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Prospective memory development across the lifespan:

An integrative framework

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Abstract

Prospective Memory (PM; the ability to remember to perform planned tasks) represents a key proxy of healthy aging, as it relates to older adults' everyday functioning, autonomy and personal well-being. The current review illustrates how PM performance develops across the lifespan and how multiple cognitive and non-cognitive factors influence this trajectory. Further, a new, integrative framework is presented, detailing how those processes interplay in retrieving and executing delayed intentions. Specifically, while most previous models have focused on memory processes, the present model focusses on the role of executive functioning in PM and its development across the lifespan. Finally, a practical outlook is presented, suggesting how the current knowledge can be applied in geriatrics and geropsychology to promote healthy aging by maintaining prospective abilities in the elderly.

Key words: prospective memory, lifespan, development, executive functions, aging

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Introduction

In the context of an aging population, a key question that many European countries are facing is how to maintain older adults' autonomy, personal safety and well-being. One cognitive marker of these domains that has started to attract attention in recent years is prospective memory. Prospective memory (PM) is defined as an individual's ability to accurately perform planned intentions in the future (Kliegel et al., 2016). Typical everyday examples for PM task are remembering to call a family member on their birthday, remembering to turn off the stove after cooking, or remembering to take medication before a meal. Thus, PM importantly contributes to social relations, well-being, health, personal safety, and maintenance of autonomy and functional independence, especially in old age (Hering, Kliegel, Rendell, Craik, & Rose, 2018; McDaniel & Einstein, 2007a; Woods et al., 2015).

Consequently, in the context of healthy aging, it is crucial to better understand how PM develops across the lifespan, which factors lead to intact or erroneous PM performance, and how one can promote maintaining or even improving PM in older adults. These aspects will be the main focus of the current review. First, from a descriptive starting point, we review the currently available literature on PM development adopting a lifespan perspective. Second, switching to a mechanistic level, we systematically examine factors that contribute to PM performance and we illustrate how they might influence lifespan development. Third, integrating those research lines, we present a new, integrative framework of how possible cognitive and non-cognitive factors may modulate the sub-processes of PM and may drive PM development across different PM task types. In a fourth step, we move towards an applied angle and briefly outline the practical relevance how a better understanding of PM lifespan development may contribute to healthy aging.

The development of PM across the lifespan

Our first (descriptive) goal was to delineate the developmental trajectories of PM across the lifespan. Specifically, we aimed, for the first time, to comprehensively review all available *lifespan* studies in order to approximate the developmental patterns of PM throughout the life course. In contrast to studies only focusing on the performance of separate (often extreme) age-groups, lifespan studies have the advantage that they assess the same task in multiple age-groups, allowing for more generalizable evaluation of how PM develops across the lifespan.

Literature research, inclusion criteria and data acquisition

We searched the most common online databases (Web of Science, PubMed, PsychInfo, and Science Direct). As search parameters, we targeted studies that used a key-word potentially describing PM (i.e. *prospective memory, planned actions, future intentions, intended actions, intentional behavior, implementation intention, intentional memory, memory for intentions, future memory*) in combination with a key-word related to its development (i.e. *development, lifespan, trajectory*). For each word, its derivates were also included (e.g., for *behavior*, this included *behavio(u)r(s)* and *behavio(u)ral*). The final search was completed in December, 2018. Studies were included if they examined the development of PM in a lifespan perspective, meaning that they covered at least three of the following five age-ranges: childhood, adolescence, young adulthood, middle adulthood, old adulthood (thus, studies which labelled themselves as “adult lifespan” were also included, although they did not provide data on children or adolescents). For the subsequent analyses, only data regarding PM performance of typically developing, healthy individuals was extracted (if studies reported performance of other cognitive abilities such as retrospective memory, or performance of clinical groups, these data were not included in the present review). If a study only represented data visually (in a figure) but exact numbers were not reported, respective authors were contacted in order to inquire additional information. For studies, where such information was not available, we used program DataThief III to extract precise numbers from the figures (Tummers, 2006; for a similar approach, see Kliegel, Phillips, & Jäger, 2008).

Data preparation

As different studies used different PM paradigms (which varied in terms of cognitive load, task importance, difficulty, etc.), raw accuracy scores would not be comparable in absolute terms across studies. Thus, for each of the retained studies, we calculated standardized PM scores so that the different trajectories could be compared. In detail, we standardized the score of each age-group according to the score of the best-performing age-group. Specifically, we subtracted PM accuracy achieved by the age-group with the best performance (i.e., peak of PM performance in that particular study) from PM accuracy of each age-group. Hence, the best-performing age-group always has score of 0. Thus, after standardizing the scores, the peak of PM performance is indicated by a score of 0 for all studies, whereas negative scores show differences of PM performance in relation to peak performance. Next, to provide a visual representation of overall PM development we calculated a mean trend level in 5-year steps. It represents the mean of the standardized scores across the studies that provided data on a specific age-group (e.g., for all the studies providing data on 20-year olds (± 2.5 years), the mean standardized score was - .012).

Results

A visual representation of all included lifespan studies is depicted in Figure 1. Overall, the reviewed studies indicate that the development of PM capacities across the lifespan can best described by a curve that follows an inverted U-shape: (1) PM abilities start developing at a very young age, (2) they improve over childhood and adolescence, (3) they reach a peak during (late) adolescence or the beginning of young adulthood, and (4) they subsequently decrease toward old age.

Inspecting the mean level trend in Figure 1 in more detail shows that the lifespan studies suggest a peak of PM at age 20, followed by a decrease throughout adulthood. We argue that the two bursts in performance toward the end of middle adulthood do not represent sudden improvements of PM, but are rather driven by methodological differences between the studies and administered tasks (e.g., using more/less difficult tasks, examining multiple conditions, etc.) Most relevant for the current review, Figure 1 illustrates that PM starts to decline relatively early in the adult lifespan and that it generally continuous to decrease throughout middle adulthood and within old age. However, despite this robust and quantifiable overall trend across the available literature, in the context of healthy aging, it is also important to highlight that some individual studies did observed that under specific circumstances PM performance may remain at a relatively high level even in old age. Thus, in next section, we will zoom-in on possible moderators of age-related trends and present different cognitive and non-cognitive factors that influence PM performance discussing how these factors influence PM development across the lifespan.

Factors influencing PM performance and its development

Task-inherent factors

In order to examine the factors influencing PM performance and its development across the lifespan, it is important to note that PM tasks can be distinguished into two main task types: *time-based* PM tasks, which have to be performed *at/after a certain time in the future* (e.g., calling someone at 11 a.m. or after 2 hours) and *event-based* PM tasks, which have to be performed *when/after a particular event occurs* (e.g., taking one's medication before lunch). One particularity of PM tasks is that the planned action has to be performed *while being occupied with another activity*, which is labelled as the *ongoing task* (e.g., remembering to take one's medication *while setting the table*). Thus, to perform a PM task, one has to redirect attentional resources from the ongoing task and allocate them to the PM task. In event-based tasks, an external event – referred to as the *PM cue* – indicates when to do so. This cue can be *focal*, meaning that its detection can rely on processes similar to the ones that are deployed by the ongoing task (i.e., high process overlap between the PM and the ongoing task) or the cue can be *nonfocal*, meaning that its detection relies on processes that are different from the ones deployed by the ongoing task (McDaniel & Einstein, 2000).

Cue focality constitutes one of the key factors in the *multiprocess framework* (McDaniel & Einstein, 2000), which examines the strategic versus automatic demands of different PM tasks. According to the multiprocess framework, the detection of focal cues mostly relies on automatic processes, as there is a high overlap between processing the ongoing and the PM task. As a consequence, focal tasks are less resource-demanding and thus should show smaller age-effects (see e.g., Henry, MacLeod, Phillips, & Crawford, 2004; Ihle, Ghisletta, & Kliegel, 2017; Kliegel et al., 2016; Kliegel et al., 2013; Kliegel et al., 2008; Mahy, Moses, & Kliegel, 2014; Wang et al., 2011). In contrast, nonfocal tasks entail higher cognitive demands, as monitoring for the PM cue requires additional controlled processes. Thus, PM performance is typically lower and age-effects are larger (e.g., Henry et al., 2004; Kliegel et al., 2013; Kliegel et al., 2008; Wang et al., 2011).

In contrast to event-based tasks, time-based tasks do not provide any external cues on when the task has to be performed. Hence, to detect the right moment to perform the PM task (i.e. the PM target-time) one has to monitor the progression of time. Consequently, time-based PM tasks are generally seen as particularly resource demanding and age-effects are typically even more pronounced than in event-based tasks (for meta-analyses on PM and aging, see Henry et al., 2004; Ihle, Hering, Mahy, Bisiacchi, & Kliegel, 2013; also see Kretschmer-Trendowicz & Altgassen, 2016).

Beside cue focality, the multiprocess framework suggests other factors that influence the degree of automatic versus strategic resources demands. Examining these factors, the literature has established that PM performance is generally higher and that age-effects are generally smaller when (1) the absorption by the ongoing task is lower, (2) when the importance of the PM task is higher, (3) when the association between the PM cue and the PM task is larger, and (4) when the distinctiveness or salience of the PM cue is higher (e.g., Ballhausen, Schnitzspahn, Horn, & Kliegel, 2017; Hering, Phillips, & Kliegel, 2014; Kliegel et al., 2013; Schnitzspahn, Ihle, Henry, Rendell, & Kliegel, 2011).

Task setting and the Age Prospective Memory Paradox

In addition to these task-inherent factors, age-related PM performance is further influenced by the setting in which the prospective task has to be performed. Specifically, research addressing the so called *Age Prospective Memory Paradox* (Rendell & Craik, 2000) has revealed that older adults typically perform worse on PM tasks than younger adults when evaluated in the laboratory, but that they perform as well or even better than younger adults when PM is assessed in everyday life. To explain this unique pattern – which has been repeatedly replicated across studies and by several studies testing the same individuals in both settings (e.g., Azzopardi, Auffray, & Juhel, 2015; Kliegel, 2011; Kvavilashvili, Cockburn, & Kornbrot, 2013; Weber et al., 2011) – in recent years, additional factors have been examined that may contribute to age-related PM performance across task setting. In detail, it has been suggested that older adults may perform better in naturalistic settings because (1) they use more or better compensatory memory strategies and external memory aids in real-life environments, (2) because they perceive higher social importance and thus are more motivated to succeed at real-life tasks, (3) because they are better at planning in routine contexts, (4) because they have more prior task experience, and (5) because they are less absorbed by their daily activities (e.g., Aberle, Rendell, Rose, McDaniel, & Kliegel, 2010; Hering, Cortez, Kliegel, & Altgassen, 2014; Maylor, 1996; Schnitzspahn et al., 2011).

In a recent study, focusing on the age deficit in the laboratory, we added a novel, socio-motivational factor to the Age Prospective Memory Paradox: *age-related stereotype threat*. Stereotype threat describes situations, in which a person is more likely to demonstrate a stigmatized behavior or performance (due to explicit or implicit awareness of the stereotype) that confirms the stereotype regarding their social group (e.g., performing bad on a test because one is expected to perform bad; Steele & Aronson, 1995). To lead to diminished performance, the effect of stereotype threat depends on different situational factors: first, a social group has to be stereotyped in a particular context (e.g., older adults being associated with bad memory in certain cultures); second, the individual has to be aware of the group-stereotype and feel targeted (e.g., knowing about the stereotype and identifying oneself as an older adult); and third, the stereotype must be activated and relevant for the situation (e.g., realizing that the test one is about to perform requires memory skills; e.g., Aronson, Lustina, Good, Keough, & Steele, 1999). Regarding stereotypes and age, the literature indicates that most western societies have negative representations of aging and of old adulthood: Society anticipates older adults to deteriorate in memory and other cognitive domains, and further associates older adults with having reduced physical abilities (e.g., Cuddy, Norton, & Fiske, 2005; Kite, Stockdale, Whitley, & Johnson, 2005). Research shows that such stereotypes have a detrimental impact not only on older adults' subjective well-being (Coudin & Alexopoulos, 2010) but also on their actual cognitive performance (see Horton, Baker, Pearce, & Deakin, 2008, for a meta-analysis). Regarding the development of PM in old age, we recently demonstrated for a first time that age-related stereotypes can also negatively impact older adults' performance in typical PM laboratory tasks (Zuber, Ihle, Blum, Desrichard, & Kliegel, 2017). Specifically, we showed that when task instructions of a laboratory PM task highlighted the memory component of a PM task (which evoke the stereotype of "having bad memory" in older adults) older adults performed worse compared to younger adults, which is typically found in laboratory studies. However, if the task instructions did not refer to the memory component (sparing the older adults of stereotype threat), older adults performed equally well as the young adults. Most interestingly, older adults were able to perform as well as younger adults in the laboratory even on a strategically more demanding nonfocal task, when they were not threatened by age-related stereotypes, very much in contrast to the predictions of the multiprocess framework.

The importance of executive resources for PM and its lifespan development

So far, we have discussed different cognitive and non-cognitive factors that may influence PM performance and age effects. Specifically, PM performance and age differences seem to depend on the amount or type of cognitive resources that are deployed, which varies depending on different characteristics of the PM task (e.g. focal versus non-focal) or the task setting (e.g., laboratory versus naturalistic). This leads to the underlying core conceptual question of which cognitive processes specifically drive PM performance and age effects? PM has mostly been considered as a sub-type of *episodic memory* (e.g., Roediger, 1996), which traditionally describes the ability to recollect past events (i.e. retrospective memory) but which also comprises the ability to imagine and to plan future events (i.e. mental time travel and PM; see Kellogg, 2012). Consequently, PM has been shown to rely on retrospective memory processes (e.g., one has to remember 'which specific intention' to perform in the future; see Mattli, Schnitzspahn, Studerus-Germann, Brehmer, & Zöllig, 2014). However, age-effects on PM consistently persist after controlling for retrospective memory performance (e.g., Gonneaud et al., 2011; Salthouse, Berish, & Siedlecki, 2004). Thus, a different group of cognitive processes has recently received most attention in context of PM resource-deployment: *executive functions* (see Mahy et al., 2014, for a review).

Executive functions can be defined as a group of top-down attentional resources, which are involved in a variety of higher-order processes, such as controlling one's thoughts, elaborating and implementing plans, adapting to novel situations and suppressing habitual responses, programming one's motor activity, monitoring and adjusting one's behavior, learning from past experiences, achieving one's goals, self-regulating, being attentive, and solving problems (e.g., Cummings & Miller, 2007; Diamond, 2013). Today, one of the most prevalent models of executive functioning constitutes the three-facet model suggested by Miyake et al. (2000). It conceptualizes EF as three independent yet interrelated processes: *shifting*, *inhibition* and *updating*. *Shifting* describes our ability to move our attentional focus from one task set toward another task set. *Inhibition* can be defined as one's capacity to refrain from performing a particular action, to overcome a predominant response, to stop/control one's thoughts, or to ignore non-pertinent, distracting information. *Updating* is the ability to briefly stock, manipulate, refresh, and replace information in one's mind.

In recent years, on a mostly correlative level, executive functioning and PM have frequently been associated. First, both are related to making and executing plans, to performing an action in order to achieve a goal. Second, both domains rely on the same cerebral networks, prominently comprising (pre-)frontal regions such as BA 10 (e.g., Anderson, Jacobs, & Anderson, 2008; Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015). Third, both follow a similar lifespan trajectory, with increase of performance during childhood, and generally an (accelerated) decrease toward old age (e.g,. Anderson et al., 2008; Mattli et al., 2014). Finally, multiple studies have shown a link between individual differences in executive functions and individual differences in PM across the lifespan (e.g., Mahy & Moses, 2011; Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013; Zuber, Kliegel, & Ihle, 2016; Zuber, Mahy, & Kliegel, 2019).

Taken together, there is a growing body of evidence that associates executive resources to PM. Consequently, focusing on child development, Mahy et al. (2014) presented an executive framework of PM, which suggests how the different executive processes contribute to *planning* and *performing* a prospective task in children. Although this gave first insights on global resource deployment during PM tasks, three main extensions of this idea are offered by the present paper in its next section. First, we extend the reasoning to a full lifespan perspective. Second, we additionally account for conceptual differences between time- and event-based PM tasks. Third, besides considering executive processes, the impact of cognitive and non-cognitive factors presented above is integrated in one conceptual framework. Thus, in the next section, we will present a new, process-based framework of how executive resources specifically contribute to detecting, retrieving and performing prospective tasks, while distinguishing between focal, nonfocal and time-based tasks. Further, this **integrative** framework suggests how different cognitive and non-cognitive factors influence these processes. Then, we will present how these factors influence PM development and how they contribute to the typically observed age-effects.

PM retrieval and execution:

A new, integrative framework and its relevance for lifespan development

The literature largely agrees on the conclusion that for certain tasks, the *detection* of the PM cue can more strongly rely on automatic/spontaneous processes (e.g., Ihle et al., 2013; Kliegel et al., 2008; McDaniel & Einstein, 2007b; Shelton & Scullin, 2017). For example, on tasks with focal or highly salient PM cues, cue-detection can be relatively spontaneous and may therefore require little to no executive control. However, in contrast to this conceptual argument, we illustrated above that even for such tasks, the majority of empirical studies find significant associations between executive resources and PM performance (e.g., Zuber et al.,

2016) and also age effects (Kliegel et al., 2008). Thus, based on previous empirical findings and conceptual models, we suggest a new, integrative framework of PM retrieval and execution that may resolve this inconsistency in the literature (see Figure 2). Specifically, we argue that the *retrieval* and the *execution* of any type of prospective task still rely to a certain degree on executive resources. We further argue that the overall age effects found in meta-analyses even on this type of laboratory PM task stem from those processes and their development across the lifespan rather than by the development of memory capacities in its traditional sense.

First, in order to develop how specific executive resources are deployed by different PM types, we will use the example of a computer-based PM task, in which participants' ongoing task is to categorize cards by indicating whether the cards depict living or non-living objects using the left- versus right-arrow key. As PM task, participants have to remember to press another key either when the card depicts an animal (focal task), or when the card depicts something that contains the letters "ant" (e.g., *elephant*; nonfocal task), or when two minutes have elapsed (time-based task).

Regarding the retrieval and the execution of these tasks, in our framework we suggest that *updating* resources are deployed by all three PM tasks. Specifically, updating resources are necessary for all PM tasks because one has to maintain and refresh the prospective intention in mind, but one also has to maintain and refresh the instructions of the ongoing task. This is supported by multiple studies that found an association between inter-individual differences in updating and focal PM (e.g., Ford, Driscoll, Shum, & Macaulay, 2012; Mahy & Moses, 2011; Shum, Cross, Ford, & Ownsworth, 2008; Zuber et al., 2016), nonfocal PM (Spiess, Meier, & Roebers, 2015) and time-based PM (Kerns, 2000; Kretschmer, Voigt, Friedrich, Pfeiffer, & Kliegel, 2014; Mackinlay, Kliegel, & Mantyla, 2009; Mäntylä, Carelli, & Forman, 2007; Voigt et al., 2014).

In addition, when a *focal* PM-cue appears (e.g., picture of an elephant) one would have to refrain from treating it as an ongoing task stimulus (e.g., *not* pressing the green button although it depicts a living creature) in order to perform the PM task. Thus, although the detection of PM cues in focal PM tasks may be relatively automatic, the retrieval and the execution of focal PM tasks would further require inhibition resources. This is in line with multiple studies demonstrating an association of focal PM performance and inhibitory resources (e.g., Atance & Jackson, 2009; Ford et al., 2012; Shum et al., 2008).

In contrast to focal tasks, in *nonfocal* tasks, individuals have to constantly reallocate cognitive resources between performing the ongoing task (e.g., categorizing words in living and non-living creatures), and strategically monitoring for the PM cue (e.g., checking every stimulus for the letter-string *ant*, an information that is not necessary to perform the ongoing task, and therefore needs additional executive resources). As illustrated in our framework, this continuous and repeated reallocation of resources between ongoing task and cue-monitoring would deploy shifting abilities, which is supported by correlational studies finding correlations between shifting nonfocal PM performance (Schnitzspahn et al., 2013; Spiess et al., 2015; Zuber et al., 2016). Because of this regular interruption of the ongoing task, we suggest a rather counter-intuitive consequence, which could explain some of the so far surprising findings: on a nonfocal task, participants might in fact be less absorbed by the ongoing task, as they detach from it on a regular basis. Thus, once the nonfocal cue appears, less inhibitory control would be required to refrain from performing the ongoing task. Therefore, although nonfocal tasks are generally seen as requiring more executive control, specifically inhibitory control may be less important for the retrieval and execution phase of nonfocal tasks (see e.g., Zuber et al., 2016, for a latent-level examination of this hypothesis).

Next, our framework illustrates that time-based PM tasks may be even more resource-demanding. Whereas cue-monitoring in nonfocal tasks leads to a binary decision that deploys shifting (either “the PM-cue is present”, then “perform the PM action”, or “the PM cue is not present”, then “shift back to performing the ongoing task”), time-monitoring should impose additional cognitive costs (in the form of deploying more updating resources), because one has to constantly update the progression of time, maintain how much time is left until target-time, and refresh this information after every clock-check. Such differences between cue- versus time-monitoring are sustained by studies which suggest that target-cue monitoring in nonfocal tasks would engage different cerebral activation than time-monitoring in time-based tasks (e.g., Gonneaud et al., 2011).

We further suggest that once the PM target-time occurs, inhibitory control would *not* substantially be required to refrain from performing the ongoing task. In contrast to event-based tasks – where the PM cue can appear at any random moment – in time-based tasks the target-moment progressively approaches, and its occurrence can thus be predicted with certainty (e.g., “There are 15 seconds left until I have to press the white button”). As a consequence, individuals can anticipate when the PM action has to be performed, and put up preparatory process to prepare task-execution (for a detailed examination of resource-reallocation between ongoing and time-based PM tasks, see e.g., Zuber, Mahy, et al., 2019). Thus, inhibitory control would be less required to refrain from treating the ongoing task after the target-time is detected.

Executive resource deployment and lifespan development

Taken together, this new, integrative framework of retrieving and executing planned tasks specifies how different cognitive and non-cognitive factors contribute to PM development across the lifespan. Importantly, it stands in contrast to the traditional view that impaired PM performance in old age would mainly be the consequence of a memory deficit (e.g., Brandimonte, Einstein, & McDaniel, 1996; Zöllig et al., 2007). Instead, in line with more recent models (e.g., Mahy et al., 2014), it supports the hypothesis that age-differences in PM are rather driven by the development of executive resources. Developmental studies show that executive resources are strongly influenced by age and that they are among the first domains showing age-related deficits (Wiebe & Karbach, 2017). This decline of executive resources is associated to changes in the structure and activity-pattern of frontal brain regions: with increasing age, the frontal regions reduce in volume, and their activation becomes less specific and less efficient (e.g., West, 2017). Consequently, PM tasks with high strategic demands would be more difficult to be retrieved and executed (e.g., Kliegel, Martin, McDaniel, & Einstein, 2002; Martin, Kliegel, & McDaniel, 2003; Schnitzspahn et al., 2013; West & Craik, 2001).

Finally, our framework – which aims at simultaneously integrating cognitive and non-cognitive factors – suggests that additional non-cognitive factors such as motivation and stereotypes (perceived by the older individual her- or himself when performing the task) further influence the executively guided resources required in PM tasks. This is supported by previous PM-theories such as the multiprocess framework (McDaniel & Einstein, 2000) and the Age Prospective Memory Paradox (Rendell & Craik, 2000), as well as by recent studies examining additional factors such as stereotypes (Zuber et al., 2017). The latter specifically illustrates that only the strategic processes that are deployed to perform the nonfocal tasks were affected by stereotypes, as older adults performed equally well as younger adults in the absence of stereotype-threat. Hereby, the present framework adds a new nuance to the previous literature, not only because it suggests a new factor in form of age-related stereotypes, but also because the previous studies did not specify on which level non-cognitive factors would intervene. Based on this integrative review, in the final section we discuss the relevance of such findings, and how they should be implemented in future studies as well as in everyday practice of geropsychology to promote healthy aging.

Practical implications and outlook: How to promote prospective abilities in older adults

First, the current framework illustrates that for certain PM tasks (e.g., tasks with focal or highly salient cues) detecting the prospective cue can rely more on automatic processes and consequently that remembering to perform a specific task can be relatively spontaneous. For such tasks, performance is typically better and age-effects are smaller across the lifespan. Consequently, to promote PM and healthy aging, one should find strategies and techniques that efficiently reduce the strategic demand of a PM task and allow for more automatic processes to take over. For example, recent studies illustrate that applying *implementation intentions* effectively decreases the resource demand of a planned task, and allows for automatic retrieval of the prospective cue, which specifically benefits the performance of older adults and thereby reduces age-differences (e.g., Brom & Kliegel, 2014; Burkard et al., 2014; McFarland & Glisky, 2011; Zimmermann & Meier, 2010). Implementation intentions represent self-regulatory strategies that help individuals to remember performing actions by linking an intended action to a specific time and location of execution ("when X occurs, then I do Y"; Gollwitzer, 1999). Thus, instead of the relatively unspecific plan of taking medication before a meal, older adults could for example learn to encode this task as "before every lunch, when I set the table, I will take my medication". Similarly, geropsychologists could teach strategies that apply to older adults' real-life environment. For example, increasing the salience of a prospective cue (e.g., using a colorful medication box that is placed at a frequently visited location in the apartment) may favor automatic detection and benefit performance. Similarly, linking tasks to cues that are more automatically detected (e.g., setting a daily alarm at 12:00 to remember taking medication before lunch) may facilitate automatic retrieval of an intention. Future studies will have to assess if such strategies are easily applied by older adults, and to which degree they improve PM.

Second, we have seen that for other tasks (e.g., tasks with nonfocal and time-based cues) detecting the prospective cue relies more on strategic monitoring and thus require more attentionally guided resources. For these tasks, performance is typically lower and age-effects are larger across the lifespan. Importantly, in contrast to the traditional view of memory decline with age, the current framework highlights that age-differences for strategically demanding tasks are more strongly driven by changes in executive functioning. This is important from a practical perspective, as it implies that classical interventions targeting mnemonic abilities (e.g., using memory strategies such as visualization or chunking) will not efficiently help older adults to remember their intentions. Instead, interventions should focus on helping older adults to detect the appropriate moment to perform an intention (rather than aim at improving their memory). In this context, research suggests that learning to frequently and actively monitor for PM cues can improve performance (Umanath, Toglia, & McDaniel, 2016). Similarly, in recent study, Ihle, Albinski, Gurynowicz, and Kliegel (2018) show that repeatedly rehearsing the planned actions (thinking of which tasks one was supposed to do) can increase PM performance of older adults. Thus, it may be beneficial to teach older adults' to regularly think of what they had planned to do, to evaluate and control their activities and to strategically check the clock. To further facilitate this process, simple aids in older adults' natural environment could benefit their PM. For instance, helping them to develop the habit of regularly using a *task-review list* ("Which tasks did I have to today? Which do I still have to do?") and checking it several times across the day could increase the number of performed intentions. In this context, Umanath et al. (2016) suggest a guided metacognitive strategy framework to train PM. Specifically, authors suggest to apply different strategies that may help older adults to define how they will approach a task, which strategies they will use, but also to self-evaluate their performance and to adopt this to future tasks. Future empirical studies will have to evaluate applicability and efficiency of such strategies.

Third, our framework illustrated how executive resources specifically interplay with retrieving and executing different prospective tasks. As executive resources are strongly influenced by age, a better understanding of such mechanisms seems primordial when aiming to promote PM performance and healthy aging. Thus, besides intervening on a strategy-level, an additional approach could be to directly target the required resources. Specifically, an increasing body of research has examined the efficiency of cognitive trainings in older adults (see Kliegel, Hering, Ihle, & Zuber, 2017 for an overview). On a meta-analytical level, Karbach and Verhaeghen (2014) conclude that cognitive training can improve older adults' executive resources, and that training-induced improvements can translate to other domains.

Further, studies show that such interventions can increase the neural activity of the frontal brain regions, which accommodate executive resources (e.g., Constantinidis & Klingberg, 2016). However, it is important to highlight that most of the currently available cognitive interventions have targeted older adults in their sixties and seventies. So far, only very few data are available regarding the older (i.e. eighty and above). Although first results seem promising (again, see Kliegel et al., 2017 for an overview) as the number of older adults above 80-years will importantly increase over the next decades, it is crucial that future studies investigate potential training of this population in more detail.

Fourth, the current framework also illustrated the role of more socio-motivational factors. Specifically, we have illustrated that older adults remember prospective intentions better if they perceive the task as socially relevant, which should be considered when encoding future intentions. Studies show that adding a social component to forming an intention can increase older adults' motivation and their performance, which may be particularly useful for strategically more demanding tasks (Altgassen, Kliegel, Brandimonte, & Filippello, 2010). Thus, instead of labelling a task as "I have to not forget to make a phone call on Friday at 10 a.m.", a more efficient way for older adults could be "I promised person X to call her on Friday at 10 a.m."

Taken together, the four points above are examples of how scientific findings can help to create new strategies which should be adopted in future interventions. Such interventions can support older adults' PM abilities, and thus help improving everyday functioning and maintaining independence. However, in an aging society, the responsibility to promote healthy aging does not only fall on the older adults themselves but should be a shared effort of our society. Respective to this, the current framework also illustrated the role of socio-cultural factors in older adults cognitive functioning. Specifically, we highlight that negative stereotypes can have detrimental influence on older adults' cognitive performance and their personal well-being, but also that older adults can perform comparably well to younger adults when their performance is not stereotyped (e.g., Zuber et al., 2017). In an aging society, it therefore seems central to help the general population better understand older adults' cognitive capacities, how they are perceived and stereotyped by our society, and how such stereotypes may influence older adults' cognitive functioning and personal well-being. On an individual level, it also seems essential to accurately evaluate older adults' performance under fair and reliable conditions that allow them to perform to the best of their abilities. Further, as researchers we also have to highlight that the elderly may not always be impacted by age as much as they believe, and we have to provide and circulate information regarding the different factors that may interfere with older adults' cognitive skills but also present factors and strategies that can benefit their performance in everyday life. Together, such measures should reduce age-related stereotypes and ageism on a societal level, but it should also help older adults to improve their own image of aging and the development of their abilities on an individual level.

As a final outlook, future research will have to extent the current findings by exploring additional domains in order to further uncover the complex array of factors that contribute to

PM development across the lifespan. For example, the role of personality traits, individual habits and personal preferences in managing planned tasks seems relatively unexplored. In this context, we are currently investigating the role of procrastination (i.e. voluntarily delaying a planned action) in PM performance and find a negative link between the two domains. Specifically, first results indicate that participants who postponed a planned action for a longer period of time were associated with lower PM performance, whereas participants that acted on their intention to perform a task more rapidly showed better PM performance (Zuber, Cauvin, et al., 2019). This constitutes an interesting first finding that may help further understanding the processes that lead to intact PM – or to PM errors. For example, it seems plausible that for certain missed PM actions we might spontaneously remember during the day that we still having to perform a particular task, but that we then decide to delay it for a while – which may lead to forgetting the intention at a later point in time and thus not performing it after all. As these mechanisms remain speculative at present, future studies will have to examine in more detail whether procrastination – alongside with personality traits and other individual characteristics – form global factors that may hamper PM performance in general, or whether their impact varies between more versus less resource-demanding PM tasks. Here, future research may detect additional mechanisms and thus unveil new pathways to promote PM development across the lifespan.

Conclusion

The current paper highlights that PM is a key skill in real-life, which supports everyday functioning, autonomy and well-being, particularly for the elderly. Thus, a better understanding of how PM develops, of which processes are involved and of how to apply such knowledge to maintain PM intact in old age seems of particular interest. The present review illustrates the developmental trajectories of PM across the lifespan, with major increases of capacities during childhood and adolescence, and with overall decreases in and across old age. Most relevant in the context of healthy aging, a new, integrative and process-based framework depicts how different cognitive and non-cognitive factors of PM tasks may influence the deployment of executive resources, and how this may affect age-related performance. With a rapidly aging population across European countries, it is crucial to integrate such findings in geriatrics, gerontology and geropsychology. A solid body of research on the development of prospective abilities currently seems primordial in order to allow for fair evaluation, early diagnosis, reliable prevention and efficient interventions. Thus, we elaborated different cognitive strategies, techniques and potential interventions to promote PM among the elderly. Overall, this may help older adults to remember planned intentions, which could improve their personal well-being and thereby extend their ability to live independently of caregivers.

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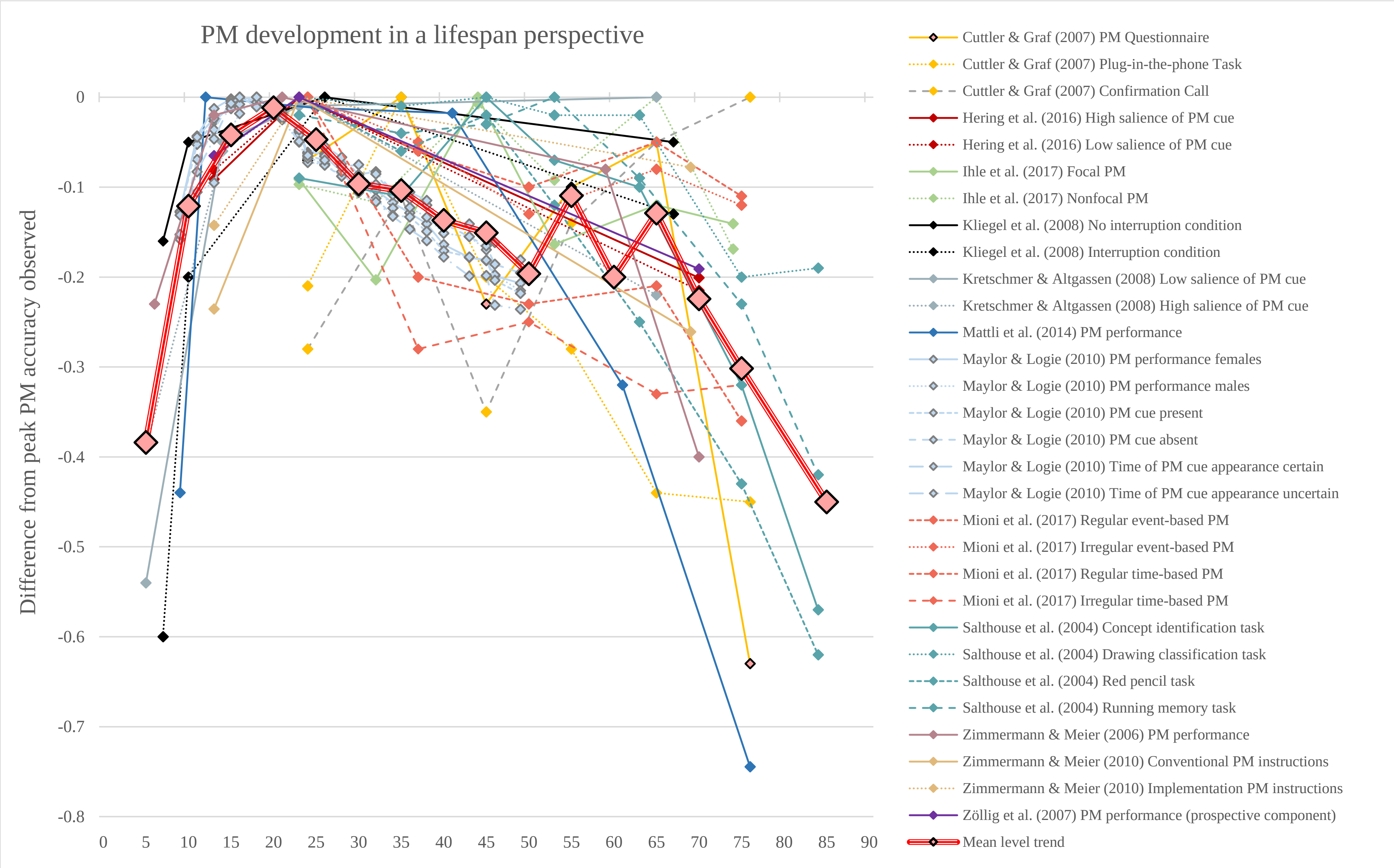

Figure 1. Developmental trajectories of studies that examined PM throughout lifespan or over a large age-range (separated by different conditions of each study). Scores represent PM accuracy of a particular age-group *minus* PM accuracy of the age-group with the highest performance in that study. *Mean trend level* = mean performance across respective studies in 5-year steps.

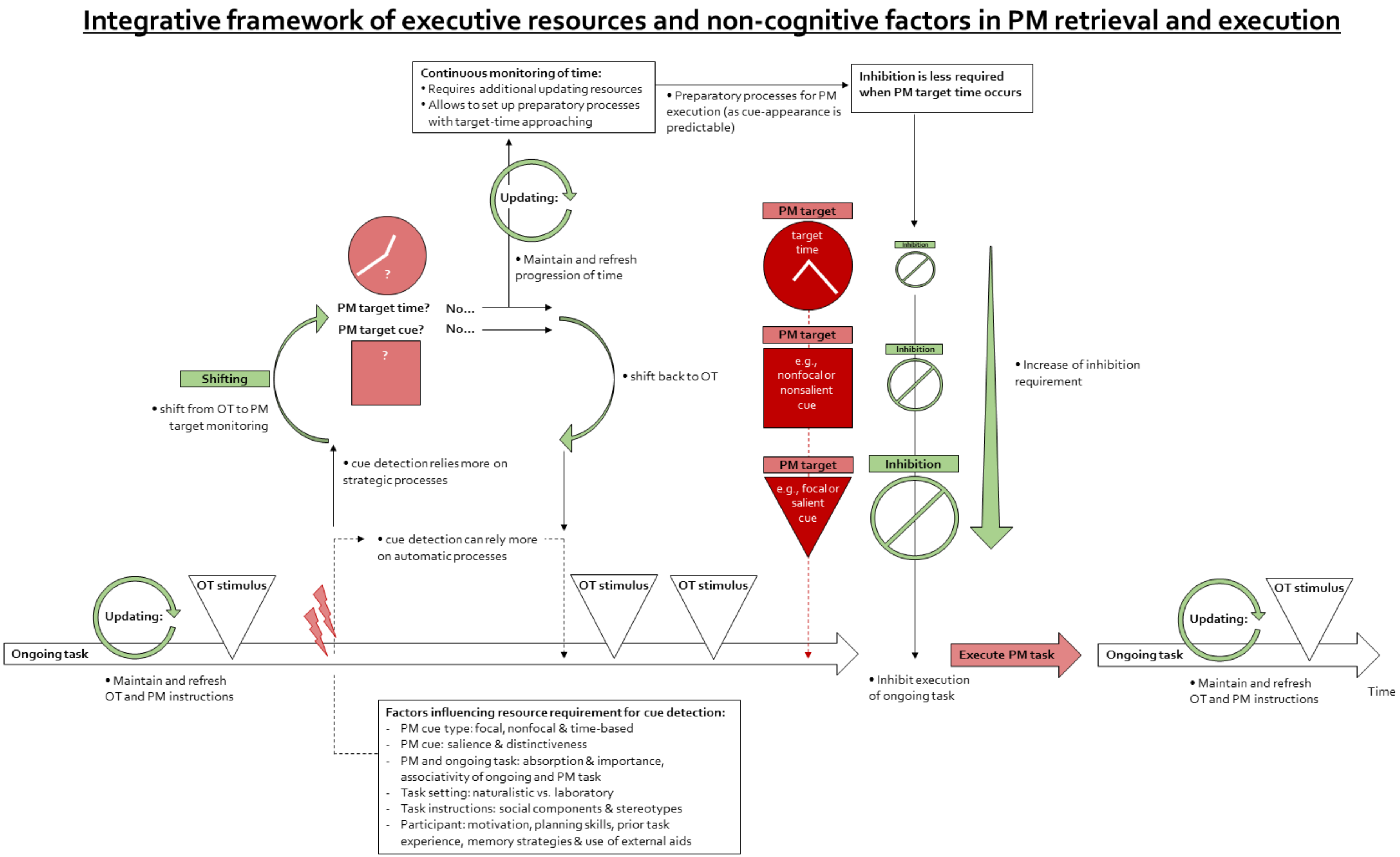

Figure 2. Integrative framework of the interplay of executive resources and non-cognitive factors in PM task retrieval and execution. *Note*. OT = ongoing task. Figure should be read from lower left to upper right