Preserving Prospective Memory in Daily Life: A Systematic Review and Meta-analysis of Mnemonic Strategy, Cognitive Training, External Memory Aid, and Combination Interventions

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Abstract

Objective: To preserve or improve independent functioning in older adults and those with neurocognitive impairments, researchers and clinicians need to address prospective memory deficits. To be effective, prospective memory interventions must restore (or circumvent) the underlying attention and memory mechanisms that are impaired by aging, brain injury, and neurodegeneration. We evaluated two decades of prospective memory interventions for objective effectiveness, subjective/perceived effectiveness, time/resource costs, and ecological validity.

Methods: We systematically reviewed 73 prospective memory intervention studies of middle-to-older-aged healthy adults and clinical groups (N=3,749). We also rated the ecological validity of each study's prospective memory assessment/task using a newly developed scale. When possible (72% of studies), we estimated effect sizes using random-effects models and Hedges's g.

Results: We identified four categories of prospective memory interventions, including: mnemonic strategy, cognitive training, external memory aid, and combination interventions. Mnemonic strategy (g=.450) and cognitive training (g=.538) interventions demonstrated efficacy. Combination interventions showed mixed results (g=.254), underscoring that "more is not always better." External memory aids demonstrated very positive outcomes (g=.805), though often with small-sample, case-series designs. Prospective memory assessments had high ecological validity in external memory aid studies (84%), but not in mnemonic strategy (14%), cognitive training (20%), or combination intervention (50%) studies, p<.001, η_p^2=.33.

Conclusions: Everyday prospective memory can be meaningfully improved, perhaps particularly with external memory aids, but larger comparative effectiveness trials are required to optimize treatments, increase adherence, and broaden implementation in daily life.

Key Points

- Question: Which types of interventions are most effective at aiding prospective memory in everyday settings in healthy adults and clinical groups?
- Findings: External memory aids, mnemonic strategies, and cognitive training demonstrated efficacy, but only electronic memory aids demonstrated effectiveness with ecologically valid assessments.
- Importance: Provides recommendations for improving everyday prospective memory in older adults and individuals with brain injuries/disorders.
- Next Steps: Electronic memory aids require systematic testing using large-sample randomized controlled trials whereas other interventions need to test their efficacy in everyday settings with ecologically valid prospective memory assessments.

Introduction

Remembering to perform daily intentions, or prospective memory, is a cornerstone of independent living. This ability underpins many activities of daily living such as remembering to take a specific medication dose at the appropriate time, remembering to pay bills, and remembering social obligations (Hering et al., 2018; Woods et al., 2012). In laboratory settings, prospective memory performance declines gradually with increasing age (Kliegel et al., 2016), particularly for complex and cognitively-demanding tasks (Einstein et al., 1992; McDaniel & Einstein, 2007). Paradoxically, in naturalistic settings, older adults may outperform young adults, depending on their level of motivation (Haines et al., 2020; Kvavilashvili & Fisher, 2007; Schnitzspahn et al., 2011; Woods et al., 2014). Whereas normal aging is only sometimes associated with functional, everyday decline in prospective memory, the decline is often precipitous and functionally-impairing for persons with neurocognitive conditions such as dementia (Duchek, Balota, & Cortese, 2006). To prevent or slow cognitive decline, the World Health Organization (WHO; 2019) has recommended lifestyle and compensatory interventions including better nutrition, increased aerobic activity, reduced substance use, and cognitive training. These interventions are often intended to have a broad impact on multiple cognitive systems, and their effectiveness for everyday prospective memory tasks remains understudied.

Understanding why prospective memory fails, and identifying effective interventions for such failures, requires understanding how cognitive processes dynamically interact to support intention encoding, storage, and retrieval (Shelton, Scullin, & Hacker, 2019). Both top-down and bottom-up cognitive processes support *time-based* prospective memory (performing intentions after a specific time interval) and *event-based* prospective memory (performing intentions in response to a cue or context). Top-down monitoring is a cognitively demanding process whereby individuals rehearse their intentions and/or actively search their environment for cues that signal that the intention should be performed. Engaging top-down monitoring increases the probability of remembering to perform an intention, but because monitoring is a cognitively-demanding process that requires sustained anterior prefrontal cortex activation (Cona et al., 2015), it is unlikely to be sustained over long time intervals (Koslov et al., 2019; Morgan et al., 2012). Given that aging and many clinical conditions compromise prefrontal cortex functioning and top-down control processes, it is no surprise that monitoring is often impaired in older adults and individuals with brain injuries/disorders (McDaniel & Einstein, 2007).

In the absence of top-down monitoring, prospective memory can sometimes be supported by bottom-up spontaneous retrieval processes (at least for some types of event-based prospective memory; Scullin, McDaniel, & Shelton, 2013). Spontaneous retrieval is a relatively automatic process that is introspectively experienced as an intention "popping" into mind. Most evidence indicates that spontaneous retrieval is supported by ventral parietal alerting regions and hippocampal memory regions (Cona et al., 2016; Scullin, Ball, & Bugg, 2020). Therefore, any condition that affects these regions—including mild cognitive impairment (MCI) and Alzheimer's disease (AD)—reduces the probability of a spontaneous retrieval (McDaniel, Shelton, Breneiser, Moynan, & Balota, 2011; Kvavilashvili, Niedźwieńska, Gilbert, & Markostamou, 2020). Another limitation to relying on spontaneous retrieval is that it is dependent on the availability of a strong environmental cue. Therefore, if an individual fails to encode or consolidate a strong association between the cue and the target action, or if the environmental cue is not fully processed at the time when the intention should be performed, then there may be a failure in prospective memory (Scullin et al., 2019).

To the extent that prospective memory declines in these clinical groups, so does the ability to perform instrumental activities of daily living (Nurdal et al., 2020; Schmitter-Edgecombe et al., 2009). Such activities include remembering to take medications, shopping independently, managing financial matters, and related tasks. Although most researchers agree that the processes underlying prospective memory are vital to everyday functioning, there has long been debate over whether laboratory-based prospective memory assessments can accurately predict medication adherence or other everyday health-related activities (Hertzog et al., 2000). Therefore, it is paramount to consider the ecological validity of assessments before generalizing study results to everyday prospective memory functioning (Phillips, Henry, & Martin, 2008; Rummel & Kvavilashvili, 2019).

The loss of prospective memory in persons with neurocognitive disorders not only reduces their independent functioning, but can also have cascading effects on the caregiver (typically a spouse) who becomes burdened with a "double to-do list." Such burden is known to detrimentally affect health, quality of life, and produce a financial burden of $290 billion globally (e.g., lost wages and productivity; Alzheimer's Association, 2019; Gao, Chapagain, & Scullin, 2019). Therefore, there is an urgent need for empirically-supported interventions that can promote independent living by buffering against prospective memory decline. The purpose of this systematic review and accompanying meta-analysis is to address the strengths and weaknesses of existing prospective memory interventions, to critically evaluate the ecological validity of existing assessments, and to provide recommendations for improving everyday prospective memory in healthy older adults and clinical groups.

Review and Meta-Analysis Aims

Several authors have written scoping reviews of prospective memory and aging in both healthy adults and clinical groups (e.g., Kliegel et al., 2016; McDaniel & Einstein, 2007; Van Den Berg et al., 2012; Zogg et al., 2012). However, there remain at least three important, unanswered questions that we aimed to address. First, we sought to identify broad intervention categories and examine their efficacy across objective and subjective measures of prospective memory. Second, we investigated whether the interventions were being tested with measures of high ecological validity, that is, with measures that correspond to the actual prospective memory demands of daily life. Third, we weighed each intervention's efficacy against study design issues (sample size, random assignment, long-term follow-up) and pragmatic issues that impact the likelihood of broad implementation (adherence, time commitment, monetary costs, cognitive demands).

Methodology

Literature Search Protocol

The literature search was conducted through October 2019, using PubMed and PsycInfo. Boolean search terms entered into each search engine started with either "prospective memory" or "memory for intentions" followed by 1) "training," 2) "medication," 3) "technology," 4) "rehabilitation," 5) "implementation intentions," 6) "electronic memory aids," 7) "intervention," 8) "STOP," 9) "self-generation," 10) "elaboration," 11) "calendaring," 12) "SMS," 13) "texting," 14) "Google Calendar," 15) "spaced retrieval," or 16) "cognitive training." Constraints on each search limited results to human studies published between 1996 and the end of October 2019. This search method generated 1186 unique results (Figure 1).

Abstracts were reviewed to determine the final list of studies considered for the review. The criteria for inclusion were: 1) reported empirical studies, 2) measured prospective memory outcomes, 3) assessed a non-pharmacological intervention, and 4) included a sample whose mean age was 30 years or older. Criteria were checked incrementally in the order presented during a title and abstract review, resulting in 101 studies for full evaluation. After further reading, an additional 28 studies did not meet the inclusion criteria. This review focuses on the remaining 73 studies, which included data from a total of 3,749 participants.

The designs of the included studies varied between randomized controlled trials (51%), single case or single case series (18%), within-subject treatments (11%), and a mixture of other pseudo-random assignment or quasi-experimental designs (16%). Table S1 provides additional details regarding study and intervention designs.

Ecological Validity Ratings

The goal of memory interventions is to support independent living and improve quality of life. Building on Phillips et al.'s (2008) qualitative classifications, we conducted a systematic assessment of the ecological validity of the prospective memory assessments in each study to inform our recommendations on which intervention(s) are ready to be broadly implemented.

We rated, from 1 to 5, the ecological validity of each study's prospective memory assessments. Because most studies evaluated intervention efficacy with several types of assessments, the study's rating was determined by the highest-validity assessment included. The criteria for rating assessments were: a) the assessment required performance of a delayed-intention task (rather than only self-report), b) the assessment took place outside the laboratory setting (i.e., at home), and c) the assessment included participant-generated tasks based on their personal daily activities (rather than researcher-generated tasks). Based on these general criteria, Table 1 provides the operational definitions for each ecological validity rank (for similar qualitative approaches, see Phillips et al., 2008; Rummel & Kvavilashvili, 2019).

Meta-Analysis Procedure

The meta-analysis examined whether interventions significantly changed prospective memory performance. In addition to analyzing data from studies regardless of study design, we repeated the analyses with studies that only included random assignment to treatment groups, and those focused specifically on improving prospective memory (rather than general memory complaints). We did not systematically assess for bias in individual studies, but we did exclude case studies that did not implement case-control designs, studies with ceiling effects, and studies in which insufficient data were available (either in the paper or via attempting to contact the corresponding author). In cases where interventions from two categories were compared, the data were coded into the category of the higher-performing intervention. Fifty-eight of the systematically reviewed studies met the inclusion criteria.

Available data were entered into the Comprehensive Meta-Analysis software (version 3.0; Borenstein et al., 2013) to generate and compare effect sizes (Hedges's g). Post-intervention means, standard deviations, and sample sizes for independent treatment and control groups were entered to evaluate intervention effects. Although post-test group comparisons can inflate effect sizes, especially in smaller sample studies, we utilized these data to be as comprehensive as possible given the heterogeneity in study designs. In cases where a study only reported pre- and post-intervention data, the intervention effect for the study was based on the change in performance. An average effect was computed for studies that reported multiple prospective memory measures. The primary goal was to examine intervention-related effect sizes across prospective intervention categories. Secondary goals were to compare intervention-related effect sizes between healthy groups and clinical groups, and to compare intervention-related effects in studies with the strongest designs (randomized to treatments, focused on prospective memory).

Overview of Interventions

The 73 reviewed papers contained interventions that fit into one of four categories: mnemonic strategies (Table S2), cognitive training (Table S3), external memory aids (Table S4), and combination strategies (Table S5). The four categories are distinguishable in their mechanistic approach to compensating for prospective memory impairment, as summarized in Table 2. First, mnemonic strategies require the engagement of cognitive resources during intention formation or during the retention interval, with the aim of improving the efficacy of spontaneous retrieval processes (note though that such approaches sometimes also impact monitoring). Second, cognitive training involves the repetition of cognitive tasks with the goal of strengthening the underlying processes (typically focused on top-down monitoring) so that those processes can be more effectively used to complete novel tasks (i.e., transfer of training). Third, external memory aids make no attempt at strengthening monitoring or spontaneous retrieval; instead, the goal is to "offload" a prospective memory onto to-do lists or alert-enabled "smart" devices that circumvent the need for storage/retrieval cognitive processes. Fourth, combination interventions train individuals on some, or all, of the aforementioned approaches in a manner that is atheoretical (i.e., no mechanism of action is targeted). Our classification approach overlaps with previous intervention classification approaches that were based on the stage/phase model of prospective memory (e.g., Zogg et al., 2012).

Outcomes and Adherence by Intervention Category

Mnemonic Strategies

Implementation intention interventions. Many regard implementation intention encoding - a mnemonic strategy - as the "gold" standard of prospective memory interventions. In this strategy, individuals are taught to generate a specific environmental cue to pair with their intention (Gollwitzer, 1999) as doing so enhances the probability of a spontaneous retrieval (Rummel, Einstein, & Rampey, 2012). They then speak their intention aloud using the following structure: "If I see Cue X, then I will perform Intention Y." Variants of this mnemonic strategy have included training participants to repeat the cue-action pairing three times and/or visualizing performing the prospective memory task.

Several laboratory-based studies in older adults have demonstrated the efficacy of implementation intentions for prospective memory (Table S2). For example, Zimmerman and Meier (2010) had healthy young adults and older adults perform an ongoing lexical decision task with an embedded (keyboard response) prospective memory task. Relative to a standard encoding group, implementation intentions improved prospective memory performance without altering ongoing task performance, indicating that it increased the likelihood of spontaneous retrievals. Interestingly, with the implementation intention strategy, older adults' performance increased to the level of the young adults who used standard encoding (for a reduction of age differences in the Virtual Week with implementation intentions, see Henry et al., in press).

Establishing intervention efficacy in the context of lexical decision tasks is appropriate for identifying mechanisms of action, but such tasks provide little information about the generalizability of an intervention to everyday settings. However, the benefits of implementation intentions have been observed in healthy older adults for remembering to check blood pressure at-home (Brom et al., 2014) and remembering to write the day of the week at the top of forms (and other more naturalistic tasks; Chasteen, Park, & Schwarz, 2001; Burkard et al., 2014b; McFarland & Glisky, 2011). Therefore, at least for a short time interval, implementation intentions can benefit prospective memory in healthy older adults.

The evidence for implementation intention efficacy in clinical groups is more mixed. Positive outcomes have emerged from Shelton et al.'s (2016) work on healthy older adults and persons with very mild AD who performed the Virtual Week. In this task, simulated prospective memory tasks are assigned (e.g., get a haircut at 2pm) that can be fulfilled via button presses and selection boxes as the participant moves a token around a (digital) game board. Relative to a read-aloud condition, healthy adults and persons with very mild AD who were randomly assigned to use implementation intention encoding performed significantly better on their prospective memory tasks (see also Lee, Shelton, Scullin, & McDaniel, 2016). Similar benefits of implementation intentions on Virtual Week performance have been observed in Parkinson's disease (Foster, McDaniel, & Rendell, 2017) and multiple sclerosis (Kardiasmenos et al., 2008).

The above notwithstanding, mixed findings for implementation intentions have emerged in at least two studies. First, Schnitzspahn and Kliegel (2009) found that implementation intentions were effective in young-old adults (M_{age} = 68.2) but not in old-old adults (M_{age} = 81.5). Second, in a mixed sample of participants with MCI and dementia, Burkard and colleagues (2014c) found that implementation intentions only benefited prospective memory performance in participants with higher working memory scores. One possibility though is that implementation intentions produced a benefit that was not captured by the experimenter-dictated tasks. For example, in a separate study, Burkard et al. (2014a) had 12 participants with mixed cognitive complaints (e.g., MCI, AD, TBI) attend 1-hour, bi-weekly implementation intention training sessions for 5 weeks. The objective, experimenter-dictated, prospective memory tests showed no pre-to-post intervention improvements, but the participants reported reduced concerns about forgetting prospective memory tasks at post-test. This pattern might reflect placebo effects, but it raises the possibility that the implementation intention strategy helped the participants to complete everyday prospective memory tasks (i.e., those that were not experimenter-dictated).

Visual imagery interventions. Closely tied to (and often combined with) implementation intention interventions, visual imagery is thought to improve cue-action association by having individuals visualize themselves performing an action in response to "seeing" the cue in the environment. Using this strategy, persons with TBI have shown improved performance when instructed to remember to press a target button when cue words were presented during an ongoing, general knowledge task (Grilli & McFarland, 2011). Furthermore, individuals who had a stroke showed an immediate improvement following visual imagery training on virtual reality simulations of everyday event-based tasks (e.g., buying items at particular stores) and time-based tasks (e.g., taking medications at specified times; Mitrovic et al., 2016). They then maintained this improvement across four weeks of treatment. Griffiths et al. (2012) found that visual imagery benefited time-based Virtual Week performance in social drinker participants, though not in participants with alcohol dependence. Therefore, in general, visual imagery seems effective at improving prospective memory, at least in the laboratory.

Spaced retrieval interventions. Implementation intentions and visual imagery involve minimal "cognitive effort" (i.e., they only require cognitive resources at encoding). Other mnemonic strategies require more time and effort, and so it is important to evaluate if that additional investment produces greater success for improving prospective memory in clinical groups (Table S1). For instance, one of the best learning strategies is to have people space retrievals across incrementally longer intervals (Landauer & Bjork, 1978). Ozgis, Rendell, and Henry (2008) compared Virtual Week performance in healthy adults and individuals with MCI while using the spaced retrieval strategy (i.e., recall prospective memory tasks at 5, 10, 20, 40, and 60 sec intervals). Relative to massed encoding (i.e., recall prospective memory tasks three times each), spaced retrieval led to better performance in both the healthy group and the MCI group, particularly on irregular/infrequent prospective memory tasks. Kinsella and colleagues (2007) reported similar benefits of spaced retrieval on laboratory-based prospective memory performance in individuals with mild AD.

Self-awareness interventions. Another approach is to increase people's self-reflections, or awareness, of their daily prospective memory functioning. The idea here is that greater awareness of prospective memory forgetting will encourage people to engage monitoring or cue generation strategies that prevent further errors (though doing so should require greater cognitive effort). For example, Fish and colleagues (2007) trained 20 participants with either TBI or cerebrovascular disease to use self-reflections such as "Am I forgetting anything?" without any direct task reminders. As part of their training, participants received text message prompts at random intervals to engage in self-reflections (without telling them what to try to remember). Self-reflection training lasted 30 minutes and then participants were given the prospective memory task to call a voicemail server at scheduled times over the following 10 days. Experimenters cued participants eight times on five of the days. Participants demonstrated a higher proportion of completed calls on cued days than on un-cued days. These patterns were generally replicated in another study of 59 individuals with acquired brain injury (Gracey et al., 2017). However, the benefits of self-reflection training were only observed when one was actively receiving text message prompts (cf. section on External Memory Aids). In other words, the intervention increases transient monitoring processes rather than sustained self-awareness.

Cocktail mnemonic strategy interventions. Perhaps no single mnemonic strategy can simultaneously prevent errors at encoding, storage/consolidation, and retrieval stages. A solution might be to train participants on multiple mnemonics—a “strategy cocktail” (Table S1). The idea is to equip people with multiple mnemonic strategies to handle a diversity of prospective memory challenges (note that the distinction between strategy cocktails and combination interventions is that the latter is not limited to mnemonic strategies). The potential drawback is that the extensive training in mnemonic strategies might become overwhelming. Though many of the following cocktail mnemonic interventions focused on multiple aspects of memory, our review will only focus on the training of and impact on prospective memory.

McDougall’s (2000) intervention is a classic example of a cocktail mnemonic strategy. Across eight bi-weekly, 90-minute group sessions, 16 healthy, assisted-living older adults trained to use strategies for internal and external organization, visual imagery, concentration and relaxation, and health promotion. Participants demonstrated pre-to-post improvements on the Rivermead Behavioural Memory Test (RBMT), particularly on prospective memory items such as remembering to ask for a belonging, remembering to ask about an appointment, and remembering to deliver a message. Participants even indicated higher memory self-efficacy following the intervention.

Waldum, Dufault, and McDaniel (2016) had 62 healthy older adults (55-75) learn to use strategies for clock checking, task monitoring, mistake monitoring, and implementation intentions across separate weeks (total of 8 weeks). Participants in the intervention group showed significant improvements relative to an education-only control group for time-based prospective memory tasks, but not for event-based tasks. As with other cocktail mnemonic strategy interventions, it was unclear which specific strategy (or strategies) contributed to the prospective memory improvements or why only time-based prospective memory benefited when some of the trained strategies are known to benefit event-based prospective memory (e.g., implementation intentions).

In the longest intervention, Stringer (2011) trained participants to write, organize, picture, and rehearse memory items across 20 weeks (the EON-Mem intervention). Following EON-Mem, 33 cognitively impaired participants (mixed-etiology stroke, TBI, and brain injury) showed modest gains on time-based prospective memory tasks. Therefore, longer interventions are not necessarily more effective interventions, and focusing on a single strategy might ultimately yield better outcomes by avoiding "information overload."

Cognitive Training Interventions

Cognitive training interventions target retrospective memory and attentional processes that are theorized to underlie prospective memory performance (Table S3). For example, Costa and colleagues (2014) provided training on set-shifting (attention) skills to individuals with Parkinson's disease across 12 sessions that each lasted 45 minutes (three sessions per week). Control group participants only did language ability exercises, which were not expected to underlie prospective memory functioning. Participants who received set-shifting training improved performance on computerized prospective memory tasks, demonstrating larger post-training scores than the control group.

In one of the few comparative effectiveness trials, Richter and colleagues (2015) randomly assigned stroke and TBI participants to receive computerized cognitive training or a cocktail mnemonic strategy. The cognitive training involved nine, 30-minute sessions of computerized working memory tasks (remember and recall a series of cards in reverse order), semantic structuring tasks (organize and generate a category label for a list of words), and word fluency tasks (generate as many words as possible within a given category). The cocktail mnemonic strategy consisted of 1-hour group therapy sessions provided three times per week, in which participants practiced spaced retrieval, rehearsal of learning strategies, and cued recall of retrospective information. Cognitive training resulted in significantly better post-intervention RBMT prospective memory performance.

Some interventions have designed training protocols to specifically target prospective memory. Rose et al. (2015) showed that healthy older adults improved their prospective memory performance after participating in 12, 1-hour sessions over a month, in which they performed the computerized Virtual Week. The control groups included a no-contact group and a computerized music training program over a comparable training period. Older adults in the training condition showed improved performance on the Virtual Week task and on a naturalistic phone call-back task when compared to data collapsed across both control groups. As might be expected from a prospective memory-targeted training method, these training benefits did not transfer to laboratory-based measures that emphasized planning or working memory.

Some cognitive training interventions have used virtual reality to simulate the environments in which the cognitive processes will need to be used. Yip and Man (2013) provided virtual reality training on retrospective memory, inhibitory, and prospective memory processes. Individuals with brain injury practiced each cognitive domain in the context of a virtual convenience store, whereas the control group practiced reading and table game activities. The treatment phase consisted of 12 sessions (30-45 minutes each). The cognitive training group not only exhibited within-group improvement on prospective memory measures collected in the virtual setting, but also improved performance on laboratory-based prospective memory assessments (e.g., CAMPROMPT-CV) and a shopping list task in a real-world supermarket.

To summarize, few prospective memory studies have attempted cognitive training interventions, but these studies have all reported that training benefitted prospective memory. Given the small number of studies, it remains to be seen whether cognitive training can benefit individuals with amnestic MCI and AD, whether training can produce long-term effectiveness following the intervention (versus requiring booster sessions), and whether adults who have been "prescribed" training by a clinician will adhere to this treatment (training sessions) to the same degree as adults who opt-in to reearch studies.

External Memory Aid Interventions

Analog memory aids. Making a "to-do list" may be the most intuitive strategy for improving prospective memory (Table 2). Most adults have at some point used lists, calendars, and other analog memory aids (AMAs) to offload prospective and retrospective memories (Table S3; Risko & Gilbert, 2016). Groot and colleagues (2002) observed that, when given a prospective memory task, 46% of healthy controls and 39% of individuals with brain injury spontaneously adopted a note-taking strategy. Those who adopted note-taking strategies showed better performance than non-note-takers on the Cambridge Behaviour Prospective Memory Test (CBPMT), a test that includes several naturalistic time-based and event-based prospective memory tasks (e.g., giving messages to the experimenter).

However, not just any to-do list suffices. McKerracher et al. (2005) showed that when participants were asked to maintain a memory diary and complete prospective memory tasks for eight weeks, their prospective memory performance was markedly better when they kept the to-do list on their diary entry pages (75%) rather than when they kept the to-do list in a different section (5%). These findings indicate that the organization of information in an external memory aid is critical to prospective memory outcomes.

A limitation of AMAs is that individuals must still “remember to remember” to check their to-do lists, an ability that is thwarted when there are deficits in spontaneous retrieval and/or monitoring processes. Therefore, Fleming and colleagues (2005) added an alarm feature to help participants remember to check the details of their to-do list, finding that the alarm improved its efficacy. Their findings showed that it is necessary to train people to practice regular checks of their to-do lists or, alternatively, to include electronic-based reminder systems that remove the need to “remember to remember.” We next turn our attention to such electronic-based systems.

Electronic memory aids. Electronic memory aids (EMAs) more fully remove the need to “remember to remember.” EMAs can encode/store detailed retrospective information such as appointments and to-do lists (like AMAs), and also assist with retrieval (unlike AMAs). As one example, mobile phones allow people to program auditory and tactile notifications to check a to-do list at specific times of day.

Several studies have tested the efficacy of EMA devices (Table S4). For example, two studies trained individuals with brain injury (or mixed etiology) to use an electronic voice organizer over the course of a multi-week control-experimental-control design (Van de Broek et al., 2000; Yasuda et al., 2002). The voice organizer in these studies was verbally programmed with a date and time to give an auditory alert to deliver task messages. Both studies showed that the clinical sample completed more everyday prospective memory tasks (e.g., delivering messages) while using the EMA device (76%) than during control weeks (10%-21%; Van de Broek et al.). Thus, individuals with mixed etiology neurological complaints can rapidly adopt EMAs to support their everyday prospective memory tasks.

A potential concern with EMA interventions is that the EMA device might become lost. To circumvent this problem, Lemoncello and colleagues (2011) installed a device that provided reminders via the participant's home television. In a within-group crossover experiment, individuals with brain injury showed a significantly higher rate of remembering to complete voicemail tasks while receiving television-based reminders (72%) than when relying on their own reminder strategies (43%). Most people do not have access to television-driven reminders, but, theoretically, smart home personal assistant systems such as Google Assistant and Amazon Alexa could serve similar functions (Reis, Paulino, Paredes, & Barroso, 2017).

Due to privacy concerns, many people have not adopted Amazon Alexa or other "always-on" home personal assistant systems (Neves & Vetere, 2019). By contrast, more than a billion people globally have access to digital calendars, which can provide reminders across computers, tablets, smartphones, and related devices. Using a randomized crossover design, McDonald et al. (2011) tested whether the most popular digital calendar, Google Calendar, could support prospective memory in participants with brain injury. These participants and their caregivers first identified everyday prospective memory tasks to use as targets during the study. Then they were trained how to use either Google Calendar or a standard diary during a 90-minute session. During the 5 weeks of using the standard diary, participants completed 55% of their prospective memory tasks; during the 5 weeks of using Google Calendar, participants completed 82% of their tasks. Nearly every participant (92%) reported a desire to continue to use Google Calendar after the study, an impressive distinction from the mixed long-term adherence rates seen with mnemonic strategies.

Digital calendars are effective specifically because of their alert reminder systems (rather than for their ability to organize information). Ferguson, Friedland, and Woodberry (2015) had participants with brain injury use a smartphone-synced digital calendar (Google or Hotmail) for four weeks. Using a crossover design, they manipulated whether alerts were enabled or disabled.

The participants with brain injury showed consistently better prospective memory performance during alert-enabled weeks (71%-74%) than alert-disabled weeks (41%-53%).

There is currently a debate as to whether EMAs can be effectively trained and used in all older adults or whether age-associated technology aversion prevents some older adults from adopting EMAs (Neves & Vetere, 2019). Consider, for example, Bos, Babbage, and Leathem's (2017) anecdote of one individual with brain injury from a single-case series smartphone EMA study (n=9). This individual stated that phones should only be used "for phone functions," and consequently, did not use the reminder functions of the smartphone during the study, leading to an overall decline in prospective memory performance. Of course, not all participants had this reaction; another participant experienced initial difficulty and frustration with the EMA, but after adhering to the training and practicing using the device, he/she self-reported a positive experience with the device and showed prospective memory improvements. If these anecdotes are generalizable, then future EMA training in older adults and clinical groups might be improved when paired with growth mindset training (Dweck, 2008).

Over the last decade, technology aversion has been a significant hurdle for EMA research in older adults. The critical question is whether this age-related "digital divide" is a cohort effect such that most old-old adults will own smartphones in 1-2 decades or, alternatively, whether age- and disease-related cognitive impairments prevent the use of technology (Benge & Scullin, 2020; Niehaves & Plattfaut, 2014). Two survey studies inform this question. On the one hand, only 1 in 10 older adults used smartphones in 2011, but this number skyrocketed over the following six years to over half of adults in their 50s-60s (Pew Research Center, 2017). More recently, 75% of participants at a neuropsychology clinic reported owning a smartphone, which was significantly lower than the observed 100% ownership rate in their age-similar spouse caregivers (Benge et al., 2020). Smartphone ownership, however, was particularly reduced in individuals with suspected geriatric cognitive disorders such as AD. While the latter data indicate that cognitive impairment *reduces* one's ability to use technology, the data do not indicate that EMAs cannot be used in such clinical conditions. For example, in the same study, 55% of caregivers reported to using their smartphone to support caregiver tasks such as prospective remembering, and 30% of the participants reported using digital calendar and electronic reminder apps every day, approximately three times as likely as an age-matched healthy control group (Benge et al., 2020). Thus, while technology use is negatively associated with age and disease, technology aversion is not universal amongst older adults or a deterministic feature of cognitive disorders.

Combination Interventions

Earlier, we introduced cocktail mnemonic interventions in which individuals are taught multiple mnemonic strategies. Combination interventions take a similar philosophy— "more is better"—but are distinct in that they cut *across* intervention categories. These interventions are Herculean endeavors, attempting to address deficits in most/all mechanisms of prospective memory impairment across many weeks or months (cf. single-session targeted approaches, see Table 2).

The efficacy of combination interventions has most frequently been tested via group therapies (Table S5). For instance, Troyer (2001) administered a group therapy that offered education about aging and health. Over the following weekly sessions, they introduced a set of mnemonic strategies (e.g., spaced retrieval, visualization, semantic association, and elaboration) and classic AMA offloading strategies (e.g., writing information down). Following the combination intervention, participants improved their performance on remembering to call the experimenter at specific days/times, though participants did not improve on any other memory tasks or perceive that their prospective memory functioning was improving. As with most combination intervention studies, no data were available for which, if any, of the trained strategies were adopted.

The most investigated combination intervention, detailed by Radford et al. (2010), provided prospective memory training across six weekly, 2-hour group sessions, including homework based on each week's instructional topic. During each intervention week, group leaders introduced topics in memory education (e.g., types of memory including prospective memory), relevant lifestyle habits (e.g., diet), mnemonic strategies (e.g., spaced rehearsal), AMAs (e.g., note-taking), and EMAs (e.g., alarms). Across three studies of individuals with epilepsy, TBI, or stroke, Radford and colleagues found either no overall significant effect of the intervention (Miller & Radford, 2014) or benefits limited to subjective measures with temporary or no corresponding improvement to objective measures (Radford et al., 2011; 2012). The dissonance between subjective and objective outcomes in these studies might reflect expectation effects (Boot, Simons, Stothart, & Stutts, 2013), though they could also indicate that some aspects of the intervention were beneficial to some aspects of everyday prospective memory (i.e., in tasks that were not dictated by the experimenter).

Another series of studies provided further evidence of inconsistent effectiveness in group-style combination interventions. Twamley and colleagues (2012) found that teaching external memory aid and mnemonic strategies during a group therapy produced marginally significant improvements on the Memory for Intentions Test (MIST; Raskin, 2009) for individuals with primary psychotic disorders. When a similar group therapy was provided to veterans with TBI (Twamley et al., 2014, 2015), there was a disconnect between the laboratory and 24-hour components of the MIST. The laboratory summary scores initially showed nonsignificant effects at the 3-month post-test but improved to a moderate effect size (d=.55) by the 12-month follow-up. Conversely, the 24-hour delayed call-in component showed significant prospective memory improvement at post-test and 6-month follow-up, but this effect was no longer significant by the 12-month follow-up. In other words, therapy training appeared to elicit long-term change in laboratory-based measures of prospective memory, but at-home measures indicated that the initial improvement in naturalistic-based measures declined over time.

For combination interventions to be more effective, they might need to include family caregivers. For example, consider the two combination intervention studies by Kinsella and colleagues (2009, 2016). In one study of amnestic MCI participants, six weeks of group therapy did not improve performance on the Cambridge Prospective Memory Test (CAMPROMPT; Kinsella et al., 2016). However, when individuals with amnestic MCI and their caregivers were randomly assigned to either a waitlist control group or a combination intervention (memory education, mnemonic strategies, organizational skills, external memory aids), the participants with MCI successfully increased their performance on prospective memory tasks such as reminding experimenters to provide appointment cards. These benefits persisted at 2-week and 4-week follow-up assessments. Unfortunately, self-reported usage of trained strategies significantly decreased by the 4-week follow-up, suggesting that even a caregiver-inclusive combination intervention might produce only temporary gains in functioning for adults with MCI (cf. high acceptability/adherence rates after 5 weeks of training only to use Google Calendar; McDonald et al., 2011).

Meta-Analysis Results on Intervention Efficacy

Based on inferences drawn from the systematic review, we tested three hypotheses on intervention efficacy: 1) prospective memory functioning can be improved, even in clinical groups; 2) targeted (single mechanism) interventions are as effective as combination interventions; and 3) external memory aids are the most effective intervention type. Figure 2a displays the overall meta-analytic data, Table 3 separates the data by study design, and Table 4 separates the data by healthy versus clinical samples.

The overall model showed that prospective memory interventions improve performance in healthy adults (Figure 2a; $g = .585$, $K=22$, $Z=4.636$, $p < .001$, $Q = 28.526$), and even in clinical groups (Table 4; $g = .479$, $K=42$, $Z=5.655$, $p < .001$, $Q = 55.967$). Effect sizes were highly similar when limiting to studies that randomly assigned participants to treatment groups and to studies that focused on prospective memory outcomes (rather than memory complaints in general; Table 3). Targeted interventions tended to be more effective than combination interventions, the latter showing the smallest benefit to prospective memory ($g = .254$, $K=14$, $Z=3.093$, $p = .002$, $Q = 16.666$), particularly in studies of clinical groups ($g = .162$, $K=9$, $Z=1.361$, $p=.173$, $Q=7.452$). Furthermore, external memory aids showed a large effect size ($g = .805$, $K=13$, $Z=3.836$, $p <.001$, $Q = 14.562$), greater than both mnemonic strategies ($g = .504$, $K=27$, $Z=3.719$, $p < .001$, $Q = 33.376$) and cognitive training ($g = .579$, $K=4$, $Z=3.400$, $p = .001$, $Q = 0.479$). Thus, when revisiting our three hypotheses, we found that: 1) prospective memory can be improved in older adults and clinical groups, 2) simple targeted interventions are more favorable than complex interventions in clinical groups, and 3) training individuals to offload their intentions by using external memory aids might yield the strongest benefits.

Ecological Validity of Prospective Memory Assessments

To this point, we have seen several examples of interventions demonstrating significant benefits to laboratory-based prospective memory assessments with minimal or no benefits to everyday prospective memory assessments. These patterns are important because one cannot assume that an intervention will transfer well to the dynamic challenges of daily life until the intervention has been tested in that context. Inter-rater reliability of the ecological validity of prospective memory rating scale was assessed by having two of the authors (WJ and JB) perform independent ratings of the included studies. A linear, weighted Cohen's k coefficient was obtained to account for the ordinal nature of the ratings. There was a high rate of agreement (k=.84) between independent raters, with all differences resolved following discussion.

Figure 2b shows that the majority of intervention studies have used prospective memory assessments with low to moderate ecological validity (M = 2.99, 95% CI: 2.70–3.27). Ecological validity ratings were low for mnemonic strategy (M = 2.43, 95% CI: 2.08–2.78) and cognitive training (M = 2.40, 95% CI: 1.47-3.33) intervention studies relative to external memory aid (M = 4.05, 95% CI: 3.58-4.53) and combination intervention studies (M = 3.14, 95% CI: 2.59-3.70), $F(3, 69) = 10.68$, $p < .001$, η_p^2=.32. Combination intervention studies showed nominally better ratings than cognitive training studies ($t(17)$=1.29, p=.22) and significantly better ratings than mnemonic strategy studies ($t(47)$=2.32, p=.02; the latter two did not differ: $t(38)$=0.06, p=.95). Importantly, external memory aid studies showed substantially higher ecological validity than mnemonic strategy, $t(52)$=5.62, p<.001, cognitive training, $t(22)$=2.81, p = .01, and combination, $t(31)$=2.26, p =.03, interventions.

The likelihood of using at-home assessments of prospective memory (ratings of ≥4) significantly differed across categories, Odds Ratio (OR)=2.36, 95% CI: 1.50-3.71, p<.001 (Figure 2b). At-home assessments were used in 84% of external memory aid studies, a dramatically higher proportion than the 14% of mnemonic strategy studies, OR=5.66, 95% CI: 2.60-12.31, p<.001, the 20% of cognitive training studies, OR=21.33, 95%CI: 1.73-263.67, p=.017, and the 50% of combination intervention studies, OR=5.33, 95% CI: 1.06-26.90, p=.043.

Participant-generated prospective memory tasks (rating of 5) were used in 42% of external memory aid studies, but almost never in mnemonic strategy (3%; OR=4.97, 95% CI: 1.67-14.84, p=.004), cognitive training (0%; Fisher's Exact p=.13), or combination studies (7%; OR=9.46, 95% CI: 1.02-87.80, p=.048; Figure 2b). Clearly, increasing the ecological validity of prospective memory assessments is needed for future intervention studies.

Study Design Considerations

The literature on prospective memory interventions is marked by considerable design heterogeneity. Some of the key factors are illustrated in Figure 3 (and detailed in Table S1). Although combination interventions and mnemonic strategy interventions have used reasonable sample sizes, the samples have generally been smaller in cognitive training studies and very small in external memory aid studies (Figure 3a), $F(3, 69)=3.73$, $MSE=4747.13$, $p=.015$, $\eta_p^2=.140$. Only a single prospective memory intervention study has included N>500 (Zimmerman & Meier, 2010). Furthermore, Figure 3b shows that participants were likely to be randomized to treatment conditions in mnemonic strategy, cognitive training, and combination interventions, but not in external memory aid studies, $X^2(3)=17.09$, $p<.001$, $\phi=.48$. Figure 3c shows that fewer than ¼ of all studies included a follow-up test (beyond immediate post-intervention test) to determine whether the benefits were durable. Though there was a trend for a longer follow-up period for combination interventions than the other three intervention types, this pattern was not significant, $F(3,69)=2.41$, $MSE=368.02$, $p=.074$, $\eta_p^2=.095$ (individual comparisons were also nonsignificant, ps> .10).

Pragmatic Considerations

Time, monetary, and cognitive effort costs can limit the feasibility of an intervention or how broadly that intervention can be implemented. For example, extended training schedules increase the likelihood of attrition and add direct and indirect monetary costs (increased travel, more clinical supervision hours, etc.). Such costs and consequences might be exacerbated by advancing disease severity, reduced functional capacity, and the presence of mental health comorbidities (e.g., depression and anxiety). Table 2 summarizes the estimated costs for each intervention category.

The primary sources of monetary cost for mnemonic strategies, cognitive training, and combination interventions come from the number of session visits needed for effective training. Although mnemonic strategies such as implementation intentions often avoid this cost by requiring only minutes for training, cocktail mnemonic interventions, cognitive training, and combination interventions tend to require several sessions per week for at least one month. External memory aid strategies can be trained in one or two sessions, but EMAs can confer additional costs such as purchasing the EMA device (e.g., smartphone, home assistant), paying digital service fees (e.g., data plans), and learning new technology (cognitively demanding for persons with AD; Benge et al., 2020). For new users, these costs might be prohibitive, though this perception is likely to change over time as more older adults switch to owning smartphones for social and entertainment purposes (Benge & Scullin, 2020).

General Discussion

Supporting independent living in an aging population requires access to cost-effective and accessible prospective memory interventions. Given the minimal evidence that pharmacological agents can improve prospective memory specifically (Costa et al., 2008; Fuermaier et al., 2016), or memory symptoms in general (Cacabelos, 2007; Feldman, 2003; Johannsen, 2006; Roman et al., 2005), clinical options are currently limited to behavioral interventions. Fortunately, our systematic review and accompanying meta-analysis indicated that many behavioral interventions—mnemonic strategies, cognitive training, and external memory aids—can alleviate prospective memory impairments in healthy older adults and clinical groups. These benefits were typically captured by objective, laboratory-based measures of prospective memory, though subjective responses from participants and caregivers also indicated that prospective memory interventions can provide a meaningful, positive shift in everyday quality of life and memory functioning. In the following sections, we will summarize the advantages and disadvantages of each intervention, as well as compare the interventions on efficacy, cost, feasibility/acceptability, and use of ecological measures. We will conclude with a recommendation on which intervention to most frequently use, when to use it, and what still needs to be done to optimize prospective memory interventions for everyday use.

Advantages and Disadvantages by Intervention Category

Mnemonic strategy interventions. The literature provides convincing evidence that mnemonic strategies acutely benefit prospective memory performance in healthy adults and clinical groups. However, one general take-away was that mnemonic strategies sometimes showed rapidly declining strategy use/adherence when no longer prompted by experimenters (Gracey et al., 2017; Insel et al., 2016). If mnemonic strategies are going to be a viable solution for prospective memory in clinical groups, then future interventions will need to leverage theories of behavioral change to augment the likelihood of continued engagement with their mnemonic strategy (Chapman, 2019). A second general take-away was that even though implementation intentions have long been considered a “gold standard” strategy, the literature suggested that spaced retrieval was more effective for clinical groups (note that too few studies were available for a meta-analytic comparison). One possible explanation is that implementation intention training is too brief and/or too often limited to a single context to produce lasting benefits in clinical groups. Clearly, there is a need for comparative effectiveness trials to determine whether spaced retrieval outperforms implementation intentions (with and without booster practice) in healthy adults or clinical groups.

Cognitive training interventions. Cognitive training studies also displayed efficacy for improving prospective memory, and were perhaps most effective when prospective memory processes were specifically trained (rather than general attention/memory processes). However, some have expressed concerns that the control groups in cognitive training studies do not eliminate placebo effects and others have cautioned that cognitive training might not transfer to functioning on everyday tasks (e.g., Boot et al., 2013). We echo these concerns, but we also note that such criticisms could be levied against many existing mnemonic strategy, external memory aid, and combination studies. Rather than try to solve the riddle of creating the perfect control group for interventions that have established efficacy, our recommendation is that researchers test comparative efficacy (e.g., cognitive training versus implementation intentions) to determine the best intervention for specific clinical conditions.

External memory aid interventions. External memory aids showed the strongest improvements to prospective memory performance in clinical groups and in daily life situations. For EMAs to be effective, the device must have an alert-reminder system, be portable (for maximal access to reminders), have easy physical interface controls (for individuals with impaired manual dexterity), and have a clear display (and auditory clarity for individuals with hearing impairments). Programming the EMA needs to be simple, and there should be few notifications and on-screen prompts to avoid overwhelming individuals who are unfamiliar with technology. While the future is bright for EMAs, future research needs to address issues of small sample sizes, single-group and case study designs, and potential selection biases (i.e., people who are technology averse are unlikely to participate), all of which can inflate effect sizes. Furthermore, much of the work on EMAs has focused on middle-aged adults with brain injury (approximately ¾ of EMA studies), and additional work is required to determine whether EMAs can be a solution for the prospective memory difficulties of persons with AD and related dementias (King & Dwan, 2019).

Combination interventions. Combination interventions are the Swiss-army knife approach to supporting prospective memory, attempting to equip individuals with an array of tools that they can customize to their needs. The combination interventions in this meta-analysis showed mildly effective results for healthy older adults (Table 4; for evidence for larger effects, see Henry et al., in revision). But, the combination interventions did not benefit individuals with neurocognitive disorders (i.e., the 95% confidence interval overlapped with zero; Table 4).

We see three reasons why longer and more detailed training does not mean larger and more sustained benefits. First, by packaging multiple interventions together, individuals might not have the opportunity to practice specific strategies to a level of mastery. Second, with so many options, individuals might lose interest or become overwhelmed, particularly if they have neurocognitive disorders. Third, simply teaching individuals about compensatory strategies does not ensure that they understand how to select the strategy that is best for them or best for the situation (caregivers might help with this selection though; Kinsella et al., 2009). Overall, combination interventions depict the clinical uncertainty surrounding prospective memory treatment, where any available intervention has seemed just as likely as the next to improve prospective memory.

Intervention Comparisons on Efficacy, Cost, and Feasibility/Acceptability

For an intervention to be broadly implemented it must show efficacy in laboratory and naturalistic contexts, reasonable costs (time, money, cognitive effort), and feasibility/acceptability (including long term adherence).

First, consider overall efficacy. We observed moderate-to-high efficacy for the mnemonic strategies, external memory aids, and cognitive training interventions, with combination interventions having only a small overall effect (Figure 2a). Review of studies within the cognitive training category indicated that benefits were greatest when the training was specific to prospective memory situations. Within the external memory aid category, alert-enabled external memory aids (e.g., Google Calendar) outperformed traditional AMAs (e.g., to-do lists). Within the mnemonic strategy category, several interventions produced benefits in healthy adults, but only spaced retrieval consistently yielded positive outcomes in clinical groups. Therefore, based upon the systematic review and the meta-analytic evidence, digital calendars, spaced retrieval, and implementation intentions showed the most efficacy. It is important to recognize that efficacy estimates were based upon tests during the intervention interval (or immediately after), and only 22% of studies included follow-up measures to examine effect durability of prospective memory measures (Figure 3c). Of the 16 studies reporting follow-up data, 9 (56%) reported durability of intervention-related performance increases, but this represented too few of cases to meaningfully compare across intervention categories. However, it is possible to meaningfully compare the intervention categories on their use of ecologically valid prospective memory assessments (Figure 2b). Currently, there is minimal evidence supporting the transferability of mnemonic strategy or cognitive training intervention effects to naturalistic environments, because those studies were almost exclusively conducted in laboratory settings. By contrast, nearly all external memory aid studies were conducted in naturalistic settings.

Second, consider the cost of each intervention type. Interventions that maintain efficacy while minimizing time costs and cognitive demands offer an advantage. For example, participants can learn how to use an implementation intention in minutes and external memory aids can be trained across only 1-2 sessions. By contrast, cognitive training, cocktail mnemonic interventions, and combination interventions require extensive time and effort commitments across several weeks or months (Table 2). Healthcare monetary costs would also be associated with total time commitment because individuals might be charged for each clinical/training session. By this logic, cognitive training and combination interventions would incur the largest monetary costs. Mnemonic strategies would require minimal monetary costs, unless booster training sessions are needed to encourage sustained adherence. External memory aids would also require fewer training-session costs than cognitive training or combination interventions (but more time costs than mnemonic strategies). However, EMA devices such as smartphones are limited in being expensive and cognitively demanding for some people, unless they are already owned and used for other reasons (as is often the case for smartphones, Pew Research Center, 2017). Because many EMAs might not currently qualify for insurance coverage as medical devices, these costs would be out-of-pocket if individuals are not trained to use existing devices and free services (e.g., Google Calendar).

Third, consider the feasibility, acceptability, and adherence factors. Cognitive training and combination interventions can be done, but because of their extensive time requirements they are less feasible than mnemonic strategy and external memory aid interventions. Distinguishing the mnemonic strategy and external memory aid interventions is more complex. Mnemonic strategies are acceptable to participants in intervention studies (i.e., usage is high at immediate testing), but usage appears to decline across time (i.e., long term adherence is questionable). External memory aids, or at least digital calendars, showed a high likelihood of continued adherence even at the conclusion of a study (McDonald et al., 2011), but EMA interventions are not acceptable to technology-averse individuals (Benge et al., 2020). A general dilemma is that very few prospective memory studies have measured or reported adherence, real world transfer, or long-term efficacy. Such measures must be included in future comparative efficacy trials to determine whether the investment—in any intervention—is worth the costs.

Overall Recommendation

The ultimate goal of prospective memory interventions should be to adapt the intervention type to specific cognitive disorders (or to the individual, i.e., "precision medicine"). Until such precision can be achieved, a one-size-fits-all recommendation is still needed. Based on efficacy, ecological validity (of the assessments), feasibility, and estimated likelihood of long-term adherence, we recommend that individuals use alert-enabled external memory aids to preserve their prospective memory functioning. Writing a prospective memory reminder in a notebook, paper calendar, or analog planner has long served the purpose of offloading memories and intentions. With technological developments, EMAs relieve the need to actively monitor or rely on spontaneous retrieval. The technology that supports these automatic reminders is already widely accessible outside of the clinical scope, and technological developments are making these applications increasingly viable for older adult groups (i.e., simplified interface, improved voice recognition). This overall recommendation does not dismiss the concerns over previous study design limitations or some older adults' technology aversion; instead, it highlights that the value of EMAs outweighs its currently known weaknesses.

To address the issue of technology aversion, we see two general pathways for future research and device/software engineering. First, EMAs need to be developed with age- and clinical-group user-friendliness. This development should go beyond just improving the visibility and audibility of the device, such as by incorporating solutions for impaired manual dexterity. Because many people suffering from prospective memory impairments also suffer from comorbid attention and retrospective memory impairments (e.g., brain injury), these devices and the apps tailored for them should reduce display clutter and avoid rapid screen transitions. Second, researchers need to develop effective training techniques to instruct cognitive- or memory-impaired individuals in the use of EMAs. These training methods must consider how individuals will apply the device to their daily life. The key elements for the success of these training strategies will be to include caregivers and to guide participants in recognizing how the EMA will improve their daily lives (to overcome technology aversion). Initial training might center on a critical set of tasks for personal maintenance, but long-term training goals should emphasize the application of the strategy to recreational and social activities to maximize long-term adherence.

Conclusions

Reducing the financial cost and caregiver burden of cognitively-impairing conditions hinges on promoting independent living in individuals with neurocognitive disorders. Implementation intentions, spaced retrieval, and cognitive training can acutely boost prospective memory functioning. However, this systematic review and meta-analysis identified that the greatest promise for supporting prospective memory comes from external memory aids. Even as technology is still progressing (to be “age friendly”), external memory aid functionality and device training methods provide the most comprehensive, cost-effective means of prospective memory support. Ideally, future clinical trials will identify the optimal strategy for clinicians to provide targeted training, including how to overcome technological aversion even in the oldest participants in a sample. If these aims are successfully achieved, then cognitively impaired individuals will be empowered by the knowledge that the tool that they need to manage their prospective memory difficulties has been by their sides—or in their pockets—all along.

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Table 1.

Ecological Validity Rating Criteria

Validity Rank	Rating Criteria
1	PM assessed by self-report/questionnaires
2	PM assessed by researcher-created tasks performed in the laboratory setting (e.g., button-press tasks, day-of-week tasks, etc.)
3	PM assessed by a selection or simulation of tasks from participants' daily activities which are performed in the laboratory setting (e.g., Virtual Week, virtual reality simulations, etc.)
4	PM assessed by researcher-created tasks performed "at-home" or otherwise outside of the laboratory (e.g., scheduled phone calls, mailed forms, etc.)
5	PM assessed by tasks selected from participants' daily activities which participants perform "at-home"

Table 2.

Summary of Prospective Memory Intervention Categories, including Estimates of Time, Monetary, and Cognitive Costs

	Mnemonic Strategies	Cognitive Training	External Memory Aids	Combination
Number of Studies	35	5	19	14
n	2315	162	177	1095
Targeted Cognitive Process	Strategies selectively promote spontaneous retrieval or monitoring	Strengthens monitoring processes via practice in targeted cognitive domains	Circumvents monitoring and spontaneous retrieval via intention offloading	Nonselective, typically atheoretical
Time Cost Estimate	Low - Moderate	High	Low - Moderate	High
Time Cost Sources	Mix of 1 session and multi-week training schedules	Multi-week training schedules	1-2 training |sessions	Multi-week training schedules
Monetary Cost Estimate	Very Low - Moderate	Moderate	Moderate	Moderate
Monetary Cost Sources	Clinical sessions	Clinical sessions	Clinical sessions; device cost; service fees	Clinical sessions
Cognitive Cost	Low - Moderate	High	Low to High, due to technology experience	High
Cognitive Cost Sources	Effort at encoding and/or retrieval	Effortful attention/working memory training	Offloads cognitive demands, but may be difficult to initially learn	Learning many strategies and exerting effort at encoding/retrieval

Abbreviations: II=implementation intentions

Table 3.

Meta-analysis of prospective memory performance across intervention categories

	K	Hedges's g	Z	*p*	95% CI	*Q*
Mnemonic Strategy	27	0.504	3.719	<0.001	(0.238, 0.769)	33.376
Cognitive Training	4	0.579	3.400	0.001	(0.245, 0.912)	0.479
External Memory Aids	13	0.805	3.836	<0.001	(0.394, 1.216)	14.562
Combination	14	0.254	3.093	0.002	(0.093, 0.415)	16.666
Overall	58	0.398	6.411	<0.001	(0.276, 0.519)	73.658
Randomized Controlled Trials Only						
Mnemonic Strategy	23	0.453	2.989	0.003	(0.156, 0.750)	29.590
Cognitive Training	4	0.579	3.400	0.001	(0.245, 0.912)	0.479
External Memory Aids	4	0.756	2.192	0.028	(0.080, 1.432)	4.033
Combination	12	0.252	3.070	0.002	(0.091, 0.412)	13.839
Overall	43	0.355	5.444	<0.001	(0.227, 0.483)	53.027
Randomized Controlled Trials & Focused on Prospective Memory Only						
Mnemonic Strategy	22	0.427	2.767	0.006	(0.125, 0.730)	28.663
Cognitive Training	3	0.639	3.215	0.001	(0.249, 1.029)	0.134
External Memory Aids	4	0.756	2.192	0.028	(0.080, 1.432)	4.033
Combination	4	0.276	2.664	0.008	(0.073, 0.479)	4.279
Overall	33	0.392	5.092	<0.001	(0.241, 0.543)	41.089

Table 4.

Meta-analysis of prospective memory performance across neurocognitive status

	K	Hedges's g	Z	*p*	95% CI	*Q*
All Categories						
Healthy	22	0.585	4.636	<0.001	(0.338, 0.832)	28.526
Clinical	42	0.479	5.655	<0.001	(0.313, 0.645)	55.967
Overall	64	0.512	7.279	<0.001	(0.374, 0.650)	84.978
Mnemonic Strategy						
Healthy	14	0.594	2.960	0.003	(0.201, 0.988)	16.254
Clinical	17	0.545	3.751	<0.001	(0.260, 0.829)	21.385
Overall	31	0.562	4.774	<0.001	(0.331, 0.792)	37.679
Cognitive Training						
Healthy	1	-	-	-	-	-
Clinical	3	0.538	2.569	0.010	(0.127, 0.948)	0.366
Overall	4	0.579	3.400	0.001	(0.245, 0.912)	0.479
External Memory Aids						
Healthy	1	-	-	-	-	-
Clinical	13	0.797	3.757	<0.001	(0.381, 1.213)	14.430
Overall	14	0.834	4.477	<0.001	(0.469, 1.199)	14.559
Combination						
Healthy	6	0.423	3.021	0.003	(0.149, 0.697)	6.074
Clinical	9	0.162	1.361	0.173	(-0.071, 0.394)	7.452
Overall	15	0.271	2.991	0.003	(0.093, 0.448)	15.555

Note: External Memory Aids and Cognitive Training interventions had too few healthy groups for comparison; *K* presented for healthy groups in both categories.

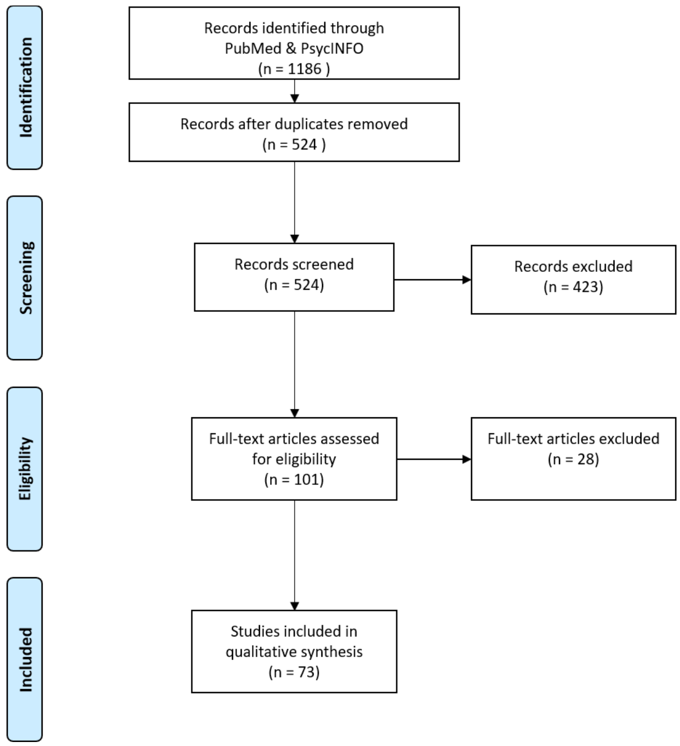

Figure 1. Inclusion flowchart detailing articles remaining after each phase of inclusion criteria checks.

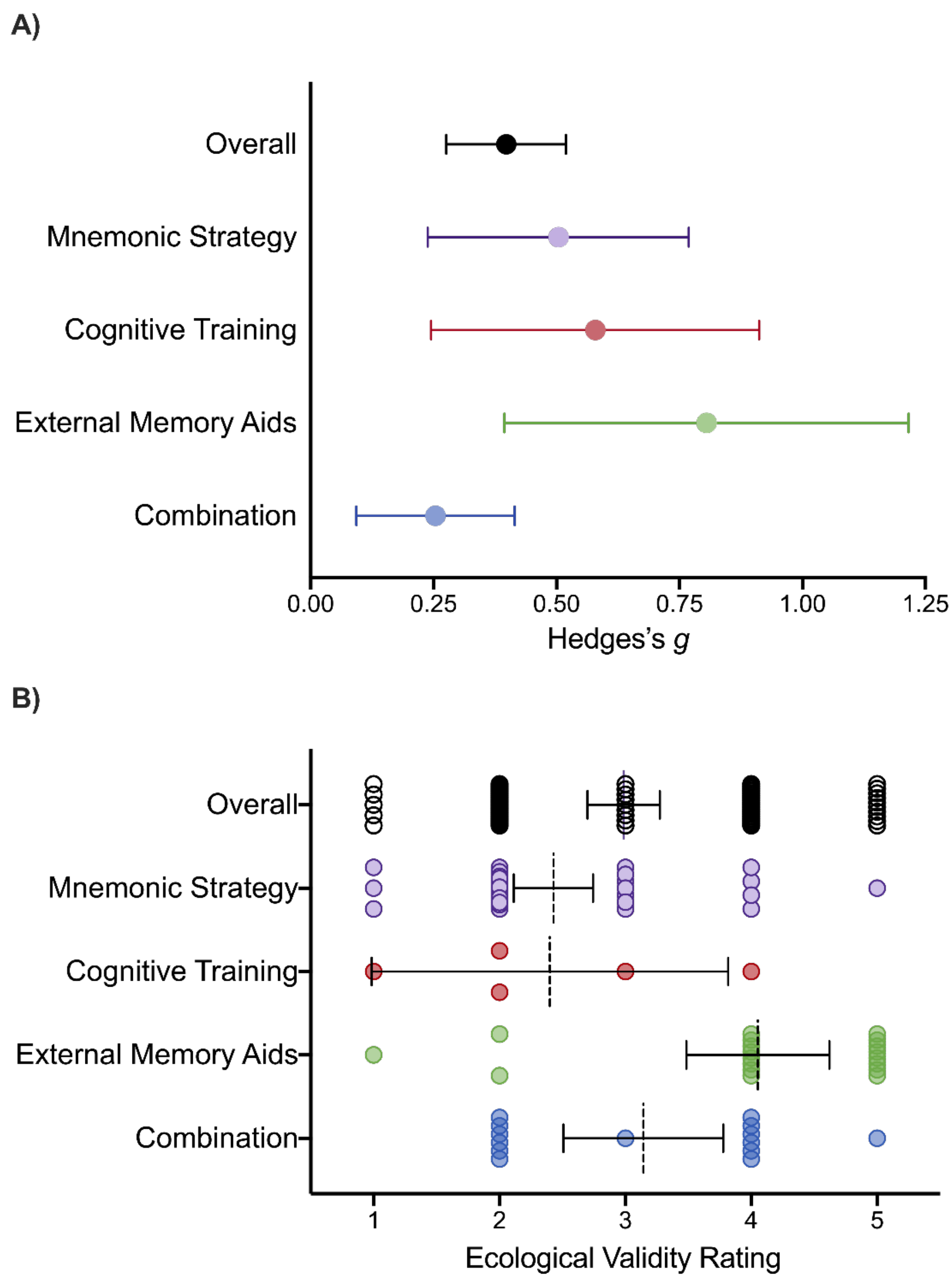

Figure 2. Comparison of intervention categories on intervention efficacy (A) and ecological validity ratings (B). Data are shown as mean with 95% confidence intervals. For B, lower ratings indicate fewer naturalistic methods in the prospective memory assessment, and individual study points are plotted to illustrate the distribution.

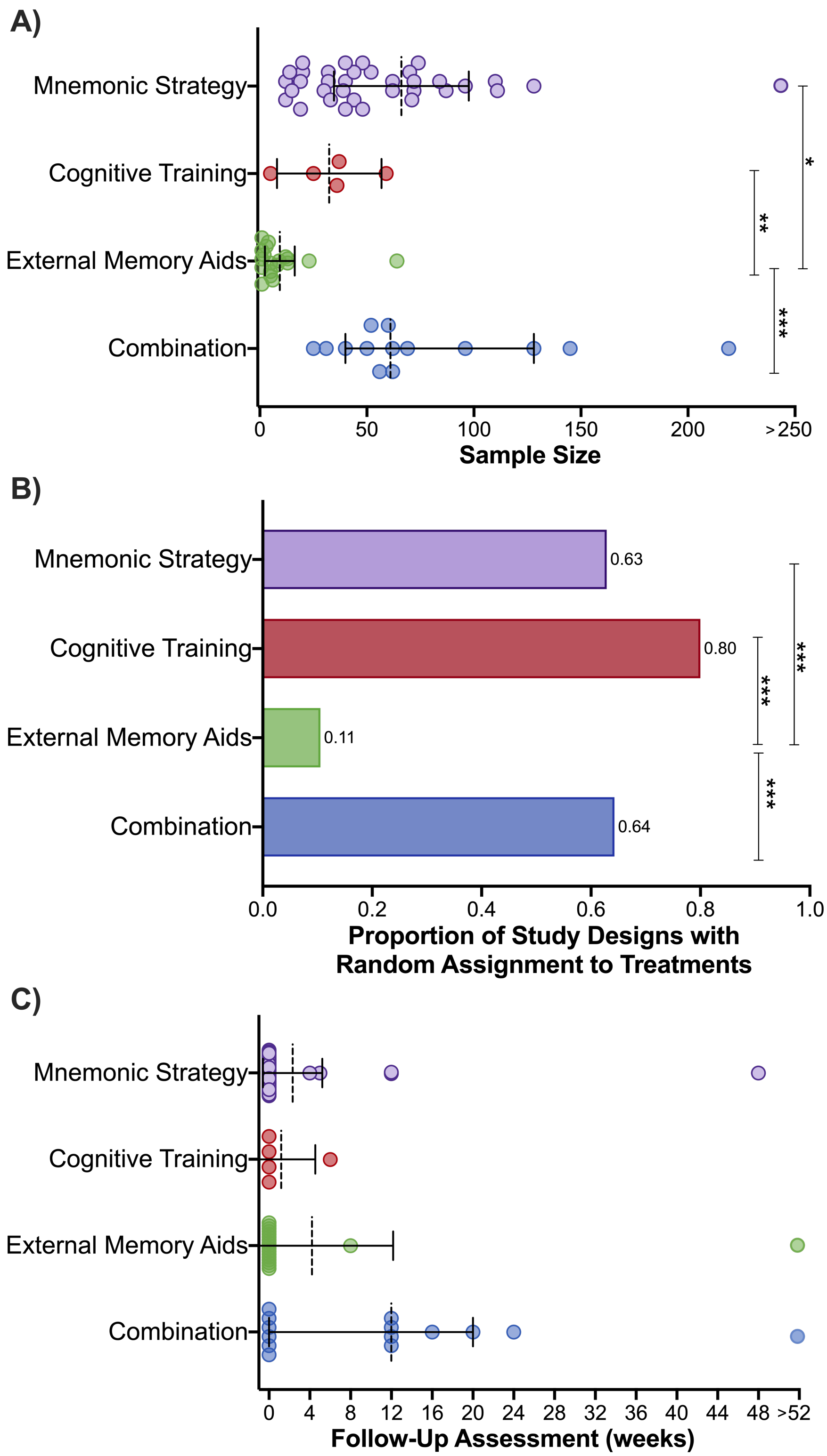

Figure 3. Comparison of sample size (A), proportion of randomized study designs (B), and follow-up duration (C) across intervention categories. The data in A and C are plotted as median value (vertical dashed line) with a 95% confidence interval (CI). * indicates *p*<.05, ** indicates *p*<.01, *** indicates *p*<.001.

Online Supplemental Materials

Preserving Prospective Memory in Daily Life: A Systematic Review and Meta-analysis of Mnemonic Strategy, Cognitive Training, External Memory Aid, and Combination Interventions

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Table S1. *Prospective Memory Study Designs*. The column "PM-Focused" indicates whether the intervention targeted PM specifically; the column "Training Duration" refers to approximately how long participants were actively trained on the intervention; the column "Intervention Duration" refers to how long participants were expected to use the intervention; and the column "PM durability" refers to whether longer-term follow-up testing occurred after the intervention duration was completed.

Studies	Intervention Category	Study Design	Control	PM-Focused	Training Duration	Intervention Duration	PM Follow-up
Andrews et al., 1996	Mnemonic	RCT	Placebo	Mixed	30 Min	1 Mo	N/A
Baldwin et al., 2015	EMA	Single Case	Baseline	Yes	1 Wk	6 Wk	N/A
Bos et al., 2017	EMA	Single Case Series	Baseline	Yes	2 Wk	6 Wk	N/A
Brom et al, 2014	Mnemonic	RCT	No Treatment	Yes	1 Hr	1 Week	N/A
Bugg et al., 2013	Mnemonic	RCT	No Treatment	Yes	30 Sec	<1 Hr	N/A
Burkard et al., 2014	Mnemonic	Single Group Experiment	Pretest-Posttest	Yes	3 Wk	5 Wk	5 Wk
Burkard et al., 2014	Mnemonic	RCT	Crossover	Mixed	30 Sec	<1 Hr	N/A
Burkard et al., 2014	Mnemonic	RCT	No Treatment	Yes	30 Sec	1-1.5 Hrs	N/A
Chasteen et al., 2001	Mnemonic	RCT	No Treatment	Yes	45 Sec	<1 Hr	N/A
Costa et al., 2014	CogTraining	RCT	Placebo	Yes	4 Wk	4 Wk	N/A
Cruz et al., 2016	EMA	Single Case Series	Baseline	Yes	Single Session; Not specified	3 Mo	N/A
El Haj et al., 2017	EMA	Single Case Series	Baseline	Yes	1 Week	4 Wk	N/A
Emsaki et al., 2017	Mnemonic	RCT	Placebo	Mixed	5 Wk	5 Wk	3 Mo
Evald, 2015	EMA	Single Case Series	Pretest-Posttest	Yes	6 Wk	6 Wk	N/A
Ferguson et al., 2015	EMA	Single Case Series	Baseline	Yes	30 Min - 1 Hr	4 Wk	N/A
Fish et al., 2015	Mnemonic	Single Group Experiment	No Treatment	Yes	<1 Hr	<1 Hr - 1 Week	N/A
Fleming et al., 2005	EMA	Single Case Series	Pretest-Posttest	Yes	8 Wk	8 Wk	N/A

Studies	Intervention Category	Study Design	Control	PM-Focused	Training Duration	Intervention Duration	PM Follow-up
Foster et al., 2017	Mnemonic	RCT	Placebo	Yes	30 Sec	1 Week	N/A
Gracey et al., 2017	Mnemonic	RCT	Crossover	Yes	1.5 - 2 Hr	3 Week	N/A
Griffiths et al., 2012	Mnemonic	Within Subjects Treatment	Pretest-Posttest	Yes	Not specified	2-2.5 Hr	N/A
Grili & McFarland, 2011	Mnemonic	Single Group Experiment	No Treatment	Yes	30 Sec	1 Week	N/A
Groot et al., 2002	EMA	Independent Groups Comparison	No Treatment	Yes	None	2 Hr (Healthy); 2-3 Sessions (Brain Injury)	N/A
Hildebrandt, 2006	Combination	RCT	Waitlist	No	4 Wk	4 Wk	N/A
Ihle et al., 2014	Combination	RCT	No Treatment	Yes	10 Min	10 Min	N/A
Insel et al., 2016	Combination	RCT	Active Control	Yes	90 Min	4 Wk	5 Mo
Kardiasmenos et al., 2008	Mnemonic	Fixed rotation assignment	No Treatment	Yes	30 Sec	2.5 Hr	N/A
Kinsella et al., 2007	Mnemonic	Within Subjects Treatment	No Treatment	Yes	2-3 Min	1 Hr	N/A
Kinsella et al., 2009	Combination	RCT	Waitlist	Yes	5 Wk	5 Wk	4 Mo
Kinsella et al., 2016	Combination	RCT	Waitlist	Yes	6 Wk	6 Wk	6 Mo
Lee et al., 2013	Mnemonic	RCT	Waitlist	Yes	6 Wk	6 Wk	3 Mo
Lee et al., 2016	Mnemonic	RCT	No Treatment	Yes	30 Sec	<1 Hr	N/A
Lemoncello et al., 2011	EMA	RCT	No Treatment-Crossover	Yes	Not specified	10 Wk	N/A
Mateos et al., 2016	Combination	Within Subjects Treatment	Pretest-Posttest	No	5 Wk	5 Wk	N/A
McDaniel et al., 2014	Combination	Within Subjects Treatment	Pretest-Posttest	No	2 Mo	6 Mo	N/A

Studies	Intervention Category	Study Design	Control	PM-Focused	Training Duration	Intervention Duration	PM Follow-up
McDonald et al., 2011	EMA	RCT	Crossover	Yes	90 Min	5 Wk	N/A
McDougall, 2000	Mnemonic	Quasi-Experimental	No Treatment	No	8 Wk	8 Wk	N/A
McFarland & Gliskey, 2011	Mnemonic	RCT	No Treatment	Yes	30 Sec	1 Hr	N/A
McKerracher et al., 2005	EMA	Single Case	Placebo	Yes	5 Days	8 Wk	N/A
Miller & Radford, 2014	Combination	RCT	Waitlist-Crossover	No	6 Wk	24 Wk	3 Mo
Mitrovic et al., 2016	Mnemonic	Within Subjects Treatment	Baseline	Yes	1.5 Wk	4 Wk	4 Wk
Oriani et al., 2003	EMA	Single Group Design	Baseline	Yes	Not specified	3, 1-Hr Sessions	No
Ozgis et al., 2009	Mnemonic	RCT	No Treatment	Yes	3.25 Min	1 Hr	No
Pereira et al., 2015	Mnemonic	RCT	Treatment Comparison	Yes	2.8 Min	Single Session; Not specified	No
Pereira et al., 2018	Mnemonic	RCT	No Treatment	Yes	30 Sec	1 Hr	No
Potvin et al., 2011	Mnemonic	Matched Groups Experiment	No Treatment	Yes	10 Wk	10 Wk	No
Radford et al., 2011	Combination	Pseudo-random matched groups	Waitlist-crossover	No	6 Wk	6 Wk	3 Mo
Radford et al., 2012	Combination	Pseudo-random matched groups	Waitlist-Crossover	No	6 Wk	6 Wk	No
Richter et al., 2015	CogTraining	RCT	Active Control	No	9 Hr	Not specified	No
Rose et al., 2015	CogTraining	RCT	No contact & Active controls	Yes	1 Mo	1 Mo	No
Savage and Svboda, 2012	EMA	Single Case	Baseline	Yes	Not specified	2 Wk	18 Mo
Schnitzpahn & Kliegel, 2009	Mnemonic	RCT	No Treatment	Yes	30 Sec	2 Wk	N/A

Studies	Intervention Category	Study Design	Control	PM-Focused	Training Duration	Intervention Duration	PM Follow-up
Shelton et al., 2016	Mnemonic	RCT	No Treatment	Yes	1 Min	Single Session; Not specified	N/A
Stringer, 2011	Mnemonic	Within Subjects Treatment	Pretest-Posttest	Mixed	20 Wk	20 Wk	N/A
Troyer, 2001	Combination	Within Subjects Treatment	Pretest-Posttest	No	5 Wk	5 Wk	N/A
Twamley et al., 2012	Combination	RCT	No Treatment	No	12 Wk	12 Wk	3 Mo
Twamley et al., 2015	Combination	RCT	Treatment Comparison	No	12 Wk	12 Wk	12 Mo
Van Den Broek et al., 2000	EMA	Within Subjects Treatment	Baseline	Yes	Not specified	9 Wk	N/A
Waldron et al., 2012	EMA	Within Subjects Treatment	Baseline	Yes	3 Wk	5 Wk	N/A
Waldum et al., 2016	Mnemonic	Matched Groups Experiment	Limited Treatment	Yes	8 Wk	8 Wk	N/A
Yasuda et al., 2002	EMA	Single Case Series	Baseline	Yes	Not specified	Variable by case; 3 Wk - 9 Mo	N/A
Yip & Man, 2013	CogTraining	RCT	No Treatment	Yes	4 Wk	5 Wk	N/A
Zimmerman et al., 2010	Mnemonic	RCT	No Treatment	Yes	30 Sec	Single Session; Not specified	N/A
Zolig et al., 2012	Mnemonic	RCT	No Treatment	Yes	30 Min	Single Session; Not specified	N/A
Farzin et al., 2018	Combination	RCT	Waitlist	Yes	6 Wk	6 Wk	3 Mo
Evald, 2018	EMA	Within Subjects Treatment	Pretest-Posttest	Yes	6 Wk	6 Wk	2 Mo
Fish et al., 2007	Mnemonic	Within Subjects Treatment	Baseline	Yes	Single Session; Not specified	3 Wk	N/A
Goedeken et al., 2018	Mnemonic	RCT	No Treatment	Yes	30 Min	1 Mo	N/A

Studies	Intervention Category	Study Design	Control	PM-Focused	Training Duration	Intervention Duration	PM Follow-up
Jamieson et al., 2019	EMA	Single Case Series	Baseline	Yes	30 Min	2 Wk	N/A
Lloyd et al., 2019	EMA	Single Case	Baseline	Yes	Not specified	3 Wk	N/A
Liu et al., 2018	Mnemonic	RCT	No Treatment	Yes	30 Sec	Single Session; Not specified	N/A
Raskin et al., 2019	Mnemonic	Single group crossover	Active Control	Yes	6 Mo	6 Mo	12 Mo
Withiel et al., 2018	CogTraining	Single Case Series	Baseline	Yes	6 Wk	6 Wk	6 Wk
Ihle et al., 2018	Mnemonic	RCT	Pretest-Posttest	Yes	4 Wk	4 Wk	N/A

Abbreviations: EMA: external memory aid; RCT = randomized controlled trial; PM=Prospective Memory

Table S2. *Mnemonic Strategy Intervention Studies*

Studies	*N*	Neurocognitive Status	Intervention	PM Assessment	Ecological Validity
Andrewes et al., 1996	40	40 Healthy	Multiple strategies in a handbook	Lab- & Home-based Tasks	4
Brom et al., 2014*	39	39 Healthy	II	At-home blood pressure test times	4
Bugg et al., 2013	110	110 Healthy	II	EBPM button response during lexical decision	2
Burkard et al., 2014*	12	1 TBI; 3 MCI; 1 AD; 7 other	II + Visual Imagery	EBPM tasks in the assessment sessions	2
Burkard et al., 2014*	44	22 dementia; 22 no diagnosis	II + Visual Imagery	Put card in envelope; write name on forms; ask	2
Burkard et al., 2014*	87	87 Healthy	Visual Imagery	Write day of the week at the top of all forms	2
Chasteen et al., 2001	111	111 Healthy	II + Visual Imagery	EBPM button response in working memory task;	2
Emsaki et al., 2017*	20	20 aMCI	Memory Specificity	PRMQ scores	1
Fish et al., 2007	20	14 TBI; 6 mixed vascular/hypoxia	Self-reflection strategies cued by notifications	Make scheduled calls to voicemail (from home)	4
Fish et al., 2015*	14	6 vascular; 3 hypoxia; 5 other	Errorless Learning	EBPM button response in sentence judgement	2
Foster et al., 2017*	62	62 Parkinson's Disease	II	Virtual Week	3
Goedeken et al., 2018*	52	52 Parkinson's Disease	II	PRMQ	1
Gracey et al., 2017*	74	74 brain injury	Self-reflection strategies cued by notifications	Participant's daily intentions	5
Griffiths et al., 2012*	48	24 alcoholics; 24 social drinkers	Visual Imagery	Virtual Week	3
Grilli et al., 2011*	12	9 TBI; 3 mixed	Visual Imagery	EBPM button response during trivia task	2
Ihle et al., 2018*	44	44 Healthy	Visual Imagery	EBPM button response during lexical decision	2
Kardiasmenos et al., 2008*	48	24 MS; 24 Healthy	II + Visual Imagery	Virtual Week	3
Kinsella et al., 2007	32	16 AD; 16 Healthy	Spaced Retrieval	EBPM word substitution during reading task	2
Lee et al., 2013*	19	19 AD	Computer-assisted Errorless Learning	BAPM questionnaire	1

Studies	*N*	Neurocognitive Status	Intervention	PM Assessment	Ecological Validity
Lee et al., 2016*	72	34 very mild AD; 38 Healthy	II	EBPM button response during category decision	2
Liu et al., 2018*	84	42 Schizophrenia; 42 Healthy	II	EBPM and TBPM button responses during lexical	2
McDougall, 2000*	19	19 Healthy	CB-MEM intervention	RBMT	2
McFarland et al., 2011*	32	32 Healthy	II	EBPM button response during trivia task	2
Mitrovic et al., 2016*	15	15 Stroke	Visual Imagery	CAMPROMT scores; VR-presented PM tasks	3
Ozgis et al., 2009	70	30 MCI; 40 Healthy	Spaced retrieval	Virtual Week	3
Pereira et al., 2015*	128	64 aMCI; 64 Healthy	Speak aloud/ enactment	EBPM button response during word sorting	2
Pereira et al., 2018*	96	32 aMCI; 64 Healthy	Speak aloud/ Enactment	EBPM button response during 1-back word task	2
Potvin et al., 2011*	30	30 TBI	Visual Imagery	Perform actions at filmed locations	3
Raskin et al., 2019*	40	20 Brain Injury; 20 Healthy	Visual imagery with spaced repetition	MIST score	4
Schnitzspahn et al., 2009*	71	71 Healthy	II	Underline word every 2 min; write day on form	2
Shelton et al., 2016*	72	34 mild AD; 38 Healthy	II	Virtual Week	3
Stringer, 2011	33	15 TBI; 18 Mixed	EON-MEM intervention	Message Task	2
Waldum et al., 2016*	62	62 Healthy	II and monitoring strategies	EBPM and TBPM button responses	2
Zimmermann et al., 2010*	563	563 Healthy	II	EBPM button response during lexical decision	2
Zollig et al., 2012*	40	40 Healthy	Learning sequence of events	EBPM button response in working memory task	2

*Study was included in meta-analysis

AD: Alzheimer's disease; aMCI: amnestic mild cognitive impairment; BAPM: Brief Assessment of Prospective Memory-Short Form; CAMPROMT: Cambridge Prospective Memory Test; CB-MEM: Cognitive Behavioral Model of Everyday Memory; EBPM: event-based prospective memory; EON-MEM: Ecologically-oriented Neurorehabilitation of Memory; II: implementation intention; MIST: Memory for Intentions Screening Test; MS: multiple sclerosis; PRMQ: prospective-retrospective memory questionnaire; RBMT: Rivermead Behavioral Memory Test; TBI: traumatic brain injury; TBPM: time-based prospective memory; VR: virtual reality

Table S3. *Cognitive Training Intervention Studies*

Citation	*n*	Neurocognitive Status	Intervention	PM Assessment	Ecological Validity
Costa et al., 2014*	25	17 PD; 8 Healthy	Training set-shifting abilities	EBPM button response during ongoing word-rating task; Alternate Fluency & Trail Making tasks	2
Richter et al., 2015*	36	36 ABI	Computer-based WM training + Word fluency & Semantic structuring	PM tasks from RBMT	2
Rose et al., 2015	59	59 Healthy	Trained PM using 24 levels of Virtual Week	Virtual Week; Breakfast Task; ERP measures; PM during ongoing N-back	4
Withiel et al., 2018	5	5 Stroke	Lumosity games	CAPM	1
Yip & Man, 2013*	37	37 ABI	Trained PM, RM, and Inhibition in VR convenience store	PM tasks in VR setting; CAMPROMPT scores	3

*Study was included in meta-analysis
ABI: acquired brain injury; CAMPROMPT: Cambridge Prospective Memory Test; EBPM: event-based prospective memory; ERP: event-related potential; MIST: Memory for Intentions Screening Test; PD: Parkinson's disease; RBMT: Rivermead Behavioral Memory Test; TBI: traumatic brain injury; WM: working memory

Table S4. *External Memory Aid Intervention Studies*

Studies	*N*	Neurocognitive Status	Intervention	PM Assessment	Ecological Validity
Baldwin & Powell, 2015*	1	1 TBI	Google Calendar	Entered/forgotten events; Revised Everyday	5
Bos et al., 2017*	9	9 TBI	Google Calendar	RBMT; Text or phone calls; Postcard task	4
Cruz et al., 2016	2	2 TBI	Text message reminder system	Specified everyday tasks; COPM; CAMPROMPT;	5
El Haj et al., 2017*	1	1 mild AD	Google Calendar	Specified daily life tasks	5
Evald, 2015	13	13 TBI	Smartphone memory aid	Self-report of “overview” (i.e,	1
Evald, 2018*	13	13 TBI	Smartphone memory aid	Specified everyday tasks; Questionnaires	4
Ferguson et al., 2015*	6	6 ABI, 5 caregivers	Smartphone-synced digital calendars	Specified everyday tasks; MMQ	5
Fleming et al., 2005*	3	3 TBI	Diary	MIST (in-lab only); Diary entries; CAPM	4
Groot et al., 2002*	64	28 Healthy; 22 TBI; 14 Mix	Note-taking	CBPMT	2
Jamieson et al., 2019	4	4 ABI	Smartwatch	Specified everyday tasks	5
Lemoncello et al., 2011*	23	23 ABI	Television Assisted Prompts	Task tracking logs; Bi-weekly phone calls	5
Lloyd et al., 2019*	1	1 Korsakoff Syndrome	Smartwatch	Send assigned pictures or make phone calls	4
McDonald et al., 2011*	12	12 ABI	Google Calendar	At-home tasks; Self-response questionnaire	5
McKerracher et al., 2005*	1	1 TBI	Diary	At-home tasks; self-reported impressions	4
Oriani et al., 2003*	5	5 mild-to-moderate AD	Vocal task recording with automated	In-lab TBPM tasks	2
Savage & Svoboda, 2012*	1	1 colloid cyst removal	Smartphone memory aid	Phone calls; Effort ratings; MMQ	4
Van den Broek et al., 2000*	5	5 ABI	Electronic Voice Organizer	Message-passing task and assigned domestic chores	4
Waldron et al., 2012*	5	5 ABI	PDA calendar	Specified everyday tasks	5
Yasuda et al., 2002	8	8 ABI	IC Recorder timed recorded reminders	Specified everyday tasks	4

*Study was included in meta-analysis

ABI: acquired brain injury; AD: Alzheimer's disease; CAMPROMPT: Cambridge Prospective Memory Test; CAPM: Comprehensive Assessment of Prospective Memory; CBPMT: Cambridge Behavior Prospective Memory Test; COPM: Canadian Occupational Performance Measure; CVA: cardiovascular accident; MIST: Memory for Intentions Screening Test; MMQ: Memory Mistakes Questionnaire; PDA: personal digital assistant; RBMT: Rivermead Behavioral Memory Test; RBMT-III: Rivermead Behavioral Memory Test – Third Edition; TBI: traumatic brain injury

Table S5. *Combination Intervention Studies*

Studies	*n*	Neurocognitive Status	Intervention	PM Assessment	Ecological Validity
Farzin et al., 2018*	25	25 Healthy	II + cognitive training	Questionnaire battery and computer-based tasks	2
Hildebrandt et al., 2006*	62	41 Stroke; 21 mixed etiology	Group therapy: mnemonics + cognitive	RBMT score	2
Ihle et al., 2014*	62	62 Healthy	Relaxation Exercises	TBPM every minute during 2-back task	2
Insel et al., 2016*	128	128 Healthy	Mnemonic strategies and pill box	Medication adherence	5
Kinsella et al., 2009*	52	52 aMCI	Group therapy - mnemonics + EMAs	Reminding Task; Envelope Task	2
Kinsella et al., 2016*	219	113 Healthy; 106 aMCI	Group therapy - mnemonics + EMAs	CAMPROMPT	2
Mateos et al., 2016	145	73 Clinical; 72 Healthy	Group therapy - mnemonics + EMAs	RBMT	2
McDaniel et al., 2014*	96	96 Healthy	Mnemonics + cognitive training	Breakfast task; Virtual Week	3
Miller & Radford, 2014*	40	40 Stroke	Group therapy - mnemonics + EMAs	RPA-ProMem; CAPM	4
Radford et al., 2011	31	31 Epilepsy	Group therapy - mnemonics + EMAs	RPA-ProMem; Appointment Memory	4
Radford et al., 2012	56	56 Mixed etiology	Group therapy - mnemonics + EMAs	RPA-ProMem; CAPM	4
Troyer, 2001*	60	60 Healthy	Group therapy - mnemonics + EMAs	Phone call tasks (home)	4
Twamley et al., 2012*	69	69 Psychosis	Group Therapy – mnemonics + EMAs	MIST; MIST (24 hour component)	4
Twamley et al., 2015*	50	50 TBI	CogSMART: mnemonics + EMAs	MIST; MIST (24-hour component)	4

*Study was included in meta-analysis
aMCI: amnestic mild cognitive impairment; CAMPROMPT: Cambridge Prospective Memory Test; CAPM: Comprehensive Assessment of Prospective Memory; CogSMART: Cognitive Symptom Management and Rehabilitation Therapy; EMA: external memory aid; MIST: Memory for Intentions Screening Test; MMQ: Memory Mistakes Questionnaire; RBMT: Rivermead Behavioral Memory Test; RPA-ProMem: Royal Prince Alfred Prospective Memory Test; TBI: traumatic brain injury; TBPM: time-based prospective memory