

## Exercise and Prospective Memory

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The purpose of this paper was to review the literature to evaluate the potential effects of exercise on prospective memory (PM). A narrative review was employed. In this review, we provide a brief description of PM; indicate the effects of PM on health; evaluate the effects of age and neurological impairment on PM; examine the neural correlates of PM; provide a description of specific components that subserve PM; identify non-behavioral strategies used to enhance PM; and evaluate the literature and plausibility through which exercise behavior may influence PM. Regarding the latter, this paper aims to burgeon the development of a new research paradigm that will play a critical role in patient health, given that memory function, and in particular, the prospective (vs. retrospective) component of memory, is highly sensitive to aging and is critically associated with health status. This is an emerging line of research that has critical implications for patient health.

**Key Words:** Age, Alzheimer's disease, Dementia, Executive function, Physical activity, Working memory

### INTRODUCTION

This purpose of this paper is to suggest a potential link between physical activity and prospective memory (PM) function. Although other work has examined the effects of physical activity on episodic memory [1], there is limited work investigating the effects of physical activity on PM [2]. We specifically hypothesize that increased exercise behavior may be a potent behavior to subserve PM function. We believe that this effect may be a result of shared biological and psychological pathways linking exercise and PM

(Fig. 1).

Impaired PM is associated with reduced quality of life [3], underscoring the importance of understanding the mechanisms of PM as well as identifying ways to enhance PM. This review will cover the following topics: 1) a brief description of PM; 2) the effects of age and neurological impairment on PM; 3) the neural correlates of PM; 4) a description of specific components of PM; 5) an overview of non-behavioral strategies used to enhance PM; and 6) an overview of the literature evaluating the effects of exercise behavior on PM. Regarding the aforementioned final objective, there are few published papers evaluating the effects of exercise on PM, which served as the motivation for this article.

### OPERATIONALIZATION OF PROSPECTIVE MEMORY

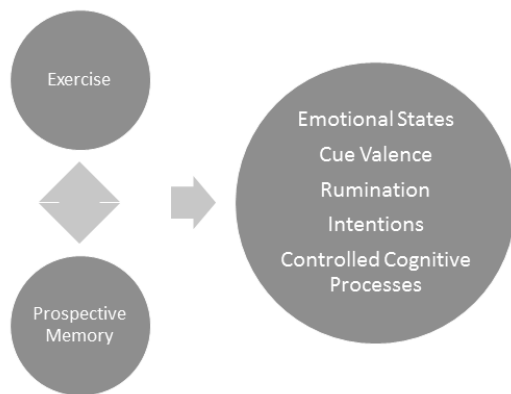
Prospective memory refers to forming an intention to be carried out after a delay, without external reminders [4].

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**Fig. 1.** Hypothetical illustration of shared pathways through which exercise may subserve prospective memory function.

Specifically, PM may be parsimoniously conceptualized as a three-phase model, including: 1) forming an intention; 2) storing the formed intention; and 3) switching from an ongoing task at the appropriate time or event to execute the intended action [5]. As will be discussed in more detail below, failure to suppress the PM intention during the ongoing task may induce detrimental consequences [6].

## AGE AND PROSPECTIVE MEMORY

Considerable research has evaluated the effects of age on PM [7]. Generally, research suggests an inverted U-shaped function, indicative of an increase in PM during childhood and adolescence and a decline in late adulthood [8]. Interestingly, research shows that older adults may outperform younger adults on PM tasks in naturalistic testing conditions, but are inferior during laboratory-based assessments, with such age- and context-based differences possibly being a result of differential attitudes toward the task [9]. This age-prospective memory-paradox has been thoroughly detailed elsewhere [10]; additional mechanisms of this paradox are multifold, suggesting that high motivation and adequate metacognitive awareness are associated with age benefits in PM in the naturalistic setting, whereas high-levels of absorption with an ongoing activity and low control over the PM cue subserve age deficits in lab-based tasks [10]. Additionally, time-based PM (vs. event-based TM; described in detail below) appears to be more sensitive to aging [7,11]. Further, the prospective component of PM (as

opposed to retrospective component of PM; described in detail below) appears to play a more important role in PM performance in young children and older adults [12].

## NEUROLOGICAL FUNCTIONING AND PROSPECTIVE MEMORY

In addition to age, substantial evidence indicates that people with neurological conditions (e.g., Alzheimer’s disease) suffer from severe deficits in PM [13], which may be a result of slow recognition of cues, inefficient encoding of cues, and difficulties in intention encoding and shifting attention between ongoing and PM tasks [14]. Notably, mechanisms mediating PM may differ based on characteristics of the aging process (e.g., normal vs. pathological aging). To illustrate, slow motor processing speed has been implicated in poor PM performance associated with normal aging, whereas slow verbal speed may impair PM in pathological aging [15]. Further, the type of PM task may be differentially influenced among those with neurological impairment; such a notion is illustrated, for example, by dementia patients performing worse on focal rather, as opposed to non-focal PM tasks [16].

## TYPES OF PROSPECTIVE MEMORY

As aforementioned, event-based and time-based are two categories often applied to PM. Focal-based PM tasks involve processes of the ongoing task that employ features of the PM cue (e.g., keeping words in working memory while remembering to press a certain keyboard key when a specific word appears). Unlike focal-based PM tasks, non-focal PM tasks do not involve the PM cue in the extraction of the ongoing task (e.g., keeping words in working memory while remembering to press a certain keyboard key when the background of the screen changes color) [17]. There is evidence to suggest shared neural circuitry for these types of PM, as well as evidence to suggest that they exhibit unique neural correlates [18]. For example, both induce activation in the posterior frontal and parietal cortices, and deactivation in the medial rostral prefrontal cortex [19]. However, occipital areas are more active during event-based PM (likely reflecting target-checking), whereas the dorso-

lateral prefrontal cortex, the cuneus, the inferior parietal lobe, superior temporal gyrus, and the cerebellum are more active in time-based PM (likely reflecting the involvement of time-estimation processes) [19]. Studies using event-related brain potentials (ERPs) demonstrate that N300 is associated with processes underlying the detection of prospective cues [20]. Other electrophysiological studies related to strategic monitoring in PM tasks demonstrate early neural activity at 130-180 milliseconds post-PM cue, which suggests that some individuals may recruit attentional resources necessary for responding to an event-based PM (i.e., increased “readiness mode”) [21]. Additionally, neuroimaging studies demonstrate that, because of the unique brain areas activated, PM is mediated by top-down processes (cognitive-controlled to automatic processes) in non-focal tasks, whereas bottom-up processes (automatic to cognitively-controlled processes) are involved in focal PM tasks [22].

Interestingly, PM also involves a retrospective component. The retrospective component of PM refers to remembering the content of the intention. People tend to have more PM failures than retrospective memory failures [23]. The PM intention needs to be realized at a particular time (time-based PM), when an event appears (event-based PM), or when an activity is completed (activity-based PM) [4]. Event-based PM requires the performance of an intended action after recognition of an external cue in the environment (e.g., taking medication at lunch; remembering to stop at the post-office after work to pick up stamps), whereas in time-based tasks, action is performed at a specific point in time (e.g., 6:00 AM) or after a certain time has elapsed (e.g., calling the doctor in two hours). The initial identification of a stimulus as a PM cue (e.g., a sign marking the post-office) and a subsequent response with an appropriate PM action (e.g., stopping at the post-office) are important components of event-based PM. These components are likely influenced by the individual’s degree of cognitive attention. Time-based PM requires the ability to inhibit an ongoing activity to check the clock, ensuring that the response decision occurs at the correct time. Thus, time-based PM largely depends on time-estimation processes, such as accurate time-monitoring (e.g., number of times an individual checks the clock) [24]. Time-based PM, as opposed

to event-based PM, is more dependent on implicit cues and self-initiated thoughts and strategies because it relies on the capacity to monitor time [25]. Not surprisingly, time-based PM (vs. opposed event-based PM) is usually considered to be more difficult because it relies on self-initiated processes for the retrieval of intention, whereas event-related PM is cued by the occurrence of an event [26]. Importantly, though, both time-based and event-based PM can be negatively affected by demanding ongoing tasks, while positively affected by the degree of motivation allocated to executing the task [27].

## EMOTIONAL STATE AND PROSPECTIVE MEMORY

Of note, the valence of the PM cue may play an important role in the prospective and retrospective components of PM [28]. To illustrate, positive-valence cues have been shown to improve the prospective component, while negative-valence cues have been shown to improve the retrospective component of PM [29]. Event-related potential research demonstrates that emotional PM cues not only trigger an automatic, bottom-up, capturing of attention, but also may facilitate a greater allocation of top-down processes; such top-down processes may assist in maintaining attention toward the emotional stimuli and may also improve the retrieval of the intention from memory [30]. Relatedly, an individual’s emotional state (including apathy [31]) may influence PM. For example, those with chronically negative emotional states, fluctuations in mood, and affective disorders have greater interference with their ability to execute intended actions [32]. From a psychophysiological approach, there is also evidence demonstrating that the physiological state may influence PM performance. As an example, individuals with a higher heart rate during presentation with a PM target were found to have superior subsequent PM performance (this aligns with other research on emotional episodic memory [33]) [34]. Additionally, greater emotional sensitivity, measured via interoceptive accuracy (i.e., the ability to accurately perceive afferent information that arises within the body), may mediate the relationship between physiological state and PM retrieval performance [34].

## FORGETTING AND PROSPECTIVE MEMORY

Failing to forget (i.e., deactivate) PM intentions can lead to commission errors (i.e., intention deactivation failure [35]), which may have serious consequences. Perseverative behavior (e.g., overmedication due to failing to deactivate an intention to take a medication, despite having already taken it) or interference with the execution of a new relevant task [35] (which could occur because of intrusive thoughts and reduced cognitive capacity) are two examples of such consequences [36]. Notably, research demonstrates that it is easier for older adults to forget (deactivate) a PM intention that was performed repeatedly than one that was never performed [37]. Relatedly, deliberate selective forgetting [38] may be illustrated by an individual intentionally forgetting the provision of incorrect directions to find a specific location. The phenomenon of motivated forgetting has been investigated (in a laboratory-based setting) using the list-method directed forgetting paradigm (LM-DF) [39]. Briefly, this paradigm involves participants studying a list of items, with half of the participants instructed to forget that list and told to study a second list instead. Meanwhile, the other half is simply told to study the second list of items. Both groups are then tested on both lists, with results generally demonstrating that those cued to forget the first list, indeed, perform worse on this first list. This supports the assertion that people can intentionally forget. Importantly, the group cued to forget the first list usually performs better on the second list [39].

### PROSPECTIVE MEMORY ERRORS

According to the Multiprocess Theory of PM, there are two distinct processes that account for PM commission errors, including spontaneous retrieval (i.e., when something “pops into the mind” at the right moment) and cognitive control (i.e., strategic and effortful monitoring). Notably, recent work (Dynamic Multiprocess Framework) suggests that these two processes (spontaneous retrieval and strategic monitoring) may not be mutually exclusive [40]. Spontaneous retrieval involves a bottom-up approach, by, for example, automatic capturing of attention and subsequent activation

of intention from the mind; cognitive control involves a top-down approach, via monitoring the environment for PM cues and actively maintaining the PM intention within one’s memory [22]. Spontaneous retrieval brings to mind the previously relevant PM intention during the finished/execution PM phase. The role of cognitive control is to deactivate the PM intention when it is retrieved during the finished PM phase [37]. Spontaneous retrieval is generally thought to occur when a PM task is focal to the ongoing task (i.e., when the ongoing task results in processing of stimuli that is relevant to the PM task) [41], whereas non-focal PM cues encourage the engagement in strategic monitoring processes [42]. For example, when processing words of a particular valence, word-based PM-specific cues may help to facilitate spontaneous retrieval. However, the opposite may also be true; via “discrepancy-plus-search” mechanisms, a PM cue that is discrepant from the category that is being processed might facilitate spontaneous retrieval. For example, if, when cleaning the house, an individual is exposed to numerous similar household items, but then comes across an item within a different category (e.g., a work-related item, such as a stapler), the ongoing task processing may be disrupted, allow the individual to recognize this potential PM cue [43].

### STRATEGIES TO IMPROVE PROSPECTIVE MEMORY

Implementation intentions (“if-then” statements; if situation Y is encountered, then I will initiate the goal-directed behavior X) is a technique demonstrated to improve PM [44], possibly via enhanced detection of critical cues and initiation of action [45]. That is, implementation intentions are thought to create a strong link between PM cues and intentions, and thus, may reduce the reliance on cognitive resources in prospective remembering. Stated differently, implementation intentions may help to form a robust associative encoding between the PM cues and the intentions, which may help to stimulate spontaneous retrieval of the intended actions [43,46]. Thus, it seems that implementation intentions may act via an automatic process. Additionally, implementation intentions may increase an individual’s perceived importance of the task, potentially resulting in greater allocation of cognitive resources to the task as well as

increased strategic monitoring for the PM targets. Notably, PM performance has been shown to increase when stressing the importance of fulfilling the intention [41]. Implementation intentions may therefore act through both automatic and controlled processes [47], causing people to spontaneously recall the intentions when PM cues are present, but to also use cognitive resources to switch attention from an ongoing task to a PM task. Thus, it seems that PM processes lie on a continuum from automatic to controlled. This helps to differentiate PM from working memory (i.e., the ability to manipulate information in the mind over a short period of time, and then update it into one's memory). Stated differently, working memory is the ability to temporally retain information to be used in a subsequent task. Working memory strongly reflects attention control [48], which aligns with the attentional controlled processes of PM (as opposed to the automatic component of PM) [49]. Given that working memory is an important component of executive function [50], models of PM should consider evaluating executive functioning, including all executive functioning components, as they may play differential roles in PM [51]. Additionally, various PM tasks may involve differential executive functioning requirements, particularly in the younger population [52]. In addition to executive function, other components, such as metacognition (i.e., an understanding of one's own mental processes) and theory of mind (i.e., the capacity to predict and interpret behavior as the results of mental states such as one's beliefs and desires) may also influence PM processes [52].

## FUTURE THINKING AND PROSPECTIVE MEMORY

Episodic future thinking (EFT) is related, yet distinct from PM. Per the episodic stimulation hypothesis proposed by Schacter and Addis [53] EFT involves the ability to flexibly recombine details drawn from past experiences, personal goals or events to construct an event that could plausibly occur in the near future (i.e., to "pre-experience" an event) [54]. Remembering past events and imaging future ones requires a processing space where information is temporarily maintained and manipulated [54], which are important components of working memory function. Thus, EFT and PM

involve similar mechanisms and both are considered examples of future-oriented cognition. Indeed, emerging work suggests that EFT contributes to PM performance in both young and older adults [55].

To briefly summarize, 1) age is associated with PM in an inverted U-shaped function; 2) the association between age and PM may be context-dependent; 3) different neural structures may uniquely influence event- and time-based PM; 4) forming an intention, storing the intention, and switching from the ongoing task at the appropriate time or event to execute the intended action are key characteristics of PM; 5) PM involves focal and non-focal tasks; 6) PM involves both retrospective and prospective components, of which are influenced by top-down and bottom-up processes; and 7) PM regulatory processes range from automatic to cognitively controlled, including higher-order cognitions such as working memory and other executive functions.

## EXERCISE AND PROSPECTIVE MEMORY

Recalling the latter, a logical question is, "Does exercise influence PM processes?" and "If exercise can alter PM processes, what are the mechanisms?" In theory, regular exercise behavior may help to facilitate PM via shared pathways (Fig. 1). For example, PM may be influenced by emotional states and cue valence, and exercise is associated with mood state [56] and emotional memory [57]. Further, exercise may reduce depression-related rumination [58], which theoretically may predispose an individual to be less aware of a PM cue. Additionally, intentions are core constructs influencing both PM and exercise [59,60]; similarly, controlled cognitive processes (i.e., executive-function related processes) moderate the relationship between behavioral intention and engagement in exercise [61] and sedentary behavior [62]. Further, similar to the critical role that working memory and other executive functions play in subserving PM, research demonstrates that these executive functions also substantively influence and can be influenced by exercise behavior [63,64]. Exercise has also been shown to stimulate neuronal activity in brain areas (e.g., prefrontal cortex, parietal lobe, cerebellum) known to influence PM [65,66]. Taken together, there is plausible evidence to suggest that exercise may favorably influence PM. Although other work

has evaluated the effects of exercise on episodic memory [67], few studies have examined the effects of exercise on PM [2,68]. Among the few studies on this topic, current findings suggest that acute aerobic exercise does not enhance PM [2,68] and may actually impair PM if the PM task occurs during the bout of exercise [69]. However, emerging work suggests that an acute bout of resistance exercise may enhance PM performance [69].

## CONCLUSION

This review details factors that influence PM and highlights the plausibility through which exercise may influence PM. Clearly, this line of inquiry is in its infancy, which provides promise for scholars interested in exercise and memory research. Given the infancy of this field, it is challenging to provide clear guidance on the initial studies that should be conducted. As a starting point, studies employing parsimonious designs may wish to first start out by investigating the effects of exercise intensity and duration on PM, considering event-based and time-based PM, as well as focal- and non-focal PM tasks. Given the age-associated effects on PM, it seems reasonable that such studies should consider age as a potential moderator. Further, in most PM paradigms, the stimuli used for the ongoing task and the PM task are typically one and the same. However, in real-world situations, PM demands require an individual to shift attention to a different stimulus than the one relevant to the ongoing task [70]. Thus, future work should consider employing both scenarios. Relatedly, given the age-prospective memory-paradox, future work should consider evaluating the effects of exercise on PM in both laboratory and naturalistic settings. Additionally, given the recent findings suggesting that exercise temporality and modality may moderate the effects of exercise on PM [69], future research should continue to evaluate these potential effect modifiers. The dearth of research in this emerging field is, in our opinion, exciting. The field awaits future investigations to determine if exercise can improve PM.

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