second key finding was that the results also failed to support the processing speed model, as there was no evidence that age-related difficulties in PM were due either to the direct effects of slower speed or the indirect effects of slower speed operating via reducing executive control.

As noted previously, a central tenet of the multiprocess framework is that different PM tasks differ systematically in the demands they place on executive functioning, with event-based PM tasks that are peripheral or non-focal to the processing of the ongoing task most likely to be mediated by controlled, strategic processes. In the

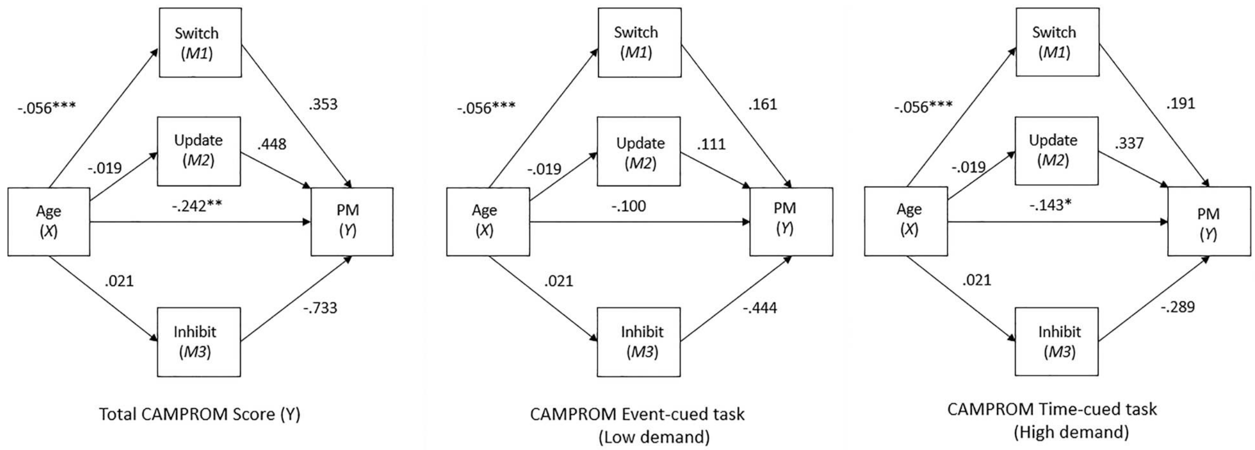

Figure 2. Parallel mediation for total scores on the Cambridge Prospective Memory Test, as well as tasks that are putatively lower (event-cued) or higher (time-cued) in strategic demands.

Note: *p < .05; **p < .01; ***p < .001. Mediator variable Z scores have been used to scale the mediator variable parameters.

present study, none of the results were significant for the. Age was the best predictor of overall PM performance on the first measure to meet criteria for Type 4 ecological validity (CAMPROMT), the second measure to meet these criteria (MIST), as well as the measure to meet criteria for Type 3 ecological validity (Virtual Week), even after measures of retrospective memory (learning and retention), processing speed, and executive control were controlled for. The mediation regression analyses further revealed that increasing age was related to small decrements in verbal learning, and that verbal learning in turn was related to better PM performance for the total and event-based proportion correct on one of the most ecologically valid measure we included (MEMO). However, the only specific component of executive control that emerged as a significant predictor of PM was inhibition, which predicted the MEMO event-based proportion correct.

Prior studies which investigated the role of shifting, updating, and inhibition in understanding adult age differences in PM have suggested that the relationship between these cognitive abilities might be smaller than previously believed, and restricted to specific types of PM and aspects of executive control (Gonneaud et al., 2011; Schnitzspahn et al., 2013; Zuber et al., 2016). Importantly however, all three of these studies operationalised PM using tasks with the lowest level of ecological validity (Type 5: lab-setting with an artificial task), and which are also inappropriate for investigating individual differences owing to their typically poor reliability (Rose et al., 2010).

Not only were four distinct types of PM tasks used in the current study (CAMPROMPT, MIST, Virtual Week, and MEMO), but all had higher ecological validity than the tasks used in prior research (Henry, 2021; Phillips et al., 2008). Across all four measures, the results were consistent in failing to support the prediction that executive functioning mediates age effects on PM tasks. Thus, across Type 4 (CAMROMPT, MIST), Type 3 (Virtual Week), and Type 2 paradigms (MEMO), all of which included a range of different PM task types, there was no evidence that executive losses explained age-related PM difficulties, providing robust evidence that the absence of an association between PM and executive control is not restricted to specific types of PM tasks, or PM task parameters.

Interestingly, however, the finding that verbal learning mediated age effects on PM for the MEMO total and event-based proportion correct score aligns with the findings of Gonneaud et al.'s (2011) study, which found that

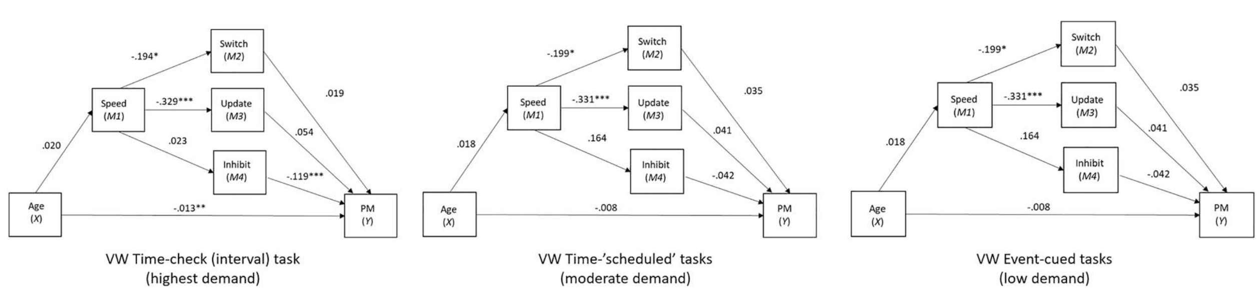

Figure 3. Serial mediation for Virtual Week tasks with putatively increasing cognitive demand.

Note: *p < .05; **p < .01; ***p < .001. Mediator variable Z scores have been used to scale the mediator variable parameters. It should be noted that as CRT in the current participant sample does not show correlations with age, nor any other variables apart from the shifting and updating variable, the conditions for testing a serial mediation model of with age (X) and PM (Y) are not technically met.

performance on a measure of retrospective memory and learning fully mediated the relationship between older adults' performance on laboratory event-based PM tasks and age. The present study is important in showing that this mediation also applies to event-based tasks completed in a naturalistic setting and suggests that learning and retention may be more important than executive control in understanding older adults' performance on more naturalistic PM measures. Further work is now needed to explore this possibility, as if correct, it suggests that strategies that focus on enhancing learning and retention might have value in improving older adults' real-life PM function.

It needs to be acknowledged that both the testing sessions, with the MEMO task in between, were carried out within a relatively compressed time period. Being exposed to such a dense collection of PM measures may have increased participants' awareness of what these tasks were targeting and orienting of their behaviour accordingly. Interestingly, if this was the case, a central tenet of the Motivational-Cognitive Prospective Memory model, is that task importance positively influences performance via multiple mechanisms, and participants' overall performance may therefore have been improved (Penningroth & Scott, 2013). Further research is needed to gain a more nuanced understanding of how PM task density influences subsequent performance, and the mechanisms by which it does so.

There were some limitations in the current study; in particular, for the MEMO, participants were loaned a secondary device and thus had the burden of remembering to carry it and keep it with them. However, the high mean proportion correct on the MEMO EBPM task suggests that most participants did not forget to take the device with them (to take photos of events in this case) and there was no anecdotal feedback of the device being a burden.

Conclusion

In sum, the present study found that age was a better predictor than the other variables measured (including executive functioning) of performance on putatively high demand PM tasks in the MIST and Virtual Week, and that verbal learning mediated older adults' performance on the MEMO total and event-based proportion correct score. However, facets of executive functioning were consistently unrelated to performance on the ecologically valid and diverse measures of PM used in this study, suggesting that the role of executive functions in understanding age-related PM performance in the wild may be far less than is commonly assumed in this literature.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article. Raw data that support the findings of this study are available from the corresponding author upon reasonable request.

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