Aging Pathobiology and Therapeutics 2026; 8(3): xx-xx *xx*
DOI: 10.31491/APT.2026.09.xxx

Aging and memory: a personal perspective

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This article belongs to the Special Issue: Ever evolving hallmarks of aging

Abstract

In this commentary, I summarize the findings and theoretical ideas on age-related differences in human memory that I have published between the 1960s and the present day. My first experiments were focused on age differences in short-term memory, the distinction between primary memory and working memory in this regard, and on the point that whereas age-related differences are minimal in primary memory, there are age-related decrements in working memory and in the "secondary memory" of events that must be retrieved and entered back into conscious awareness. After developing the levels of processing ideas in the 1970s, I suggested that memory problems in older adults were due to inefficient encoding and retrieval processing operations. Further, that these inefficiencies were attributable in part to the declining effectiveness of executive control processes in the brain's frontal lobes—giving rise to a deficit in self-initiated processing. My colleagues and I also discovered that such deficits could be reduced, and even eliminated, by the provision of adequate environmental support during both encoding and retrieval processing. The article presents some experimental work supporting these ideas. More recently I have been involved in collaborative studies using brain imaging techniques, and these studies have made a start in elucidating the brain mechanisms underlying age-related changes in memory performance.

Keywords: Aging, memory, recall, recognition, environmental support, self-initiated processing

I started my research studies of human aging quite by accident. After finishing my undergraduate degree in psychology at the University of Edinburgh I was offered two junior research positions—one in ophthalmology in London and the other (which I accepted) with a group studying the occupational aspects of aging in Liverpool (UK). In the 1960s there was a progressive shift in the types of work available in Britain away from coal mining and steel production to light engineering and service jobs. Accordingly, there was a lot of interest in retraining middle-aged workers for such new employment opportunities. The project I was given focused on the idea that the performance of middle-aged men and women may be hampered by a decline in self-confidence that would impose an artificial ceiling on their abilities, especially when learning new skills. It's a nice idea, but I found it difficult to devise a lab task that was sufficiently realistic, so turned instead to measuring individual differences in caution and decision making in a task in which participants of different ages attempted to detect faint auditory signals. These experiments provided evidence that older adults tend to be more cautious in their judgments, and to seek more information before committing themselves to a decision.

I was also struck by the role of attention in these simple perceptual tasks. At that time Donald Broadbent and his group in Cambridge were doing path-breaking research into the nature of attention and short-term memory in healthy young adults, so I decided to explore the effects of aging on these abilities. One popular technique was known as dichotic listening; two short series of digits were presented simultaneously, one series to each year over headphones, and the person's task was to recall both series, one ear at a time. Typically, participants made few errors on the first half-set reproduced, but did make errors on the second half-set. Several studies showed that older adults performed as well as younger adults on the first half-set recalled but showed age-related losses on the second-half-set. In turn this led to the idea that aging has a minimal effect on primary memory—information recently

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Received: 15 July 2026 / Accepted: 23 July 2026
Published: XX September 2026

heard or seen and maintained in conscious awareness by continuous rehearsal—but has a negative effect on secondary memory—information encoded, often in terms of meaning that is dropped from awareness, and so must be actively retrieved at a later time.

I followed up on this notion using recall of word lists ranging from 12–20 words in length. Again, we found no age differences in recall of the last three or four words presented (from primary memory) but substantial age-related decrements in recall of words from earlier list positions (from secondary memory). These experiments thus confirmed the idea that short-term memory performance reflects two rather different mechanisms, only one of which declines with age. The research questions also shifted from the nature of putative short-term and long-term "stores" to the nature of encoding and retrieval operations themselves, and how such processes are affected by aging. These experiments were reported in a book on human aging and behavior edited by George Talland [1].

Levels of processing and environmental support

After receiving a PhD in psychology from the University of Liverpool in 1965, I moved to a faculty position at Birkbeck College, University of London. I had no need to study aging in this new position so my research interests focused on the nature of primary memory (which later morphed into the construct of working memory, the idea that information held in conscious awareness may be manipulated in the service of encoding, retrieving and other higher level cognitive operations) [2]. My own thinking about memory encoding processes led to the notion of levels of processing [3]. The idea here is that memory performance may be understood in terms of the depth of processing carried out on the events to be remembered, where deeper processing refers to the engagement of meaning, and to the integration of the encoded event with its present context and with related knowledge. Empirical studies based on these ideas [4] confirmed their power, so I then wondered if age-related memory problems might be attributable, in part at least, to the notion that when older adults experience events they do not process them so deeply or elaborately as do their younger counterparts.

Around this time (the early 1970s) I was invited to write the chapter on human memory, and this contribution [5] renewed my interest in the problems of aging and memory. The chapter stressed the importance of "repairing" inefficient encoding and retrieval processes in older adults; deeper encoding could be achieved by asking simple semantic questions about each word in a list to be learned (*e.g.*, an article of clothing? SHIRT), and retrieval problems could be alleviated by giving a recognition test at a later point (Was TIGER on the list? Was SHIRT on the list?), rather than a recall test. An experiment in which younger and older participants learned a list of words, and later *recalled* as many words as possible, found large age-related decrements (the typical result). But when semantic questions at encoding were paired with a recognition test at retrieval, the age differences (in the same participants) were eliminated [5]. My interpretation was that there *are* age-related impairments in the management of encoding and retrieval processes, but that the inefficiencies can be repaired by providing more "environmental support" to both sets of processing operations. As described later, in the absence of such support from either the environment or the person's accumulated knowledge base, older individuals lack the cortical control mechanisms to initiate and carry out the requisite encoding and retrieval operations.

These ideas were illustrated in an experiment carried out with two colleagues in California [6]. The task was to recall a list of 10 common nouns presented auditorily, and recalled orally immediately after presentation. There were four conditions, involving different words on each experimental trial. In the first condition (free presentation, free recall), participants simply tried to learn the 10 words, and were then signaled to recall as many as possible. In the other three conditions, each word was accompanied by a descriptive cue, for example, a type of bird–LARK, part of a tree–TWIG. In the second condition (free presentation, cued recall) participants learned the unaccompanied list of words, but were provided with relevant cues in the retrieval phase *e.g.*, what word was part of a tree? In the third condition (cued-free), participants were provided with the cues at the time of learning (to help you remember the words), but were then asked to recall without hearing the cues again. And finally in the fourth condition (cued-cued), the descriptive phrases were provided both during learning and during the recall phase. The idea here was to manipulate the degree of environmental support during the encoding and retrieval phases.

Three groups of participants in their 70s performed the experiment, as well as one group of young adults in their late teens and early 20s. All of the older adults lived at home and looked after themselves, but they differed in their income levels and also in their levels of everyday activity. One older group (Old-1) were members of an affluent retirement community and led active lives. A second group (Old-2) were less affluent but participated in an active Foster Grandparents' Program in which they worked with developmentally disabled clients at a local hospital. The third group of older adults (Old-3) had lower incomes and were individuals who participated in a senior citizens' program which offered activities that were neither physically nor mentally challenging (*e.g.*, sing-alongs, bingo). The young adults were university undergraduates.

In general, successful recall increased successively from the free-free condition, through free-cued and cued-free to the cued-cued conditions. Recall also increased across the four groups from Old-3 (mean of 3.1 words) to Old-2 (mean of 5.5 words), to Old-1 (mean of 6.0 words) and Young (mean of 6.3 words), but the interest is also in the interaction of environmental support with each group's general ability level. So, for example, the young adults performed well without any aids (free-free) but benefited further from the cues during both learning and recall. On the other hand, the Old-3 participants performed quite poorly on the first three conditions; they did benefit from the cued-cued condition although they did not attain the level of other groups. In a further comparison, the Old-1 participants performed at the same level as the young participants in the most supported conditions, but were significantly poorer in the unsupported condition (free-free). The main message of the study is that theories of cognitive performance must model the interactions among characteristics of individuals (*e.g.*, age and ability levels), the characteristics of specific tasks, and the support provided by the environmental context.

An age-related decline in "processing resources"?

Why should older adults process events less deeply and elaborately? My assumption at the time [7] was that aging is associated with a decline in attentional resources, the notion that the amount of attention that can be deployed is limited in capacity, and that this limit declines in the course of aging. That is, older adults have fewer relevant resources (a sort of mental energy) to adequately fund the encoding and retrieval processes necessary for good memory performance. Presumably the limit on such resources has a biological basis—a limit on the simultaneous allocation of blood supply to relevant brain regions, or a limit on the total amount of neural activity possible at any one time, but no clear answer is available at present.

In one experiment exploring age differences in these terms [8], we again contrasted recall with recognition tests. Younger and older adults first studied lists of 12 words in which each word was accompanied by a descriptive phrase (*e.g.*, A body of water–POND). Participants were tested on ten such lists; five lists (at random) were tested immediately after presentation of each list by cued recall, and the 60 words in the remaining five lists were tested in a recognition test in which the 60 presented words (without cues) were mixed with 60 new words after presentation (and recall) of all ten lists. In an attempt to quantify the notion of processing resources, participants also performed a continuous 4-choice reaction–time (RT) task both alone and during the retrieval phases. The RT task consisted of a visual display of one of four alphanumeric characters, with each character associated with one of four response keys. A correct key-press response caused a further character (chosen randomly) to appear immediately, so when the RT task was performed by itself for one minute (baseline performance), the participant's processing abilities were fully occupied. The visual-motor RT task was also performed concurrently with the memory retrieval tests. In the recall test for each list, the 12 descriptive phrases were presented auditorily at a 5-s rate, and the participant attempted to recall the associated word orally. In the recognition test, a series of 12-word lists (6 targets mixed with 6 lures) were presented auditorily at a 5-s rate, and the participant responded "yes" or "no" orally depending on whether the word had been studied previously. Performance on the RT task was obviously slowed by the concurrent effort to recall or recognize words; our assumption was that the amount of slowing (RT costs) would measure the attentional resources necessary for the retrieval operations. We were therefore interested both in any age-related differences in the levels of recall and recognition, and also in age-related differences in retrieval costs. Our predictions were that retrieval costs would be greater in the older participants (owing to their depleted attentional resources) and that costs would generally be greater for recall than for recognition (owing to the enhanced environmental support provided by recognition tests).

The results showed exactly that pattern. The amount by which the RT task was slowed from baseline (task alone) to performance concurrently with retrieval, was greater for older than younger participants, greater for recall than for recognition, and the two variables interacted—the recall-recognition difference was greater in the older group. The memory results were also in line with prediction; there was an age-related decrement in recall, but no significant age difference in recognition. Looked at from another angle—age-related declines in memory may be attributed in part to a reduction in available processing resources, but these losses may be mitigated by providing greater contextual support at retrieval.

Environmental support, self-initiated activities, and aging

In two theoretical papers in the 1980s [9], I proposed the idea that normal perception and comprehension of events involves both information from the external environment and mental operations performed on that information. Further, that memory retrieval essentially reflects the cognitive system attempting to re-create as nearly as possible the same set of mental operations associated with processing the original event. The success of these retrieval processes will therefore be facilitated by the extent to which the retrieval environment provides the same (or a similar) set of circumstances that existed at the time of the initial event—including physical surroundings, but also weather conditions, social conditions, mood, and indeed everything that contributed to the quality and meaning of the original experience. This notion of environmental support is in line with the common observation that memory is aided by reinstatement of the event's initial context, and by experimental findings that recognition memory (in which the target event is re-provided along with similar lure items) is typically superior to unaided recall.

However, it is clearly possible to remember events in very different present surroundings (last year's summer holiday in Spain remembered in Toronto in February!), so the re-creation of the initial experience must be accomplished by what I termed self-initiated activities—mental operations initiated top-down on the basis of accumulated personal knowledge, and presumably guided by approximations to the sought-for recollection. It seems likely that such control processes reflect operations in the frontal lobes [10]. My further suggestion was that self-initiated activities and environmental support are complementary—more of one requires less of the other, and that different types of memory and learning reflect this balance. For example, procedural learning of a cognitive or physical skill involves a lot of environmental support but requires little in the way of self-initiated activity, whereas free (unaided) recall requires a great deal of self-initiated activity [11].

With regard to aging, my suggestion was that self-initiated activities are less efficient in older adults—possibly owing to the declining effectiveness of frontal lobe operations with age [12]. It follows then that older adults must rely more than their younger counterparts on environmental support for memory to be successful, and that the extent of the age-related memory decrement should be reduced as a function of the degree of environmental support provided. Exactly this pattern was shown in the comparisons of recall and recognition described previously [8, 13] and in studies in which encoding cues are gradually reprovided at retrieval [6].

The conclusion that age-related memory problems are at least partly attributable to the declining efficiency of frontal lobe functions is now generally accepted [14, 15], but it is likely that other brain regions are also involved. In particular, medial-temporal regions are known to be heavily involved in the initial encoding of episodic events, and age-related atrophy in these areas is linked to memory impairments [14, 16].

Prospective memory and aging

Prospective memory (PM) is remembering to carry out an intended action at a later time; it could be after seconds (fetch a book from upstairs), hours (collect milk on the way home), or days (your mother's birthday next week). Some researchers proposed that PM is a separate memory system, but my own view is that the behavior simply reflects the normal sequences of encoding and retrieval. It is an error-prone form of memory because the intention (especially for everyday domestic instances) is often set in a casual, transient manner, and the planned retrieval context often provides few or no reminders to carry out the action—especially in time-based PM cases.

With regard to aging, some early work suggested that PM holds up well with age [17], but subsequent work, and my own view, is that PM is one form of memory that is particularly vulnerable to the aging process. This perspective follows from the points that older adults may encode intentions less deeply and elaborately, and also that they lack the ability to overcome the absence of a supportive context at retrieval with self-initiated compensatory retrieval processing. We have carried out lab experiments that showed this result [18], but interestingly in a real-life version of the same tasks older adults actually performed more successfully than their younger counterparts. This paradoxical difference between lab and real life tasks has also been observed by other researchers. One possibility is that older adults typically have a more regular and structured lifestyle than the younger adults, who were university students. Another possibility is that the older participants were more involved in the real-life experiment, were more motivated to succeed, and thought more about the tasks they must perform. This feeling of being "in an experiment" and having their actions monitored does not apply to normal daily activities, so my present view is that PM abilities typically decline with age, but can be overcome by heightened awareness and motivation under some conditions.

Aging and memory: evidence from neuroimaging

The University of Toronto obtained a positron emission tomography (PET) scanner in the early 1990s, and I then became involved in collaborative PET studies of memory with Endel Tulving and others. One of these studies [19] found that the intentional learning of words for a later memory test was associated with enhanced activation of neural tissue in the left inferior prefrontal cortex (PFC), whereas later retrieval of the same words was associated with activations in the right PFC. This encoding/retrieval asymmetry was explored in older adults by Cabeza *et al*. [13]. The study found that aging was associated with decreased neural activation in the left PFC and occipitotemporal regions during encoding, and in the right PFC and parietal regions during retrieval. These decreases in activation were interpreted as showing less efficient processing in older adults, possibly giving rise to their poorer memory performance. The same study found increased neural activation in older participants in the left PFC during recall, and also increases in bilateral PFC and in the cuneus/precuneus in a recognition test. These age-related increases in activation were speculatively attributed to functional compensation in the older brain as compensatory activities for the reduced efficiency of other brain regions.

Although I have participated in several further brain-scanning studies of age-related changes in memory, my main later contributions to the area have been in the form of opinion pieces, reviews and commentaries [20-24]. It is currently an active area, but there is still much to be understood about how age-related changes in brain structure and function relate to changes in memory performance.

Hallmarks of aging: memory changes

By way of summary, here are some hallmarks of age-related changes in memory as I see them. Memory *does* decline in the course of healthy aging, but more so in some situations than in others, and more with some types of memory than with others. Further, some age-related memory problems can be mitigated or even eliminated under certain conditions. Holding some small amount of information in mind—a short telephone number shows very little change with age, so testing a person's memory by asking them to repeat 3 or 4 digits or words is not a valid test of general memory ability. When the material held in mind must be manipulated and reorganized, however (working memory), age-related changes emerge. For example, I have used a test in which an individual is given a short list of words and asked to repeat them back in correct alphabetical order ("alpha span"), and performance on this test declines with age [25]. But most real-life memory problems in older adults are seen in situations in which the individual learns some information or simply processes an event without any specific intention to remember it later. I suggest that in such cases older adults do not process the information as deeply and elaborately as do younger adults. These age-related deficits can be repaired, however by inducing semantic processing in various ways, as described in the previous sections. Retrieval processes are also inefficient in older adults, but can again be repaired by supplying more environmental support—as in recognition testing. As described earlier, prospective memory is particularly vulnerable to aging, for the same reasons—encoding is often perfunctory, and retrieval of the intended action often takes place in the absence of environmental support. Another major hallmark of age-related memory problems is a deficit in associating and integrating disparate fragments of information, or associating new information to its context of occurrence [26]. Adequate assessment of age-related memory problems should therefore touch on these various aspects of strength and weakness, and should also assess the ability of older individuals to benefit from the support provided [6].

Declarations

Availability of data and materials: Not applicable.

Financial support and sponsorship: None.

Conflicts of interest: Not applicable.

Ethical approval and informed consent: Not applicable.

Consent for publication: Not applicable.

AI and AI-assisted tools statement: Not applicable.

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Cite this article as: Craik FIM. Aging and memory: a personal perspective. *Aging Pathobiol Ther*, 2026, 8(3): xx-xx. doi:10.31491/APT.2026.09.xxx