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The Role of Shifting, Updating, and Inhibition in Prospective Memory Performance in Young and Older Adults

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Prospective memory performance shows a decline in late adulthood. The present article examines the role of 3 main executive function facets (i.e., shifting, updating, and inhibition) as possible developmental mechanisms associated with these age effects. One hundred seventy-five young and 110 older adults performed a battery of cognitive tests including measures of prospective memory, shifting, updating, inhibition, working memory, and speed. Age effects were confirmed in prospective memory and also obtained in shifting, updating, and inhibition. Yet, facets of executive control differently predicted prospective memory performance: While inhibition and shifting were strong predictors of prospective memory performance and also explained age differences in prospective memory, updating was not related to prospective memory performance across adulthood. Furthermore, considering executive function measures increased the amount of explained variance in prospective remembering and reduced the influence of speed. Working memory was not revealed to serve as a significant predictor of prospective memory performance in the present study. These findings clarify the role of different facets of controlled attention on age effects in prospective memory and bear important conceptual implications: Results suggest that some but not all facets of executive functioning are important developmental mechanisms of prospective memory across adulthood beyond working memory and speed. Specifically, inhibition and shifting appear to be essential aspects of cognitive control involved in age-related prospective memory performance.

Keywords: prospective memory, executive functions, aging

Prospective memory (PM) refers to those processes that are associated with the formation and delayed realization of intended actions (Kliegel, McDaniel, & Einstein, 2008), such as remembering to pay an electricity bill on time or to send a birthday card to a friend. PM tasks are prevalent in everyday life and errors in PM may account for more than half of all daily memory problems (Crovitz & Daniel, 1984). In line with the ubiquitous nature of PM, the effects of age on PM performance have received increasing research attention, because PM failures can hamper autonomy and independence in old age (Einstein & McDaniel, 1996). For example, problems such as remembering to turn off the oven or to take medication may increase the need for external assistance to prevent those everyday PM failures.

Data on PM performance across the lifespan indicate an inverted U-shaped function with an increase of PM performance across childhood and adolescence and a decline in late adulthood (e.g., Kliegel, Mackinlay, & Jäger, 2008; Maylor & Logie, 2010; Zöllig et al., 2007). One of the core issues in the current developmental debate is the question of which developmental mechanisms may be underlying this descriptive pattern. Two prominent candidates that have received attention are the role of episodic (retrospective) memory (e.g., Zimmermann & Meier, 2006; Zöllig et al., 2007) and the need for controlled attention (e.g., Kliegel, Mackinlay, & Jäger, 2008; McDaniel & Einstein, 2007; McDaniel, Einstein, & Rendell, 2008). Over the last decade, several studies have consistently demonstrated that retrospective memory for the intended

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action appears not to be the dominating factor in explaining age differences in PM, especially in adulthood (e.g., Kliegel, Mackinlay, & Jäger, 2008; Kliegel, McDaniel, & Einstein, 2000; McDaniel & Einstein, 2007; McDaniel et al., 2008; Zimmermann & Meier, 2006). What is less clear is the role of controlled attention in age-related PM performance (McDaniel & Einstein, 2007).

The conceptual rationale for predicting an important role of controlled attention in age-related PM performance is based on the multiprocess theory of PM (McDaniel & Einstein, 2000). It assumes that PM retrieval may rely on either spontaneous or attention-demanding retrieval processes (Einstein & McDaniel, 2010). The first of these two possible routes supposes that an involuntary associative memory system may enable *spontaneous retrieval* of the intended action (Guynn, McDaniel, & Einstein, 2001). Here, no strategic monitoring for the cue is necessary, because the intended action is relatively automatically brought to mind, which establishes a low cognitive resource-demanding pathway (Brandimonte, Ferrante, Feresin, & Delbello, 2001; Einstein et al., 2005). The alternative route implies that retrieval of a delayed intention may be a voluntary, *strategic process* mediated by the executive attentional system, which monitors the environment for the target cue and interrupts the ongoing activity at the appropriate moment. This monitoring would likely ensure successful PM performance but at the same time requires attentional resources (see also Smith, 2003; Smith & Bayen, 2004, for similar predictions on the importance of attentional resources in PM). In terms of age effects on PM performance, McDaniel and Einstein (2000) predicted that age effects in PM would interact with any factors that modulate the degree to which either strategic attentional resources are required by a specific PM task or a PM task relies more on spontaneous retrieval. Specifically, it was predicted that age differences would be likely in conditions demanding strategic processes. In contrast, conditions that are favorable to spontaneous retrieval of the intended action should not show robust age differences. Factors proposed to determine these conditions are characteristics of the PM task target cue (e.g., cue salience), ongoing task difficulty, and individual differences. Empirical evidence for this theoretical assumption comes from studies showing that age effects are larger in PM tasks that require high levels of controlled attention, whereas age differences tend to be reduced when the demands on self-initiated retrieval are minimized (for meta-analytic reviews, see Henry, MacLeod, Phillips, & Crawford, 2004; Kliegel, Jäger, & Phillips, 2008).

Taken together, there is agreement in the literature that age effects are larger when PM tasks require executive control. However, from a conceptual perspective, a major challenge for further refining available frameworks on the development of PM is that the precise nature of those "controlled attentional processes" possibly underlying age-related PM performance is still largely unknown and a topic of current debate. So far, the theoretical discussion and the empirical literature have either focused on one single aspect of controlled processes (such as working memory capacity) or used rather global constructs (such as executive functioning). Hence, the current study set out to examine a comprehensive and theory-driven set of controlled cognitive processes in order to disentangle the facets of controlled attention that are more or less critical for age-related PM performance.

The most prominent aspect of controlled attention studied in relation to age-related PM has been working memory (WM) capacity. However, previous studies on the role of WM in (age-related) PM have produced an inconsistent pattern of results. Some studies have not found a reliable association between WM and PM (Breneiser & McDaniel, 2006; Einstein, McDaniel, Manzi, Cochran, & Baker, 2000, Experiment 3; Maylor, 1990; West & Craik, 2001, Experiment 2), but a substantial number of studies have found that the amount of age variance in PM was significantly reduced after controlling for WM performance (Cherry & LeCompte, 1999; Einstein et al., 2000, Experiment 2; Logie & Maylor, 2009; Reese & Cherry, 2002; Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010; West & Craik, 2001, Experiment 1). Nevertheless, even in studies where WM predicted (age-related) PM performance, some "unique" age-related variance remained after controlling for age differences in WM (Logie & Maylor, 2009; Zeintl, Kliegel, & Hofer, 2007). Thus, other facets of controlled attention appear to be (also) at work in age-related PM.

In this context, to additionally consider further aspects of controlled attention besides WM, it has been suggested that "executive functioning" may be relevant for age-related PM performance (e.g., Mäntylä, 2003; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999). In general, the term executive functioning (EF) describes processing related to goal-directed, nonroutine behavior or the control of complex cognition (Banich, 2009). Moreover, EF tasks share the common characteristic of recruiting frontal brain areas (Alvarez & Emory, 2006). Despite the repeatedly expressed idea that EF and PM may be related (Mäntylä, 2003; Maylor, 1996; McDaniel et al., 1999), Salthouse, Berish, and Siedlecki (2004, p. 1135) pointed out that "closer examination reveals the weakness of the available evidence for the hypothesized linkage to executive functioning." Thus, Salthouse et al. tested 330 participants between 18 and 89 years of age with a battery of tasks hypothesized to assess EF as well as other cognitive abilities such as fluid intelligence, memory, or speed. Results showed that there was substantial mediation of the age-related effects on PM through EF, and the correlation between PM and EF on a latent level reached .74. However, Salthouse et al. also indicated that the relation obtained should be interpreted cautiously because the EF construct used in their study, based on different variables hypothesized to measure EF, did not have satisfying construct validity. Furthermore, the correlations were nearly as large between PM and fluid intelligence as well as speed. Thus, the question remains whether the linkage between PM and EF may be unique and replicable with more reliable and valid EF measures. Furthermore, and conceptually even more important, Salthouse et al. did not assess WM as a separate construct and used a single, global EF factor, as the variables included in the analyses (e.g., three verbal fluency measures and proverb interpretation) did not form distinct, separable constructs. Consequently, their results do not allow one to draw conclusions regarding the relative influence of different facets of controlled attention on PM.

Thus, the present study follows up on Salthouse et al.'s (2004) work and extends the conceptual focus on disentangling the role of EF facets in age-related PM performance. This open issue is addressed by building on the conceptual EF framework suggested by Miyake et al. (2000). Their seminal model has been successfully used to show three distinct facets of EF with satisfying construct validity, namely, *shifting*, *updating*, and *inhibition*. Here, shifting concerns switching between multiple tasks or mental sets. Updating requires actively manipulating relevant information in

WM by monitoring incoming information for task relevance and then revising the items held in WM by replacing older information with newer, more relevant information. Inhibition constitutes the ability to deliberately inhibit prepotent or conflicting responses when necessary and to shield WM from distractors.

Besides the fact that Miyake et al.'s (2000) framework offers a promising model to study the specific effects of different EF facets on age-related PM, the possible (separable) role of each of the three distinct EF facets—shifting, inhibition, and updating—in age-related PM may also be predicted resting on a process-oriented view of PM and related previous studies or conceptual suggestions. In her seminal article, Maylor (1996) suggested that

> an age-related impairment occurs whenever the prospective-memory task and the background task in which it is embedded demand that stimuli are processed in qualitatively different ways. In other words, older adults may be particularly impaired at shifting constantly (which must be self-initiated) from one level or type of stimulus analysis to another. (p. 78)

Thus, without directly linking this consideration to the conceptual debate on age-related decline in specific aspects of executive control, Maylor already argued that the ability to shift between two tasks may be the crucial cognitive ability involved for successful PM in aging. In addition, the preparatory attentional processes and memory processes (PAM) theory (Smith, 2003; Smith & Bayen, 2004) proposes that successful performance of the prospective component of PM (i.e., remembering that something has to be done) involves shifting between processes related to the ongoing task and processes related to evaluating responses to the environment at a broader level. However, up to now, these conceptual propositions have awaited direct empirical testing, and the present study set out to do this. Initial evidence for a strong connection between PM and shifting comes from several studies showing that the level of PM performance in young adults was reduced when the PM cues were presented in mixed blocks of trials that required frequently switching between representations of the task set held in WM to guide task performance (Marsh, Hancock, & Hicks, 2002; McNerney & West, 2007; West, Scolaro, & Bailey, 2011, Experiment 2).

Considering the processes involved in PM as suggested by Maylor (1996), PM tasks also require inhibition of the ongoing task in order to constantly check for the PM cue and, after its retrieval, for suppressing the ongoing task response when the PM response is required (see Bisiacchi, Schiff, Ciccola, & Kliegel, 2009, for neurophysiological evidence on the role of inhibition in younger adults' PM performance). Accordingly, using single clinical neuropsychological tasks, Martin, Kliegel, and McDaniel (2003) found that inhibition and shifting ability, but not age, predicted PM performance in two standard PM tests, while both EF and age predicted performance in a complex multi-intention PM task that requires planning and the execution of several intended actions. Inhibition also mediated age effects in PM performance in a study by West and Craik (2001, Experiment 1).

Finally, with respect to updating, on a process level updating of working memory is required in the planning phase of prospective memory when ongoing task response sets have to be updated with the additional PM response set. Moreover, while working on a PM task, the environment has to be monitored for the appropriate cue to initiate the intended action and therefore WM has to be updated accordingly. Empirically, so far, updating has mostly been studied under the label of WM, as several of the previously summarized studies on WM and PM have used traditional updating tasks such as *n*-back tasks. Thus, the rather broad but inconsistent literature on WM and PM may be taken as motivation to predict an involvement of updating in age-related PM. Yet, as the effects of WM capacity and updating have been intermingled in previous studies, the present project, for the first time, aimed to empirically separate WM span from updating on the construct level when predicting age-related PM performance.

Taken together, only few studies so far have explored the role of distinct EF facets in age-related PM performance. Those few available studies have focused on single aspects and/or used single, clinical measures of EF that mostly blur the effects of different EF processes. Thus, the aim of the present study was to extend the literature by investigating the role and relative importance of three major facets of EF (which have previously been shown to have satisfying construct validity; Miyake et al., 2000) on age-related PM performance, and to do so by using multiple indicators for each construct that have been proven to be reliable and valid. Furthermore, fluid and crystallized intelligence as well as cognitive speed and WM span were assessed as control measures. Resting on previous findings and the process analysis of PM, it was expected that inhibition and shifting would predict age-related PM performance beyond WM and speed. As former studies did not clearly separate WM and updating and the extant literature on WM and PM is rather inconsistent, no specific prediction was formed in this regard.

Method

Participants

The sample consisted of 285 participants: 175 young adults (mean age = 23.16 years, *SD* = 3.43; age range: 18–39 years; 84 females) and 110 older adults (mean age = 66.0 years, *SD* = 3.74; age range: 57–77 years; 58 females). Both age groups did not differ with respect to gender distribution, $\chi^2(1) = 2.13$, $p = .15$. All young adults were undergraduate students from the local university who volunteered in exchange for partial course credit or a small monetary reward. All older adults were volunteers whose effort was reimbursed with money. Exclusion criteria were history of or current physical and mental health problems. Young (*M* = 13.25, *SD* = 2.12) and older adults (*M* = 13.53, *SD* = 2.86) did not differ with respect to years of education, $t(270) = -0.91$, $p = .37$. In terms of general cognitive abilities, the two age groups differed in both crystallized and fluid intelligence in the anticipated directions. Crystallized intelligence was assessed with a German vocabulary test (MWT–A; Lehrl, Merz, Erzigkeit, & Galster, 1974) in which older adults (*M* = 31.50, *SD* = 2.04) obtaining significantly higher scores than young adults (*M* = 30.54, *SD* = 2.11), $t(272) = -3.64$, $p < .001$. Fluid intelligence was indexed using a speeded version of the matrices test (Raven, Raven, & Court, 1998), with younger adults obtaining significantly higher scores (*M* = 12.10, *SD* = 1.93) than older adults (*M* = 8.28, *SD* =

2.12), $t(281) = 15.56$, $p < .001$. The present data are part of a larger research project to examine executive control and complex cognition in young and older adults. In an ongoing data collection, behavioral correlates and neural circuitries of executive control with a focus on impulse control are examined in normal and clinical populations at several sites.

Materials and Procedure

In two sessions of approximately 2 hr each, participants were individually administered a battery of cognitive tasks that were partly computerized and partly paper-and-pencil based. Tasks were presented in the same pseudorandomized order for all participants. Each session included a short break. After informed consent was obtained, a sociodemographic questionnaire was given to the participants. They were asked to complete the questionnaire at home and return it at the second testing session. Thereafter, the tests followed, which are described in detail below. The first session included two inhibition and two shifting tasks and one updating task as well as measures of fluid and crystallized intelligence. The second session included a second updating task, two measures of speed, WM and PM. The two tasks measuring the same construct were intermixed with measures of other constructs and never administered directly one after another.

PM and EF Measures

PM. Two event-based nonfocal PM tasks were administered. In each case, participants received the PM instruction and afterward performed a practice phase comprising five ongoing task trials. This was followed by an ongoing task-only block consisting of 20 trials that simultaneously served as a filler task (participants were instructed that the PM task only started in the second task block). After that, the second task block followed, comprising 59 trials in which three PM cues were presented (i.e., on Trials 16, 39, and 57). Here participants had to self-initiate the PM response (i.e., press the space bar) and were not reminded of the additional PM task. Stimuli were presented until a response was registered or a timeout of 3 s was reached, after which the next trial was presented. A PM trial was coded as correct if participants' first response on that trial was the PM response (i.e., the space bar). In both tasks, the proportions of correct responses to PM trials were used as dependent variables. After each PM task participants' retrospective memory for PM task instruction was verified.

The ongoing task (OT) in the first PM task was to decide which of two words, presented side by side on the computer screen, contained more syllables. Responses were given by pressing one of two prespecified keys (left and right arrow key) on the computer keyboard. When one of the two words was a verb (PM cue), participants had to remember to press a different key (space bar) as the PM response instead of the OT response.

In the second PM task, the OT consisted of semantic category judgments. In an OT trial, two words were presented side by side on the computer screen. The word pairs were presented in six different colors (red, green, yellow, blue, gray, and magenta). The participants' task was to indicate, using the same response keys as in the first PM task, whether the two words belonged to the same (e.g., *mango–banana*) or a different (e.g., *shoe–milk*) semantic category. When a word was presented in blue, the PM response was required instead of the OT response. As task order was the same for all participants, the PM syllable task always occurred before the PM semantic task.

Updating. Two of the three updating tasks reported by Miyake et al. (2000) were used: the keep-track task and the letter-memory task. In each of five overall trials of the keep-track task, an intermixed list of 15 words each from one of six semantic categories was presented for 1,500 ms apiece on the computer screen with the target category labels remaining at the bottom of the screen. Participants were instructed to remember the last exemplar from each target category. At the end of each trial, these last exemplars had to be recalled. The number of target categories increased over trials from two to four. As two to three exemplars from each target category were presented in each trial, a correct response required several instances of successful updating of WM during a trial. The mean proportion of correctly recalled words across five trials was used as the dependent variable.

In the letter-memory task, a list of letters was presented serially for 1,500 ms per letter in each trial. Participants' task was to recall the last three letters of each list. Given that list length varied between five and nine letters and was not known to participants in advance, this task required constant updating of WM contents throughout the trial. The participants performed 12 trials for a total of 36 letters recalled. The mean proportion of correctly recalled letters across 12 trials was used as the dependent variable.

Inhibition. In addition to the antisaccade task used by Miyake et al. (2000), a Simon task (Simon & Berbaum, 1990) was used as a second indicator of inhibition. In a trial of the antisaccade task, participants first fixated the center of the screen, where a fixation point was presented (its duration varied unpredictably between 1 and 3 s). When a cue appeared on one side of the screen, participants were instructed to shift their gaze to the opposite side, where, shortly (225 ms) after the cue, an arrow was briefly presented (100 ms) and then masked. Participants were instructed to identify the direction in which the arrow was pointing (left, up, or right) by pressing one of three response buttons. Correct identification was only possible when the gaze was immediately shifted in the direction opposite to the cue. A total of 92 trials were presented. The proportion of correct responses (i.e., trials in which participants correctly discriminated the target that was presented opposite to the cue) was used as the dependent variable.

In each trial of the Simon task, after an initial central fixation, a right (left) arrow was presented in a central location (i.e., neutral condition), on the right (left) side (i.e., congruent condition), or on the left (right) side of the screen (i.e., incongruent condition). Participants were asked to indicate the direction in which the arrow was pointing (independent from its screen position) by pressing a right or left response key. Intertrial interval was 500 ms, and a total of 120 trials were presented. The difference in mean reaction time (RT) between correct responses in the incongruent and congruent conditions was computed as the dependent variable. To account for general age-related slowing, for all dependent variables relying on reaction times (i.e., performance in the Simon task and the two following shifting tasks) proportional measures were analyzed.[1]

Shifting. To assess shifting, we used two well-established tasks from the task-switching literature: the category-switch task (Friedman et al., 2006; Mayr & Kliegl, 2000), using semantic material, and the color-shape task (Friedman et al., 2006), using geometric objects. These tasks tap the same underlying construct—shifting—as the tasks used by Miyake et al. (2000): Participants are required to shift between two tasks during their processing of a set of bivalent stimuli (i.e., stimuli on which both tasks can be performed).

In the category-switch task, words denoting objects or animals of small or large size had to be classified either as small (coin) versus large (lion) or as living (mouse) versus nonliving (table). The current type of classification was indicated by a task cue that was presented concurrently with the stimuli. In two homogeneous blocks of 28 trials, either size or living/nonliving classifications were required. In a subsequent, mixed block of 80 trials, the type of classification varied unpredictably between trials.

In the color-shape task, blue or red circles or triangles had to be classified either as blue versus red or as circle versus triangle. The homogeneous blocks consisted of 26 trials and the mixed block consisted of 82 trials. In all other aspects, the color-shape task was identical to the category-switch task. As in Miyake et al. (2000), unspecific switch costs were used as the dependent variables for both tasks, computed as the difference in mean RT between the mixed block and the two task-pure blocks.

Control Variables

WM capacity. To assess WM capacity, we used two established WM span tasks: the reading span (Daneman & Carpenter, 1980) and the counting span task (Engle, Tuholski, Laughlin, & Conway, 1999). In the former, participants had to read and evaluate the semantic coherence of simple sentences, one at a time, and memorize their last word. After two to five sentences, the last words from that trial were to be recalled in order of their presentation.

In the counting span task, instead of evaluating sentences, participants counted the number of dark blue circles in a display that also contained light blue circles and dark blue squares. After two to five counting displays, the count totals from that trial were to be recalled in order of their presentation. The number of targets per display varied from three to nine. The number of color distractors (light blue circles) and the number of shape distractors (dark blue squares) were also varied. For each task, three practice trials and eight critical trials were administered. The partial-credit unit scores (PCU; see Conway et al., 2005) were chosen as dependent variables because of their high internal consistency. PCU expresses the mean proportion of elements within a trial that were recalled correctly. Thus, credit is also given to partly correct trials. Furthermore, all items within a trial are counted equally by scoring each item as a proportion of correctly recalled elements per trial, regardless of trial length (e.g., recalling one element from a two-element trial would count as much as recalling two elements from a four-element trial—i.e., .50). These proportions are then averaged.

Cognitive speed. Two established tasks were used to assess cognitive speed: The identical-pictures and number-comparison tasks (Ekstrom, French, & Harman, 1976). The number of problems that were correctly solved within the given time served as the dependent variable. In the identical-pictures task, participants had to compare simple line drawings. A target line drawing was presented on the left along with a number of similar drawings on the right that served as the response options. One of these was identical to the one on the left. Participants were instructed to press the response button associated with the identical drawing.

In the number-comparison task, two numbers (with number of digits varying between trials) had to be compared that were presented side by side in the center of the screen. Participants were instructed to decide as fast as possible whether the numbers were identical or not. In both tasks, a time limit of 90 s was imposed, and participants were instructed to solve as many problems correctly as possible out of a maximum of 90 problems.

Results

Data Preprocessing

Before analyzing the data, we performed the following corrections and transformations: First, average RT measures were computed on correct trials only. Of the correct trials, we excluded those that had RTs more than two interquartile ranges above the third quartile or below the first quartile of each individual's RT distribution in a given task.[2] Second, variables measuring the proportion of correct responses were arcsine-transformed to assure that they were approximately distributed normally. RT difference scores were computed and multiplied by –1 so that higher values represented better performance. Individuals that were univariate outliers (i.e., values more than three interquartile ranges above the third quartile or below the first quartile) or multivariate outliers (i.e., extreme Mahalanobis distance with $p < .001$) were excluded.[3] For ease of interpretation, descriptive statistics are reported for the untransformed dependent variables in Table 1 (except for skewness and kurtosis values, which are those of the transformed variables that were used in the regression analyses) and Table 2.

Descriptive Statistics

Results revealed reliable age differences in the expected direction (i.e., age decline) in all cognitive variables with all $ps < .05$

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[1] Proportion scores were computed by dividing the dependent variable (e.g., the difference in RT between mixed and pure blocks in a shifting task) by the mean RT. The resulting proportion score expresses the magnitude of an individual's RT difference score as a percentage of his or her average response latency. The goal of this procedure is to control for general slowing effects, the underlying idea being that such general slowing effects are not of interest and instead, interactions of slowing with conditions are the variables of interest (e.g., a disproportionate slowing in mixed as opposed to pure blocks).

[2] The proportions of excluded trials were, for the young and older samples, respectively, 1.3% and 2.6% in the Simon task, 3.7% and 2.2% in the category-switch task, and 2.0% and 1.4% in the color-shape task.

[3] There were univariate outliers in the switching tasks (two young, two older adults) and the letter-memory task (one older adult). Furthermore, there were three multivariate outliers from the group of older adults. When these outliers were included, regression analyses yielded a highly similar pattern of results.

Table 1
Descriptive Statistics of Neuropsychological Tests Scores

Neuropsychological test	*N*	Min	Max	*M*	*SD*	Rel.	Skew.	Kurt.
Fluid intelligence (matrices test)	281	2	17	10.68	2.70	N/A[d]	−0.30	−0.19
Crystallized intelligence (MWT–A)	274	24	36	30.89	2.12	N/A[d]	−0.40	0.30
PM 1 (syllable task)	269	.00	1.00	.40	.35	N/A[d]	0.99[e]	0.09[e]
PM 2 (semantic task)	268	.00	1.00	.81	.27	N/A[d]	−0.76[e]	−0.87[e]
Updating 1 (keep-track task)	263	.35	.95	.66	.13	.30[c]	0.45[e]	0.23[e]
Updating 2 (letter-memory task)	274	.19	1.00	.81	.16	.71[c]	0.13[e]	−0.24[e]
Inhibition 1 (antisaccade task)	271	.33	1.00	.83	.11	.88[b]	0.13[e]	0.19[e]
Inhibition 2 (Simon task)[a]	274	−262	58	−57.87	60.12	.74[b]	−0.87	0.47
Shifting 1 (category-switch task)[a]	274	−1,465	118	−592	286.28	.89[b]	−0.19	0.56
Shifting 2 (color-shape task)[a]	274	−1,569	−21	−840	267.13	.93[b]	−0.36	0.12
WM 1 (counting span task)	270	.34	1.00	.78	.13	.64[b]	0.37[e]	0.25[e]
WM 2 (reading span task)	243	.25	1.00	.76	.15	.68[b]	0.65[e]	0.35[e]
Speed 1 (number-comparison task)	270	11	35	20.97	4.99	N/A[d]	0.26	−0.59
Speed 2 (identical-pictures task)	268	16	49	32.24	6.90	N/A[d]	−0.01	−0.63

Note. Rel. = reliability; Skew. = skewness; Kurt. = kurtosis; PM = prospective memory; WM = working memory.
[a] The sign of the response latency difference scores has been reversed. As a consequence, higher values represent better performance across all variables. [b] Spearman-Brown-corrected split-half (odd-even) correlations. [c] Cronbach's alpha. [d] Reliability could not be estimated from the data. [e] Skewness and kurtosis values are reported for the arcsine-transformed variables that were used in regression analyses.

except for performance in the color-shape task measuring shifting (see Table 2). Cohen's *d* (Cohen, 1988, defined effect sizes of 0.2 as small, 0.5 as medium, and 0.8 as large) varied between 0.00 (color-shape task) and 2.05 (identical-pictures task). The largest age effects were obtained in updating, speed, and inhibition.

Individual performance in a given cognitive construct was computed as the mean of the two indicator tasks for that construct that were standardized before. To describe relations between all cognitive constructs assessed, pairwise correlations are displayed in Table 3. Results show significant relations between PM and all other cognitive constructs except for updating. Concerning the relations between the EF facets, updating and inhibition correlated significantly ($r = .39$), while shifting showed no significant relation with the other two.

Explaining the Age Effect on PM

Regression analysis. We computed a regression analysis to investigate age effects on PM. PM served as the dependent measure. In order to examine whether nonexecutive or executive measures could account for age variability in PM, a hierarchical regression analysis was conducted. First, age was included as a predictor yielding a clear effect (which of course merely represents the abovementioned age difference). In a second step, WM and speed were included as predictors in order to test whether the age effect can be better accounted for by these general ability measures. In a third step, the executive measures updating, inhibition, and shifting were added. We used proportion scores for the RT-based indicators that are corrected for general age-related slowing.

Table 2
Participants' Mean Scores and Standard Deviations on the Neuropsychological Tests as a Function of Age Group (Young vs. Older Adults)

	Young adults				Older adults				
Neuropsychological test	*M*	*SD*	Min	Max	*M*	*SD*	Min	Max	*t*
PM 1 (syllable task)	.48	.33	.00	1.00	.27	.34	.00	1.00	5.01***
PM 2 (semantic task)	.85	.23	.00	1.00	.75	.33	.00	1.00	2.69**
Updating 1 (keep-track task)	.69	.13	.37	.95	.61	.11	.35	.90	4.85***
Updating 2 (letter-memory task)	.86	.13	.42	1.00	.72	.16	.19	.97	7.53***
Inhibition 1 (antisaccade task)	.84	.11	.43	1.00	.80	.11	.33	1.00	3.47**
Inhibition 2 (Simon task)[a]	−.05	.07	−.24	.12	−.16	.07	−.35	−.01	13.03***
Shifting 1 (category-switch task)[a]	−.41	.18	−.76	.15	−.47	.13	−.80	.02	3.22**
Shifting 2 (color-shape task)[a]	−.70	.14	−.97	−.04	−.70	.13	−.98	−.34	0.06
WM 1 (counting span task)	.80	.13	.42	1.00	.74	.13	.34	.97	3.71***
WM 2 (reading span task)	.79	.14	.36	1.00	.72	.16	.25	1.00	3.48**
Speed 1 (number-comparison task)	22.70	4.79	13	35	18.14	3.94	11	30	8.48***
Speed 2 (identical-pictures task)	35.99	5.21	22	49	26.04	4.45	16	41	16.63***

Note. PM = prospective memory; WM = working memory.
[a] The sign of the response latency difference scores has been reversed. As a consequence, higher values represent better performance across all variables. Proportion scores were used.
** $p < .01$. *** $p < .001$.

The results are summarized in Table 4. In the first step, age accounted for approximately 9% of variability in PM, $F(1, 262) = 27.12$, $p < .001$. In the second step, including WM and speed increased the explained variability to 13%, $F(3, 262) = 13.06$, $p < .001$. The only significant predictor was speed. Age was no longer significant.

Inclusion of the three EF shifting, updating, and inhibition as predictors in a third step increased the explained variability to 17%, $F(6, 262) = 10.00$, $p < .001$. Inclusion of the EF predictors reduced the effect of speed, although it remained just significant. The explained variability in PM was largely accounted for by shifting and inhibition, with inhibition emerging as the strongest predictor followed by shifting. The contribution of updating failed to reach significance.[4] In sum, age-related PM variability was accounted for by inhibition and shifting, with a smaller contribution of speed.

Structural Equation Modeling

The previous regression analysis clearly suggests that the age effect on PM performance could be accounted for by variability in EF, or more specifically, by inhibition and shifting and less by updating and WM. Yet, the role of EF in PM performance has so far not been addressed directly. We used structural equation modeling to estimate the latent (i.e., measurement-error free) correlations between the distinct EF facets and PM, after testing whether the EF factor structure could be validated in our sample. To avoid concerns that general slowing might underlie any latent correlations, again we used proportion scores for the analyses.

As a starting point, we used the three-factor structural equation model (SEM) on EF reported by Miyake et al. (2000), with the three latent variables inhibition, shifting, and updating. We applied this model to the data from both age groups in a joint analysis. With the exception of residual variances, all parameters were set equal across groups. This model provided a good account of the data, $\chi^2(21) = 19.13$, $p = .58$, root-mean-square error of approximation (*RMSEA*) $< .001$, Akaike information criterion (*AIC*) $= 61.13$, supporting the assumption that the structure of latent variables can be equated across age groups. Thus, regression weights and correlations between latent EF factors were the same for young and older adults, supporting the notion that the model suggested by Miyake et al. holds for both age groups.[5]

Table 3
Pairwise Correlations Between Performance in All Cognitive Constructs

Variable	1	2	3	4	5	6
1. PM	—					
2. Updating	.11	—				
3. Inhibition	$.32^{**}$	$.39^{**}$	—			
4. Shifting	$.16^{*}$	.10	−.003	—		
5. WM	$.18^{**}$	$.33^{**}$	$.40^{**}$	.01	—	
6. Speed	$.33^{**}$	$.43^{**}$	$.51^{**}$	$.16^{**}$	$.30^{**}$	—

Note. Dependent variables are the *z*-standardized mean values of both tasks measuring the construct. Proportion scores were used for shifting and inhibition. PM = prospective memory; WM = working memory.
$^{*}p < .05$. $^{**}p < .01$.

Table 4
Hierarchical Regression Predicting PM

Predictor	β	R^2
Step 1		.09
Age	$-.29^{***}$	
Step 2		.13
Age	−.13	
WM	.10	
Speed	$.21^{*}$	
Step 3		.17
Age	.03	
WM	.08	
Speed	$.14^{*}$	
Updating	−.13	
Inhibition	$.20^{**}$	
Shifting	$.15^{**}$	

Note. Cognitive construct variables are the *z*-standardized mean values of both tasks measuring the construct. Proportion scores were used for shifting and inhibition. PM = prospective memory; WM = working memory.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Next, we included a latent PM factor and investigated correlations with the EF factors. This model also showed a good fit, $\chi^2(42) = 48.98$, $p = .21$, *RMSEA* $= .024$, *AIC* $= 108.98$. There were substantial relations between the latent variables of shifting and PM ($r = .38$), as well as between inhibition and PM ($r = .63$), but not between updating and PM ($r = –.03$).

This pattern was confirmed by a series of model comparisons. Compared with the initial model, goodness-of-fit was significantly worse when the covariance between shifting and PM was set equal to zero, $\Delta\chi^2(1) = 5.26$, $p = .02$, and also when the covariance between PM and inhibition was set equal to zero, $\Delta\chi^2(1) = 14.42$, $p < .001$, but not when the covariance between updating and PM was set equal to zero, $\Delta\chi^2(1) = 0.07$, *ns*. Thus, the EF facets of shifting and inhibition, but not updating, were related to PM performance.

Discussion

The present study is the first to disentangle the importance of the three main facets of executive control suggested by Miyake et al. (2000)—shifting, inhibition, and updating—for predicting age-related PM performance over and above WM and speed. Most important, results suggest that EF facets differently predict (age effects in) PM, with shifting and inhibition being most influential.

Before considering this main finding and its conceptual implications, we briefly review the other results as they also add to the emerging literature on age effects in PM and EF in general. The

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[4] The negative sign of the nonsignificant updating predictor results from a suppression effect.

[5] We also tested in a series of model analyses whether the three-factor model strikes the best compromise between model fit and parsimony. Specifically, we fitted a series of two-factor models in which two out of the three factors were equated, as well as a single-factor model. None of these alternative models provided a better fit than the three-factor model (merging the updating and inhibition factors yielded the best fitting alternative model, with $\chi^2[24] = 29.16$, $p = .21$, *RMSEA* $= .028$, *AIC* $= 65.16$; for all other models, the chi-square test for comparing the observed and predicted covariance matrix signaled significant discrepancy). Thus, we used the three-factor model in subsequent analyses.

result of age effects in PM performance is in line with the PM literature (e.g., Henry et al., 2004; Kliegel et al., 2008; Zimmermann & Meier, 2006), especially as both PM tasks were nonfocal. In nonfocal PM tasks, the PM cue is not part of the information being extracted in service of the ongoing activity (e.g., keeping words in WM, while remembering to press a button whenever the background of the screen shows a particular pattern; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997). In this case, according to the multiprocess framework (McDaniel & Einstein, 2000), PM is thought to require executive attention to carry out extra monitoring for the cue, which should entail age differences as found in the present study.

As another result, age effects were also found in all three EF facets, which also largely replicates previous results (e.g., Bélanger, Belleville, & Gauthier, 2010; Mayr & Liebscher, 2001; Verhaeghen & Basak, 2005). However, Verhaeghen and colleagues (Verhaeghen & Cerella, 2002; Verhaeghen & De Meersman, 1998) have also reported results suggesting that age deficits may not always be found in measures of controlled attention and might be limited to tasks involving the maintenance of two distinct mental task sets.

Our main question, however, was which facets of EF may be predictive for PM performance in young and older adults beyond WM and speed (as suggested, e.g., by Zeintl et al., 2007). In other words, which EF facets are associated with the controlled attentional processes predicted to be required for nonfocal PM? A hierarchical regression analysis showed that the inclusion of EF measures as predictors (in addition to age, WM, and speed) led to a higher amount of explained variance in PM. While the prediction by updating failed to reach significance, inhibition and shifting were significant predictors of PM performance. Conceptually, it should be noted that the revealed influence of shifting on PM is also in line with assumptions from the PAM theory (Smith, 2003; Smith & Bayen, 2004), which proposes that successful performance of the prospective component of PM involves shifting between processes related to the ongoing task and processes related to evaluating responses to the environment on the periphery of our attentional focus. This theory is especially relevant when discussing the importance of shifting for PM in aging, as Smith and Bayen (2006) could show that age differences in PM can be traced back to impaired performance in the prospective component in older adults. However, inhibition ability reached the highest β weight and therefore emerged as the most powerful predictor. Moreover, when EF predictors were entered, cognitive speed less strongly predicted PM and the influence of age was close to zero. The finding that PM age differences were (at least partially) influenced by cognitive speed is in line with previous findings (Salthouse et al., 2004) and corroborates the processing-speed theory of adult age differences by Salthouse (1996), which suggests speed as a key cognitive resource in older adults, even for a construct as multifaceted as PM. WM did not predict PM in the present study and thus shows a similar pattern with respect to predicting age-related PM as updating. Nevertheless, the rather medium-sized correlation between WM and updating underlines the importance of distinguishing between these two constructs. In terms of first conceptual conclusions, the present findings suggest that shifting between the ongoing and the PM tasks, together with the inhibition of the prepotent OT response as soon as the PM response is required, appears to be especially critical for PM performance. As most available process models of PM (e.g., Ellis, 1996; Kliegel, Altgassen, Hering, & Rose, 2011; Kvavilashvili & Ellis, 1996) have so far been of heuristic nature and merely list (all) those processes they believe to be involved in PM (from the intention formation until the evaluation phase), the present data may help in carving out those processes that are key processes for individual differences in PM in general and for producing age effects in particular.

Finally, applying SEM, correlations between latent variables of PM and EF also supported the general results, as inhibition showed the highest correlation with PM followed by shifting, while updating was not correlated with PM. Furthermore, in line with Salthouse et al. (2004) and Zeintl et al. (2007), SEM results nicely confirm the convergent and discriminant validity of PM even in the face of a comprehensive battery of EF tests. While latent correlations between some EF facets (i.e., inhibition and shifting) and PM were on a medium level and suggest a close relation between the constructs, they show at the same time that PM and EF are empirically different from each other and have some unique variance, as the highest correlation was .63. Furthermore, the a priori assumed model in which the three separate EF facets predict PM fit the data well and thereby provides evidence for correlated but partially independent cognitive constructs. This demonstrates PM as a separate cognitive construct and suggests that PM is related, but not identical, to executive control.

Limitations of the present data concern the specificity of the applied cognitive tasks and of the sample. By using multiple indicators for assessing each cognitive construct, distortions due to a specific single task indicator should have been reduced. Nevertheless, using different indicators to measure the cognitive factors of interest may influence the respective results, and the present findings therefore await replication with other indicators.[6] In addition, even though a relatively large sample was tested in the present study, the young age group consisted mainly of university students, which may also limit the generalizability of the present results to other populations.

Taken together, results indicate that EF is an important predictor of PM in young and older adults beyond WM and speed (Zeintl et al., 2007). Specifically, the ability to shift between tasks and the ability to inhibit prepotent or conflicting responses appear to be the essential aspects of cognitive control involved in age-related PM performance. In terms of theory development, therefore, the present results make an important contribution to the refinement of the assumptions proposed, for example, by the multiprocess theory of PM (McDaniel & Einstein, 2000), as they suggest that not a broad construct but rather specific facets of controlled attention play an important role for age effects in PM. Together with early suggestions by Maylor (1996), and more recent conclusions from Smith and Bayen (2006) on the importance of shifting between the ongoing and the PM task that receive clear empirical support in the present data, the present study may offer an initial empirical basis for possible specifications of those conceptual frameworks and recent process models theoretically linking specific EF to specific

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[6] A possible limitation of the present results due to the specificity of the chosen cognitive tasks was especially suggested by one reviewer for the working memory measures. Yet, while this is indeed possible, both tasks represent established indicators of working memory.

PM process phases (Kliegel et al., 2011). Hence, future research will have to follow up on the present findings, which give first insight into which facets of EF are involved in the controlled cognitive processes often suggested to underlie age effects in (nonfocal) PM. Particularly, it will be interesting to see whether EF facets are differentially involved in different phases of PM (intention formation, intention initiation, or execution) as discussed by Ellis (1996) or Kliegel et al. (2011), or in different PM tasks, for example, in more or less focal or event- versus time-based tasks.

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