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Memory function and supportive technology

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Abstract

Episodic and working memory processes show pronounced age-related decline, with other memory processes such as semantic, procedural, and metamemory less affected. Older adults tend to complain the most about prospective and retrospective memory failures. We introduce a framework for deciding how to mitigate memory decline using augmentation and substitution and discuss techniques that change the user, through mnemonics training, and change the tool or environment, by providing environmental support. We provide examples of low-tech and high-tech memory supports and discuss constraints on the utility of high-tech systems including effectiveness of devices, attitudes toward memory aids, and reliability of systems.

Keywords

memory; aging; prospective memory; retrospective memory; episodic memory; semantic memory; metamemory; procedural memory; working memory; memory complaint; environmental support; mnemonics; memory technology; memory aid; augmentation; substitution

Review of memory distinctions

Among the concerns expressed by older adults about the aging process is loss of memory functioning [1]. This may be due in part because forgetfulness is sometimes taken as a sign that a more serious disorder, dementia, is occurring. Our main focus in this paper is to examine how technology might be used to remediate normative age-related declines in memory and possibly, non-normative ones. In order to identify potentially fruitful interventions, we first outline the types of memory that the research community has identified as more and less sensitive to normal aging processes. Then we identify and evaluate the types of interventions that may support waning memory functioning in old age, including memory support technology.

Defining memory structures and processes is a fundamental goal of cognitive psychology. Early distinctions such as short-term and long-term memory stores were advanced by psychologists such as William James in the early twentieth century. In the 1960s and 1970s the so-called modal memory model of Atkinson and Shiffrin was proposed and developed. It stressed the interplay between memory stores -- sensory memory, short-term memory, and long-term memory -- and the processes that control the transfer of information between these memory stores, such as rehearsal. Since then many memory types and sub-types have been identified. See [2] for a primer on memory.

A major focus of the earliest research was on defining the capacity of memory, particularly memory for recent information, characterized as *short-term memory* capacity. A more

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modern conceptualization, *working memory*, is usually defined as a combination of storage and manipulation capacity. In aging research, storage capacity is assessed by having people do a span task, such as listening to a sequence of numbers and repeating it back in the same order, then lengthening the list until people make an error. To estimate both capacity and storage, people are asked to remember a list of items, such as unrelated words, but then recall them in alphabetical order (alpha-span). People would have to hold and then manipulate the contents of memory to output items in alphabetical order rather than in the order they were presented. The general finding is that passive storage capacity shows minimal decline with age until late in life, but active storage and manipulation shows significant decline.

Such declines in working memory capacity can have significant impacts on critical processes such as the ability to create rich encodings of new events (needed to promote effective retrieval). Having too little working memory capacity can interfere with the ability to interact successfully with complex devices such as mobile computing devices (e.g., smartphones) that require storing and retrieving a great deal of information as the user navigates through complex menu structures. It should be noted that memory is not the only part of the human information processing system that shows significant age-related decline. Estimates of younger and older adult information processing parameters can be found in [3].

Here we focus on a few broad categories of memory systems: emphasizing types of memories such as episodic, semantic, and procedural, as well as a few sub-classes such as prospective memory and metamemory. Episodic memory refers to memory for personally-experienced events. Such memory has a strong temporal organization wherein it is possible to order aspects of the event and often recall associated information such as the place where the event occurred. Recalling what one had for breakfast this morning (or whether breakfast was skipped) entails re-instantiating some aspect of an event that one experienced. Although the domain in which most research has been conducted is with verbal information (language-based), some aspects of episodes need not be language-based. One may be able to evoke a distinctive taste or smell for the coffee one drank earlier in the day. In general, episodic memory shows quite striking age-related decline from the 20s to the 80s in cross-sectional studies, about 1 to 2 standard deviation units, or a negative correlation with age of approximately $r = -0.33$ [4]. As a comparison point, speed of processing, the ability to respond rapidly to environmental events, shows an even stronger decline of about $r = -0.5$ over a similar age range.

Prospective memory can be seen as part of this episodic memory system. It refers to setting the goal to remember to do something at a later point in time, such as visiting the doctor in a week. Prospective remembering can fail when either the time feature (when to remember) or the content component (what to do) fails to activate in a timely way. A classic modern example of failing a prospective task occurs when someone is typing that they are attaching a document to an e-mail, has their attention diverted by composing the remaining part of the message, and then forgets to attach the file before sending the e-mail. For many people, prospective remembering works best when external reminders are set or consulted (calendars, alarms), putting the cue in the world in addition to having it in the mind.

In contrast, semantic memory refers to knowledge about the world that was originally obtained as episodic information but later consolidated into generic information. Knowing that “z” is the last letter of the Roman alphabet, or that one starts out life as a newborn and then matures and grows old, are all examples of semantic information. Semantic information often is missing a temporal tag. One may know that “z” is the last letter of the Roman alphabet, but be quite unsure where and when that fact was learned or whether one learned it before or after one learned that people grow old. Semantic memory may be the result of

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decontextualizing episodic memory through processes such as abstraction and forgetting of specific features. Semantic memory is often conceptualized as a network of information (nodes and links) where different code types cluster together (e.g., for a word: its sound, written-form shape, and meaning). In general, semantic information is well preserved over the life course and measures of information or vocabulary typically show modest increases in cross-sectional studies to the decade of the 50s or 60s (r= 0.1). However, the time to access this information increases with increasing age, leading to more retrieval failures under speeded retrieval situations, and more “tip-of-the-tongue” experiences when information is recognized to be available, but is not immediately accessible. Such age-related difficulty in activating subsets of features within semantic networks has been termed a transmission deficit [5], and can result in failures such as accessing the sound or spelling of words.

Procedural memory is often, though not necessarily, associated with movement and typically involves skilled performance. Knowing how to ride a bicycle, swim, touch type, are examples of procedural information. Like semantic information, procedural information is typically quite stable across the life course. Someone could still swim after being out of water for years, though probably not as skillfully as if they continued to practice the skill (e.g., typing: [6]). The same is not true for episodic memory. Although one may remember what one had for breakfast this morning, it may be impossible to remember what one had for breakfast a year ago, unless that breakfast was associated with a particularly salient event (e.g., an earthquake).

Metamemory is a component of metacognition (knowledge about one’s cognitive capabilities) concerned with memory capabilities, strategies, and the self-monitoring that plays an important role in learning. The spared monitoring-impaired control hypothesis [7] states that an age-related decline in metacognitive skills is to blame for some decline in episodic memory performance. There is evidence for age equivalence in accuracy of both immediate and delayed judgments of learning (JOL) showing that self-monitoring of memory encoding is relatively spared by the aging process (e.g., [8]). But it seems that older adults do not make use of their accurate monitoring to direct their encoding effectively (e.g., [9]). Personal beliefs about one’s memory capabilities also seem to play a role in memory’s functioning. It has been shown that memory self-efficacy (MSE), beliefs about the degree of control one has over memory processes, is lower in older adults (e.g., [10]) and that decline in older adults’ MSE accounts for some of the age-related variance in memory performance [11]. Low MSE can lead to less effort expenditure, less persistence when encountering difficulty, lower performance goals, and higher anxiety during tasks, all of which may negatively impact performance on memory tasks [12, 13]. Some have suggested that improving MSE beliefs may be as, if not more, important than improving memory performance because it may encourage older adults to use newly acquired memory strategies in novel situations [14]. In addition, Lachman & Androletti [15] found that older adults with higher MSE were more likely to use effective encoding strategies and subsequently recall more when tested on a list of 30 categorizable words. MSE has also been found to be predictive of memory functioning 6 years later [16].

Subjective memory complaints (SMC), a facet of metamemory, shed some light on what memory difficulties older adults face most commonly and provide a starting point for the development of technological support. In a study looking at older adults’ memory complaints, Bolla et al. [17] found that the most frequent memory ones were forgetting names, where things were placed (e.g., keys), and phone numbers that were just checked. The memory complaints rated most serious in the study were losing the thread of thought in conversation, forgetting appointments, and forgetting where things were placed. Most of the research investigating the relationship between SMC and memory performance seems to

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suggest that SMC do predict dementia or later decline on cognitive tests (e.g., [18]), but there have been researchers who have found no relationship between SMC and impaired memory performance (e.g., 19]). It has been noted that SMC is associated with depressive symptoms and negative affect (e.g., [17]). Furthermore, the intensity of SMCs could be due to depression or mild cognitive impairment (MCI), a condition in which a person has problems with cognitive functioning that may not be serious enough to interfere with the individual's daily life, but are noticeable enough to be observed by others and show up on cognitive tests.

It is prudent to note that memory support provided to an individual must take into consideration their state of memory as well as their diagnosis. For example, an individual suffering from depression may mistakenly misinterpret their diminished ability to think or concentrate as a memory failure. Treatment for depression can alleviate memory complaints [20].

Having provided a brief overview of some types of memory and how they vary across the life course, we turn now to the issue of memory interventions. We first outline a general framework for intervention and then we consider existing and emerging technologies for supporting memory processes.

Framework for Memory Interventions

For a successful intervention to aid memory, a formal assessment of memory functioning (and memory complaint) is necessary. Often, an individual presents to a health care professional complaining about memory functioning. Otherwise, someone concerned about the individual encourages them to seek assessment (or in some cases, the justice system can require an assessment). In the United States, many states have supported the development of memory disorder clinics to help citizens determine if memory complaints are warranted, with specially trained staff available to carry out assessments and to advise people on how to cope with memory decline. Assessments typically involve screening and neuropsychological testing to try to determine if cognitive and memory functioning fall below levels expected from age and education norms. The initial goal is usually to determine whether the person is in the early stages of a dementia process.

If the person appears to be functioning at levels appropriate to their age and education level, then memory complaints may be an indicator of depression which can be assessed with standardized tests and can be treated. If people have particular memory weaknesses and agree to treatment then it would be appropriate to consider the nature of the difficulty and ways to remediate it. We make use of two concepts from life-span developmental views of the role of technology [21]: substitution and augmentation. In normal aging, some memory functions are impaired and can be augmented with training or via technology tools. However, with non-normative conditions, such as dementia, some functions may be too compromised to permit successful training; hence technology will have to substitute for the failed functionality.

A flow diagram for this process can be seen in Figure 1.

Two Approaches: Train the User, Change the tool or environment

The discipline of human factors [22] typically approaches human performance improvement from two directions: 1) change the user, through training, or 2) change the tool and environment by redesigning them. This strategy can be implemented via both external and internal memory aids. Internal memory aids, such as mnemonics, support memorizing performance by providing techniques for more efficient integration of new information into

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existing cognitive structures. External memory aids, such as electronic devices, create external reminders that link to internal memorizing or remembering goals. Take the earlier example of failing to attach a document to an e-mail. Possible solutions include training e-mail users to stop and attach the document when they type the word “attach” – changing the user – or having the e-mail software scan for the keyword “attach” and pop up a reminder – changing the e-mail program.

The two main approaches for changing the user’s memory capabilities are omnibus interventions that aim to improve general cognition (including memory) and tailored interventions that are memory-specific. Attempts to help support memory by improving general cognition have given similar results with modest effect sizes (change measured in standard deviation units) after intervention of 0.26 found by Ball et al. [23] and 0.25 found by Mahncke et al. [24]. However, if someone has shown normative age-related decline on the order of 1 to 2 standard deviations in performance such interventions may not be well matched to the degree of decline. McDaniel and Bugg [25] review other attempts to change memory with general interventions (such as exercise). Specific mnemonic interventions, those involving teaching people techniques for remembering episodic information seem more promising in terms of effect sizes and we review them next.

Mnemonics: Greek Method of Loci

Mnemonics training has been used as a method of improving older adults’ performance on the types of memory tasks investigated in memory research, such as learning lists of words. Although word list learning is not a typical area of complaint, it can be diagnostic for usual episodic memory performance. One project [26] trained both younger and older adults on how to use the Method of Loci, a technique that trains the use of memorized spatial locations (e.g., a serial list of Berlin landmarks) as cues to form relational images with lists of imageable words. For instance, if the first word on the list to be remembered was “bird” and the first memorized location was the Brandenburg gate, the participant would try to form an interactive image of the bird with that landmark. Similar associations would be generated for later list items and when it was time to recall items in order, the person would mentally tour the list of landmarks and retrieve and output the words. Both younger and older adults’ performance on a serial word recall task improved at a similar rate over the training period, but older adults never reached the average performance of younger adults. In fact, at the end of the study older adults still performed worse than younger adults did on the assessments right after initial training though better than young adults before training. In an extension of this study to see if professional expertise that involved mental visualization (imagery ability) had any effect on performance, Lindenberger et al. [27] enlisted young and old graphic designers. They found that older graphic designers showed less of a performance deficit than did older controls, but still did not attain the performance level of the younger controls. Using a similar design to that of Baltes and Kliegl [26], Brooks et al. [28] compared a group of younger-old to older-old on word recall and name recall after method of loci training. While they found no effects for name recall, they did find that mnemonic training benefits for word recall increased with increasing age, and may help older-old participants reach the performance of younger-old participants.

To investigate the long-term effects of mnemonics training, O’Hara et al. [29] looked at word recall in community-dwelling older adults who went through mnemonics training 4–5 years prior. They found that follow-up performance was significantly lower than post-training performance, but not significantly different than pre-training performance. Pre-training scores, training gain scores, and self-reported mnemonic use were found to be significant predictors of the number of recalled words after five years, and those that reported using the mnemonic at the five year follow-up did significantly better than their

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pre-training performance, suggesting a sustained long-term benefit for those that continued to use the mnemonic.

In a meta-analytic review of memory training studies aimed at improving episodic memory, Verhaeghen and colleagues [30] found larger gains for mnemonics training groups from pre-test to post-test (SD=.73) than for placebo (SD=.37) or control (SD=.38) groups. They also found, surprisingly, that the type of mnemonic or pre-training technique taught did not influence the treatment gain. Almost all of the mnemonic treatments they investigated involved imagery, except for two that used a verbal mnemonic, but these two did not provide larger treatment gains than the visual mnemonic interventions. A similar net effect size (d=.31) has been shown for memory training interventions in a recent review chapter [31].

Nonetheless, although the size of the training effect did not vary by mnemonic, it is well recognized that different mnemonics benefit different memorizing tasks. Also, even though mnemonic training leads to better memory performance in the lab, it is important to note that older adults often have trouble integrating this training into their daily lives (e.g., [32]). Perhaps easier methods such as writing notes are effective enough and hence used more often than the unsure and effortful process of using a mnemonic. It is telling that even memory researchers don't use or recommend using proven mnemonics [33] and even world champion memorizers write down grocery lists [25].

Forming implementation intentions (i.e., imagining yourself performing future actions in detail) has been shown to be useful for supporting older adults' prospective memory [34]. Gollwitzer [35] stated that by forming implementation intentions the individual links the intended action with specific situational cues, allowing for automatic triggering of the intention once these cues are encountered in the environment. This effect is most prominent when task completion cues tap recall processes that require controlled processing as opposed to recognition tasks with strong automatic components. The nature of this means of internal memory support sheds light on how environmental support can help memory through linking external cues to internal remembering goals.

Theoretical framework: Environmental support

Memory support for retrieval of information can also be facilitated through external means by changing the environment through redesign. Craik [36] used the phrase environmental support to explain why some forms of memory retrieval are less age-sensitive than others. Recall tasks generate larger age differences in performance than cued-recall tasks than do recognition tasks, in theory because there are more cues in the environment to prompt retrieval with the latter tests of retention, hence requiring less self-initiated processing to access the memory. Environmental Support (ES) memory aids attempt to assist memory function unobtrusively by integrating themselves into the user environment and reducing cognitive demands on the user [37]. Cognitive demands are reduced by the dual-faceted approach of reducing the demands of the task while supporting the efficient use of cognitive resources, including working memory capacity necessary to follow multi-step procedures that are a part of modern computer interfaces. Task demands are often reduced by increasing the salience of target information, providing an increased buffer for processing, and providing external aids to reduce the demand on memory and processing systems. Cognitive resources are then supported through designs that are consistent with experience and training as well as guiding attention to relevant task demands.

The most beneficial ES interventions for older adults target specific age-related deficiencies in the perceptual, motor, and memory systems. Examples of ES techniques that can be used to reduce task demands of a system for the older adult user in human computer interaction

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scenarios include increasing salience of target items in the user display (e.g. increasing the contrast between target items and background; increasing the size of icons and text), providing redundant task information (e.g. present information both audibly and visually), and using task-compatible user interface hardware (e.g. use a pointing device for an icon selection task).

As described by Morrow and Rogers [37], ES techniques are well suited to aid older adult memory function when interacting with computer systems and devices. Increasing salience of items in external displays by increasing contrast and reducing desktop clutter can increase performance by reducing demand on perceptual and attentional systems, making up for the loss of contrast sensitivity associated with aging. Cognitive demands for computer interaction can further be reduced by easing reliance on working memory by providing redundant information through multiple formats (e.g. text and audio). Audio messages can be repeated to allow for more processing time and have been shown to reduce the difference in memory ability between younger and older adults [38]. Automatic replays have been shown to be more effective than user prompted replays that can increase the burden on the cognitive system by requiring the user to expend cognitive resources making the decision to replay a message that could otherwise be directed towards processing [39]. The reliance on working memory can be further reduced by externalizing components of the task that would normally be required to be held within that system. This goal can be reached by providing accompanying visual aids along with auditory information that must be held in working memory. The visual component of menu-based computer systems also provides greater support than keystroke-based systems that rely on memory of key commands.

Design can also be directed towards supporting the use of cognitive resources along with a reduction in task demands [37]. Within older adult Human Computer Interaction (HCI) scenarios, designs can take into account existing schemas and provide compatible reminders allowing users to rely on their expectations to support memory function. For non-keyboard users, Alphabetic keyboard layouts (e.g. alphabetic listing ordered left to right, top to bottom) have been shown to benefit older users in the speed of text entry when using virtual (soft) keyboards compared to the commonplace QWERTY keyboard layouts [40]. Users were able to utilize their well established knowledge of letter order (semantic memory) to help determine key location.

External Memory Aids

Memory support can also be achieved by the addition of an external memory aid that provides the user with content or cues to assist and prime memory. A common method among older adults with a partner is the use of that individual as an external memory aid. Collaborative cognition [41] involves having people work together on memory tasks and results indicate that this works quite well to boost performance relative to one person trying to remember on his or her own. Memory performance can also be bolstered by self-managed external memory aids.

One of the oldest supports for external memory is writing, though this only works when people are literate. Ancient writing systems, such as cuneiform, were initially used to keep track of business transactions and accounts (e.g., [42]). How to balance writing's benefit in supporting memory function and its potential cost in allowing memory function to decay through lack of exercise ("use it or lose it") is an age-old dilemma. The Greek philosopher Plato argued "this invention of yours will produce forgetfulness in the minds of those who learn it, by causing them to neglect their memory, inasmuch as, from their confidence in writing, they will recollect by the external aid of foreign symbols, and not by the internal use of their own faculties. Your discovery, therefore, is a medicine not for memory, but for recollection- for recalling to, not for keeping in mind." On the opposing side of this

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argument, a Chinese proverb states: “The faintest ink is better than the best memory.” When attempting to support memory functioning, we need to keep both views in mind, improving internal memory by augmenting it via training and substituting external memory cues for internal ones.

Tasks that need memory support

Prospective memory – calendars

Older adults are thought to be able to recognize personal decline in prospective memory (via relatively intact metamemory) and to mitigate the problem with the use of low-tech prospective memory aids (notes, calendars, conspicuously placed items). Prospective memory is composed of two tasks. One must remember that a task must be completed as well as remember the identity of the task. Many low-tech memory aids address both of these components. Bolla et al. [17] found that over half of adults reported using written reminders including keeping an appointment book (69%), making a grocery list (63%), and writing notes (59%) as well as non-written reminders like keeping items that need to be addressed in a prominent location (62%) and keeping often used objects in the same location (58%). Even though these low-tech aids are used by a large portion of the population, they are not without negative features. The possibility that reminders might fail, might be lost, are difficult to display, and create a mess are all drawbacks of low-tech memory aids indicated by older adult users [43].

Einstein and McDaniel [44] list a number of ways to improve the utility of low-tech memory aids while addressing some of their drawbacks. Their recommendations for visual memory aids include using bright colors and items that are large or oddly shaped to help augment the visibility of a note or object that is intended to prompt memory. Placement of the note or item in prominent (on the door, on top of keys, etc.) or unexpected (shoes hanging on the doorknob) locations can also increase the effectiveness of the cue. The authors also note that the old adage that “tying a string around your finger” is not an ideal reminder, because you pose another unaided memory task - what does the string cue? Instead, relevant items placed in a prominent location will provide better memory support by supplying context along with the task reminder.

The efficacy of low-tech memory aids is also directly related to the temporal proximity of the reminder to its intended action. It is important that older adults are able to perform the intended action immediately when prompted by memory aids. Older adults have been shown to lose the ability to maintain intention over short delays, even those as little as 10 seconds, when compared to younger adults under a similar memory load [45]. Oftentimes when individuals are unable to act immediately upon memory reminders, it is due to involvement in some other activity that places an extra burden on working memory capacity. It is important to note however, that older adults still display an increase in prospective memory deficits when the short delays are not occupied by a secondary task.

Routine prospective memory tasks are at an increased risk for error and potential failure with low-tech memory aids. These memory aids fail when they are static in location and remain unchanged from day-to-day [44]. They indicate that the individual is supposed to remember a certain action (e.g. taking one’s daily medication) but do not communicate if the individual has remembered to do so *on that particular day*. This provides an opportunity for errors of omission (failing to perform the intended action) and errors of repetition (performing the intended action more than once). Errors of omission can arise from the failure to remember to perform a certain action, but can also occur by a successful prospective memory retrieval coupled with an incorrect memory that the action has already been performed. Errors of repetition are also characterized by successful prospective

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memory retrieval, in this case coupled with an incorrect memory that the action has not been performed, leading to multiple executions of the same action. Laboratory studies have shown that older adults are more likely to commit both types of prospective memory errors [46]. Specific to older adults, the incidence of errors of repetition was amplified by an increase in attentional demands and generally rose over 11 trials. Increased omission errors were related to greater attentional demands in early trials and the presence of memory cues in later trials. Older adults presented with a memory cue were more likely to retrospectively report that they had completed the intended action after an omission error compared to younger adults.

Both of these prospective memory error types can greatly affect medication adherence. The problem is magnified by older adults' susceptibility to these errors, especially when presented with increased or divided attention demands, and the greater likelihood that they will be taking daily medication. The Pew Research Center [47] found that 83% of older adults reported taking a prescription medication in the last 24 hours. Some low-tech memory aids have been shown to be successful with facilitating medication adherence among older adults. Simply mentally altering the prospective memory task to be event-based (linked to a reoccurring event, e.g. a daily meal) as opposed to time-based (linked to a particular time, e.g. noon) can increase older adults' prospective memory performance to levels that are statistically indistinguishable from younger and middle-aged adults (e.g. [48]). Physical memory cues like daily pill boxes or dispensers are also useful, low-cost memory aids (see Figure 2). Park and Kidder [49] report that multiple different studies have found that 7-day-with-times organizers (a 28 compartment organizer with four time compartments for each day of the week) are simple to load and promote medication adherence in older adults. It is important to note that by design, medication organizers are likely to reduce the incidence of repetition errors but on their own do not address omission errors unless the organizer is routinely checked by the individual [46].

Supportive Technology

Classes of Devices

Current technologies can include various features depending on the type of memory deficiency they are addressing, ranging from normative prospective memory decline to mild cognitive impairment to dementia. Common among all devices are prospective memory aids, often in the form of a preset calendar-based alarm system controlled by the individual or a caregiver, and having Internet connectivity. Internet access permits multiple devices (home and handheld) to synchronize information as well as permitting caregivers to be remotely involved when necessary [50]. Caprani, Porter, and Greaney [43] reported that older adults are open to the use of touchscreen user interfaces, which are integrated into many of the memory supportive technologies. Touch screens are an apt interface for smaller portable memory devices that would otherwise require the use of a small physical keyboard which could potentially hinder older adult users with poorer vision and dexterity.

The Memojog system [51] is a good example of a relatively simple technology-based prospective memory aid that utilizes text-based memory prompts that are signaled by an audible alarm. The main interface is a handheld touch screen system similar to a PDA that signals and displays reminders. The software is linked to multiple devices by wireless internet connectivity and is accessible to the patient and caregivers. A usability test with four memory-impaired adults (mean age of 60) indicated that users were happy with the system and did not find it difficult to operate.

Memory supportive technologies can also be designed towards the needs of individuals with more severe memory impairment and dementia by providing additional features to address

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various memory deficiencies. The CogKnow system [52] (see Figure 3) features a base system similar to that of Memojog that has been supplemented by various features that address the needs of this population. For example, retrospective memory support for episodic events is required in order to assist individuals with their memories of past events. Caregivers are also given more responsibility because a dementia patient may forget to set a reminder or have difficulty learning how to use the system. Unfortunately, studies related to these memory support systems are often related to usability as opposed to effectiveness for supporting prospective memory tasks.

Constraints for Intervention

While electronic memory aids are a useful tool to support retrospective memory, some inherent features of the devices unrelated to their efficacy may result in the decreased likelihood of their adoption. In a 2005 study [53], 58% of older adults responded that they would use an electronic memory support device and 75% responded they would learn how to use it. But, participants also responded that they would be willing to pay in the range of $26-$50 for the device (mode and median). Costliness was the main concern indicated regarding the use of a memory device, with 55% of participants responding that the device being too expensive was a “very important” concern. Proposed memory devices would almost surely fall outside of the desired range unless subsidized by health insurance. Devices with online connection to caregivers would also have the added monthly cost of Internet service on top of the initial device purchase, though the increasing adoption of Internet connectivity may eliminate this problem for future cohorts of older adults. As an example, in the United States in 2008 about 50% of older adults aged 65+ use mobile phones (compared to 43% using computers and the Internet [21]). As “feature” mobile phones are replaced by smartphone technology, it will become less expensive to access the Internet by mobile phone.

Another concern related to the physical memory aid device is the need for portability and the design concessions that implies. Memory support technology would preferably retain its functionality outside of the home environment, either by being entirely based on a portable hardware platform or by incorporating a separate portable component to act in tandem with a home-based system [52]. By definition, portable devices are limited in size, which places an increased demand on the visual and tactile systems of older adults for extracting and inputting information from a portable device, respectively. Tablet technology provides a promising avenue to both portability and increased screen size. ES methods can be implemented to reduce the demand of these tasks without sacrificing usability or size of the device. For example, larger font and higher contrast can be used on the screen display while software-based “soft” (e.g., touch-screen) keyboards can be used for text input on the portable device to take advantage of available size. The use of hard keyboards should be retained for text input on larger, home-based devices.

Memory support technologies can be connected to a central server, allowing caregivers access to information about the user. For example, memory support systems often give the option to delay a response to a reminder. When important reminders (e.g. take heart medication) are put off for an extended period of time, these devices could notify caregivers to call the user and check up on them and remind them of the importance of the task.

Future technologies

Current research in memory aid technologies is trending towards providing automated retrospective memory support as opposed to the prospective memory support found in the previous class of devices. Intended for use by individuals with severe, non-normative memory deficits and dementia, these systems effectively provide a prosthesis for episodic

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memory retrieval processes. These technologies all provide support for episodic memory through integrated systems that automatically collect data from the environment at periodic intervals using audio, video, and/or GPS recording. These data are then compiled by the individual or a caregiver into a meaningful form that supplies the individual with concrete information (i.e. photographs) and context from previously experienced events to aid episodic memory.

The Microsoft SenseCam [54] is an example of an image capturing episodic memory aid. This device is a lightweight camera worn by an individual that records photographs of the individual's field of view (see Figure 4). Photographs are taken manually or automatically triggered by various sensors that detect changes in the environment (i.e. changes in light level or a change in temperature indicating proximity to another person) and then later reviewed and cataloged using a coupled software program. A case study of an older adult participant with severe memory loss caused by hippocampal lesions compared episodic memory recall with no memory aid, the SenseCam, and a diary of events kept by a caregiver. Both of the memory aids were managed by the caregiver who also guided the review of their contents. The participant was questioned at periodic intervals about her memories of number of events and, when applicable, immediately followed by a review of the events captured by the memory aid. Recall of events after using the SenseCam in previous sessions was significantly greater compared to the caregiver-written diary and lack of a memory aid [54]. The likelihood of event recall was greater in the SenseCam condition even if the events had not been reviewed over a period of 3 months. These results have also been found in a case study of a 55 year old participant diagnosed with mild cognitive impairment [55].

The SenseCam has been integrated into a slightly more advanced system called MemExerciser [56] that also collects audio and GPS location information. These data are automatically compiled by a coupled software program CueChooser (still in development) that automatically assigns context to image sets based on location, movement, and photograph contents (i.e. presence of faces), allowing for the individual to use the software without caregiver intervention. Three patients with episodic memory impairment were used to compare the self-guided MemExerciser system, caregiver-guided SenseCam, and a no memory aid control condition using a within subjects design. The results indicated that use of the self-guided MemExerciser system resulted in a lower rate of forgetting that approached significance ($p<.07$) when compared to the caregiver-guided conditions. Use of the MemExerciser also resulted in an increase in the percentage of details remembered over time (using the Remember-Know-Guess scale of vividness) which was significantly different than the other conditions, which resulted in a decrease of remembered details over time. A similar system called DejaView [57] has been proposed and is designed to integrate facial recognition technology with the wearable sensors and context-assigning software. Images of faces captured by the device are transferred to a facial recognition website via a coupled wireless device carried by the individual separate from the sensor device. The name of the individual is then sent back to the device once the identification is completed. Similar to the previously mentioned devices, all of the data compiled by the device would be available for review to aid retrospective memory.

While these devices offer increased functionality compared to the prospective memory aids mentioned earlier, they are also more complex. It is important to note that all of the above memory aids require caregiver intervention for optimal use or training purposes. Also, while all of these systems have been introduced in the literature, very little research has been performed to gauge their effectiveness.

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It is worth noting that one benefit of portable devices such as tablets and smartphones is that they provide not only access to personal information (such as calendars to support prospective memory) but also, increasingly, access to Internet search engines. Skilled users of search engines in a tip-of-the tongue state could type in partial information about the target and either retrieve the relevant item online or find enough related information to induce a successful retrieval from their own memory systems. Further, having access to other people (by voice, text message) may permit collaborative memory retrieval processes. External memory aids, whether electronic or human, can greatly enhance an older individual's declining memory capacity.

Gaps in Research on Memory Support: Costs and Benefits of Memory Aids

An important dimension when considering trying to augment or substitute for unreliable memory processes is the potential cost of a memory failure for the individual. Failing to remember an item on a grocery list is likely to inconvenience you. Failing to retrieve the name of someone that you know quickly enough can be embarrassing. Failing to take a needed medication or taking the wrong dose can be fatal. Hence, even costly memory support devices could be justified if they promote better adherence in critical health-related tasks. Many health-related activities rely heavily on prospective as well as retrospective memory processes and the multistep procedures that need to be followed for obtaining vital sign data (e.g., blood sugar levels, blood pressure) can easily tax working memory capabilities of older adults. Expensive medical devices (and support devices such as robotic assistants: [58]) can also tax financial resources.

We can draw on parallels from the literature on assistive devices when considering factors that are not well-researched in memory support. Factors such as stigma associated with using the device, general attitudes toward a device, such as perceived usefulness and perceived ease of use, as well as the reliability of the device, can all be barriers to acceptance and use. See [59,60] for an overview of factors in acceptance and device discontinuance.

Attitudes and Stigma—In an effort to maintain the appearance of competence, older adults will often fail to use or abandon devices that are effective for their designed purposes but that stigmatize the user. Canes, walkers, and wheelchairs, though useful, signal that the user has a mobility disability. Hearing aids that can be concealed in or around the ear are probably more likely to be adopted than those that plainly signal hearing impairment. Memory aids may also signal cognitive impairment unless they are carefully designed and deployed.

Many telehealth interventions [61] are aimed at supporting people who have chronic conditions and who are required to monitor their vital signs, particularly because failing to do so can result in a costly emergency room visit. Automated systems (substituting machine intelligence for self-monitoring) can potentially identify problems without user intervention. Although the technology for supporting ambient monitoring via sensor systems is improving in sophistication as well as reliability and becoming less costly over time, there are significant barriers to widespread adoption. Attitudes toward the technology, which may be partly driven by concerns over privacy and confidentiality as well as cost effectiveness, need to be taken into account. Level of cognition in the individual (or caregiver) must be adequate to maintain such systems (e.g., to change or recharge batteries for portable devices).

Reliability—Particularly for electronic systems with complex supporting infrastructure, reliability of the device ecosystem becomes a challenge. Little is known about reliability for existing memory support systems. A text-messaging service that provides important

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reminders via a user's mobile phone is of limited use if the mobile device has been left at home, is turned off, the battery has discharged, or it is out of range of the cellular network. System reliability studies for memory-support devices need to be conducted.

Summary

We have reviewed the types of memory systems that show significant decline with age, particularly episodic memory and working memory, and those that are somewhat more robust: semantic, procedural, and metamemory processes. We reviewed the main complaints about memory that older adults exhibit: prospective and retrospective memory failures. We have introduced a framework for considering how to mitigate memory decline using augmentation and substitution and discussed techniques to implement mitigation programs by changing the user, through mnemonics training, and changing the tool or environment, by providing environmental support. We provided some examples of interventions that have been used that involve low-tech aids and high-tech ones. We also discussed constraints on high-tech systems and what issues still need to be addressed in the literature such as effectiveness of devices, attitudes toward memory aids, and reliability of systems. Technology holds considerable promise for supporting memory processes, but will require carefully matching the demands of supportive technology to a user's cognitive, perceptual and psychomotor capabilities [62].

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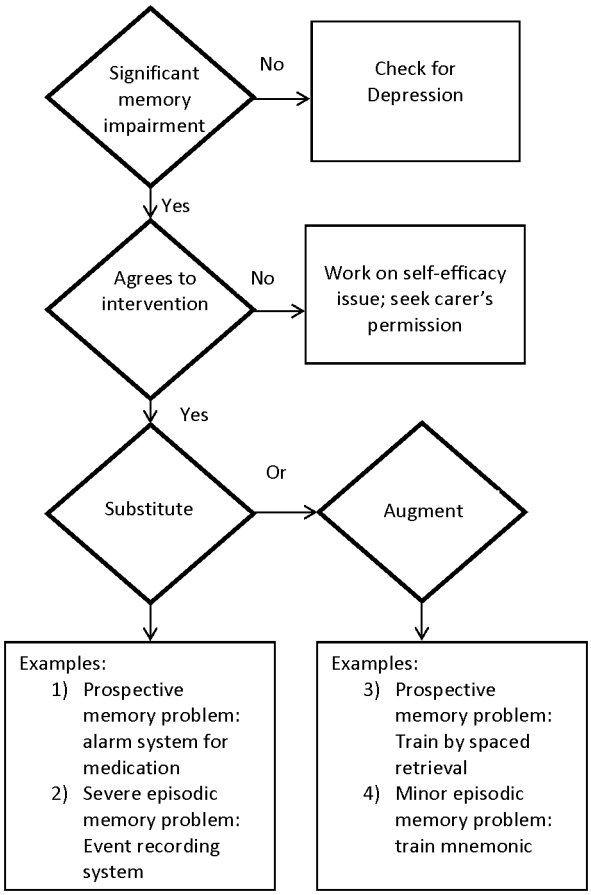

Figure 1.
Flow diagram for an intervention program to aid declining memory.

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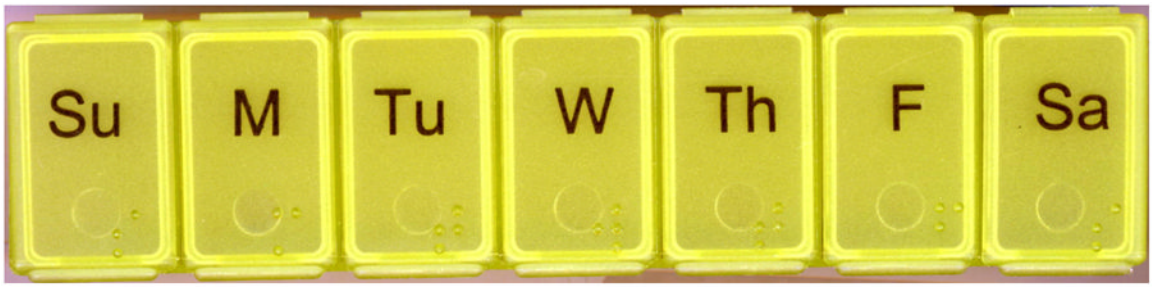

Figure 2.
A seven day pill organizer with high contrast between text and background.

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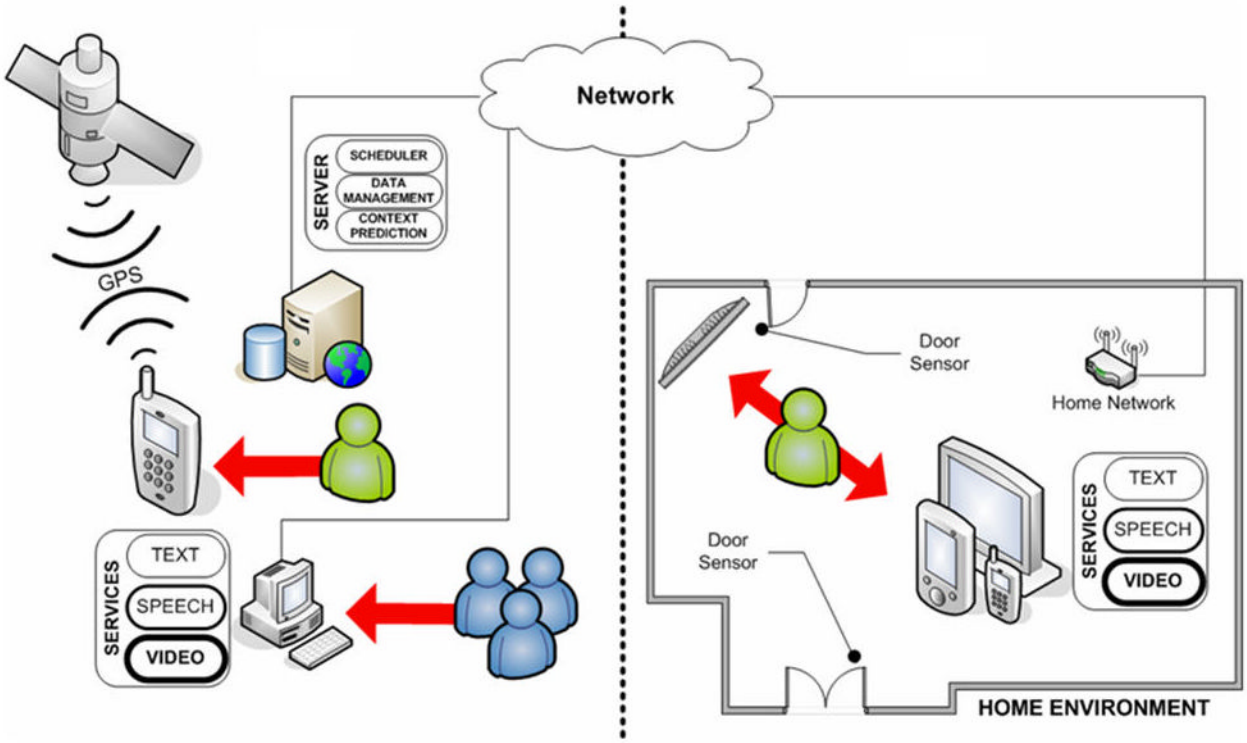

Figure 3.
Diagram of the Cogknow system network between caregivers and patients using handheld and desktop devices.

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Figure 4.
SenseCam. A wearable camera that can automatically take pictures to supplement memory.