Aging and Memory in Humans

A M Brickman and Y Stern, Columbia University, New York, NY, USA

Memory Systems

Memory is the explicit or implicit recall of information encoded in the recent or distant past. Current conceptualizations of memory, however, do not view the construct as a unitary system but rather divide it into hierarchical taxonomic modules based on duration of retention and the type of information that is being retrieved. Among the more fully elucidated conceptualizations of memory systems is one characterized by Larry Squire and colleagues, in which long-term memory is divided into declarative and nondeclarative subcomponents. Declarative, or explicit, memory refers to the ability to consciously recall facts (semantic memory), events (episodic memory), or perceptual information (perceptual memory). Nondeclarative memory requires the implicit recall of information and is usually divided into procedural, priming, or simple conditioning paradigms. Information that is retained on the order of seconds or minutes is usually referred to as short-term memory and is thought to represent a memory system distinct from long-term memory. Working memory, which comprises short-term memory, refers to the short-term store required to perform certain mental operations during retention. The following sections examine the impact of normal aging on different types of memory, as well as some of the potential moderators and mediators of cognitive aging. The information presented is organized hierarchically, following the memory systems just outlined.

Increased age puts an individual at risk for the development of neurodegenerative disorders, such as Alzheimer's disease (AD). Central to the dementia syndrome that characterizes AD is the gradual and progressive loss of long-term memory functions. Although the vast majority of older adults do not develop dementia, most experience some degree of cognitive change. Following the elucidation of memory systems and their component parts in the cognitive and cognitive neuroscience literature, there has been a recent interest in the impact of age on the different memory systems, independent of the devastating effects of dementia. Among well-screened individuals who do not meet diagnostic criteria for dementia, both cross-sectional and longitudinal studies demonstrate that the different memory component systems do not uniformly age; rather they show differential vulnerability to aging effects.

Long-Term Memory

Declarative Memory

Semantic memory As noted, semantic memory refers the recall of general or factual knowledge. Older adults commonly complain of subjective semantic memory problems when, for example, they report difficulty recalling the names of common objects or other well-learned information. Yet, despite these subjective complaints, semantic memory is among the more stable memory systems across the adult life span. The construct can be operationally defined by requiring subjects to define words or provide the answers to factual questions (e.g., the capital of a certain country), such as on the Vocabulary and Information subtests of the Wechsler Adult Intelligence Scales. Semantic memory is often included as part of the definition of 'crystallized intelligence,' which reflects an accumulation of information acquired over time and that is relatively impermeable to the effects of normal aging or mild brain disease.

It is well established that semantic memory shows very little decline in normal aging. In fact, semantic knowledge accumulation and memory increase into the sixth and seventh decades of life and may show only a gradual decline afterward. Much of our understanding of the impact of age on semantic memory has come from large-scale longitudinal and cross-sectional studies of normal aging. For example, longitudinal data from the Canberra Study , which followed a random sample of adults over the age of 70 years, demonstrated that crystallized abilities remained stable over approximately 8 years. This pattern of stability was apparent when age-associated differences (i.e., cross-sectional analysis) were considered as well. Similarly, Denise Park and her colleagues measured knowledge-based verbal ability, including three semantic memory tasks tapping word knowledge, in a large sample of healthy adults ranging in age from 20 to 92 years, and found a gradual increase in performance across the age groups. This finding is again consistent with the idea that semantic knowledge accumulates across the life span with little or no deleterious effects of normal aging.

Although there is little cross-sectional or longitudinal evidence to suggest that semantic memory changes significantly with normal aging, why are subjective complaints of semantic recall so common among older adults? One phenomenon, termed 'tip-of-the-tongue' (TOT), may explain this occurrence. TOT refers to the common experience in which individuals have the feeling that they know the correct information (e.g., a person's name, a relatively low-frequency word), yet they are unable to recall it explicitly. The frequency of the TOT phenomenon increases with advancing age and may underlie the perceived difficulty with semantic recall.

Episodic memory The contrast between episodic memory and semantic memory was introduced by Endel Tulving in the early 1970s. Episodic memory refers to the explicit recollection of events, the 'what,' 'where,' and 'when' of information storage, and though it is conceptually distinct from semantic memory, the two memory systems interact. Episodic memory binds together items in semantic memory to form conceptually related time-based events. For example, the explicit recall of a learned story about a cowboy requires episodic memory for the story and semantic memory, or prior knowledge, of the items contained within the story.

Unlike semantic memory, episodic memory declines considerably with age. Older adults, for example, when prompted, have more difficulty recalling what they had for breakfast than do younger adults. The formal observation that episodic memory is affected by aging has existed for decades and has been documented numerous times.

Episodic memory is typically tested by requiring persons to learn information explicitly (e.g., a list or story) and recall it after a delay period. The three aspects of episodic memory include the encoding phase, the storage phase, and the retrieval of the encoded and stored information. These three phases show differential aging effects. Older adults' overall difficulty on tasks of episodic memory may be partially accounted for by a more shallow depth of encoding, as compared to younger adults – that is, older adults recall less information because of more limited processing of the initial study stimuli. This idea is supported by findings of greater age-related decline in acquisition or early retrieval of new information than in the degree of forgetting (i.e., the amount of information lost relative to the amount of information encoded). However, on free-recall tasks of list-learning paradigms, older adults recall fewer absolute words than do their younger adult counterparts; when given the correct stimulus in a recognition paradigm, older adults tend to incorrectly endorse more distractor stimuli, or foils.

Several observations about episodic memory and aging have emerged from the recent literature. First, the pattern of age-related differences in episodic memory appears to be similar across several modalities and domains, such as story recall, paired associate learning, face and word recall, and recognition paradigms of verbal and nonverbal information. Second, cross-sectional data suggest that age-associated episodic memory decline begins as early as age 20 years and decline linearly until about age 60, at which time there is a more precipitous decline. Third, whether the amount of interindividual variability increases systematically as a function of age is still somewhat unclear. Greater variability with aging would suggest that episodic memory decline might be a marker for insipient brain pathology, rather than a primary aspect of normal aging.

There are several competing theories postulating the potential mechanisms for age-associated declines in episodic memory. They can generally be divided into four areas, including an age-related failure of memory monitoring, or metamemory; age-associated decreases in the depth of initial encoding; age-related impairment in processing of contextual information; and age-associated decline in a number of processing resources. While these theories have not been fully substantiated empirically, the latter has received the greatest amount of support in the cognition literature. Proponents of a 'resource reduction hypothesis' argue that central to age-associated changes in episodic memory is a reduction in primary cognitive resources such as attention or working memory, or a reduction in the ability to engage due to an age-associated diminution in attentional inhibitory control. Others argue that age-associated memory decline is not due to a reduction in available attentional resources *per se*, but rather to age-related declines in perceptual processing speed.

Source memory Episodic memory comprises the information that is being recalled as well as the context in which the information was learned. This latter aspect is referred to as source memory, and there is increasing evidence that even when older adults successfully recall information, they may have difficulty recalling the source in which the information was acquired. The phenomenon has been demonstrated in the identification of the temporal context in which an item was learned, as well as the spatial and perceptual context. Studies by Daniel Schacter and colleagues required older adults to listen to different speakers read different blocks of declarative statements, and found that memory for the source of the declarative sentences was disproportionately worse than was memory for the statements. This general finding has been well replicated and has been extended to demonstrate age-associated impairment in both specific-source memory and partial-source memory. For example, older adults have difficulty, relative to younger adults, remembering which of four people spoke a word (i.e., specific-source memory) as well as remembering partial information about the person who spoke the word, such as his or her gender (i.e., partial-source memory).

Nondeclarative Memory

Nondeclarative, or implicit, memory describes the memory system that allows learning outside of conscious awareness. It is generally divided into procedural memory and priming, each hypothesized to be mediated by a distinct neurobiological system. In general, nondeclarative systems are relatively spared across the adult life span, particularly compared to episodic memory, which shows the greatest aging effects.

Procedural memory Procedural or skill learning is one type of nondeclarative memory that refers to the nonconscious acquisition of motoric sequences. A common example of procedural memory is the process of learning how to drive an automobile. Initially, a novice driver needs to recollect consciously how to control each aspect of the automobile and the sequence in which to do so. With practice, the individual skill required to operate the vehicle enters into procedural memory, and control becomes relatively more automatic.

Little work has been conducted that explicitly examines the impact of chronological age on procedural memory, and results have been somewhat inconclusive; some studies show a decline with age and others show no apparent aging effect. A potential confounding factor in the examination of procedural memory among older adults is how much the experimental paradigm draws upon pure motoric speed and on other nonprocedural cognitive abilities, such as working memory, as well as whether the experimental paradigm addresses procedural learning versus long-term procedural memory. Studies that examine the effects of age on experts, such as pianists or typists, show a general trend of age-associated slowing, but a relative maintenance in measures of performance. Age-associated preservation of procedural memory may also be dependent on the amount of deliberate practice.

When considering age effects on procedural memory, it is important to dissociate performance time, learning, and memory for the task. For example, older adults tend to perform procedural memory tasks more slowly and learn procedural sequences at a slower rate, compared to younger adults. However, after initial acquisition, older adults will relearn a procedural memory task at rates similar to or more rapid than the rates at which younger adults relearn, even after a 2-year interval without practice. While procedural memory and aging remain somewhat understudied, there is some consensus that older adults have lasting preservation of procedural or motor memory. It is important, however, to distinguish between age-associated changes in motoric or perceptual processing speed and age-related changes in procedural memory; when accounting for aspects of the former, the latter appears to be relatively spared.

Priming Repetition priming is a special type of implicit memory that refers to the implicit impact that prior exposure to a stimulus has on later test performance. For example, an individual is more likely to complete the word stem STR__ with ONG (to form the word STRONG) than with EET (to form the word STREET) if he/she had previously studied the word STRONG. There is a long history of the examination of aging effects on priming in multiple modalities, with somewhat mixed results. In general, studies from the 1980s suggested that there are few differences between younger and older adults for priming across a number of tasks, such as word stem completion, picture naming, and word identification. There is evidence of a strong dissociation in the elderly between a preserved ability to perform implicit tasks and a deficit in performance on declarative tasks when compared to younger participants, although there are small, but reliable, age-associated decrements in priming for verbal abilities regardless of whether the dependent measure is accuracy or latency or whether the type of priming is item or associative.

Investigators such as John Rybash have distinguished among five types of priming, including (1) perceptual-item priming, (2) perceptual-associative priming, (3) conceptual-item priming, (4) conceptual-associative priming, and (5) perceptual-motor priming. Perceptual tasks are dependent upon implicit recall of properties of the stimuli presented during encoding, whereas conceptual tasks refer to priming for object meaning. There is some evidence that with normal aging there is relative preservation of performance on tasks that require perceptual priming and a relative decline in tasks that require conceptual priming. However, other investigators, such as Debra Fleischman and John Gabrieli, argue that studies that have shown no aging effect for priming may have had insufficient measurement reliability or power to detect age differences, and positive studies may have included a minority of individuals with insipient dementia. In contrast to Rybash, they argue that perceptual priming is vulnerable to aging effects, whereas conceptual priming remains relatively intact. Differences between these two conclusions may reflect differing positions on inclusion criteria for categories of priming.

For example, Fleischman and Gabrieli exclude all tasks that might include the processes that explicit memory retrieval tasks also engage. Further, they consider tasks such as category-exemplar generation to be conceptual, whereas Rybash considers these to be perceptual. In summary, although the literature is somewhat mixed, the effects of normal aging on repetition priming are of small magnitude or nonexistent, depending on modality.

Short-Term Memory

In contrast to long-term memory, in which information is stored for minutes to years, short-term memory refers to holding information in conscious awareness for the duration of seconds. While short-term memory is qualitatively a type of memory distinct from long-term memory, the two systems interact. For example, in order for information to be stored in long-term memory, the information must first exist within short-term memory. The exact mechanisms by which short-term memory is transferred to long-term storage have yet to be fully elucidated, but the 'modal model' of information transfer, proposed by Atkinson and Shiffrin in the 1960s, provided a theoretical framework that has dominated the cognitive literature for decades. Briefly, information flows from the environment to primary sensory (perceptual) stores and then into a short-term store, which can include rehearsal, coding, or decision. The capacity of the short-term store is limited and information can leave the system (i.e., forgetting), lead to a response output, or enter long-term storage, which is fairly permanent. When information is drawn from long-term memory, it exists in short-term memory while in conscious awareness. In terms of the capacity of short-term memory, a heuristic offered by Miller in the 1950s is that the average short-term memory span for a person is seven, plus or minus two items, or chunks. Although this heuristic has remained popular, more recent studies suggest that short-term memory span is closer to four items, or is contingent upon an individual's processing speed.

The term 'short-term memory' refers to the passive short-term store of information, but speaks little to the process by which information is retained in the store. It is difficult to discuss the effects of age on short-term memory without consideration of these processes. The term 'working memory' is typically applied to the process by which information is held in short-term memory and refers to the cognitive manipulation of information that is contained within short-term memory. An influential model that attempts to explain how information is stored within short-term memory was proposed by Baddeley and Hitch, in which a supervisory 'central executive' controls the information flow among three 'slave systems,' including the phonological or articulatory loop, the visuospatial sketchpad, and the episodic buffer. The first two systems rehearse phonological or visual information, respectively, and the third system integrates information from the other two systems and interfaces with long-term memory. The central executive acts to coordinate the flow of information among the slave systems, to direct attention to appropriate internal and external stimuli, and to suppress irrelevant stimuli.

Working memory paradigms require individuals to perform mental operations on items held in conscious awareness, such as reordering words or numbers. While there is little evidence that short-term memory *per se* significantly declines with normal aging, there is ample evidence that working memory abilities do. Within working memory, efficacy of inhibition and smaller span are particularly vulnerable to the effects of aging.

Working memory in aging studies is often operationally defined by tasks such as letter rotation, reading span, computation span, and line span. Performance on these tasks tends to show a linear age-associated decline that is similar to that seen for tasks of long-term episodic memory and speed of processing. Some research suggests that age-associated decline in working memory abilities mediates age-associated decline in other memory and cognitive domains. Indeed, statistical control of performance on tasks of working memory often attenuates the observed age-associated decline on other cognitive tasks.

Summary and Course

Normal age-associated memory decline is not uniform. Older adults evidence worse performance on long-term memory tasks compared to younger adults, but these differences are relatively greatest on tasks of declarative episodic memory. Semantic memory, on the other hand, remains relatively stable across the adult life span or may even increase as more semantic knowledge is accumulated with age. Similarly, working memory, or the manipulation of information that is held in conscious awareness, shows marked decline in with normal aging, and some theorists propose that working memory deficits mediate age-associated decline in other cognitive domains.

In terms of the course of memory changes across the adult life span, results from cross-sectional and longitudinal studies suggest that subtle memory changes can begin as early as the early or middle twenties and continue to decline linearly with age. Some authors distinguish between 'lifelong decline' and 'late-life decline.' Performance on tasks of episodic and working memory seems to begin to decline in the twenties and continues to decline linearly across the life span, which is supported by cross-sectional aging and cognition studies. Some longitudinal studies, however, suggest a curvilinear course of memory decline, with a more precipitous decline after about age 60 years, preceded by relatively little decline with age. Short-term memory store appears to remain relatively stable until about age 70, at which point it begins to drop, and, as noted, semantic abilities appear to remain relatively stable, at least until late life.

Moderators and Mediators of Cognitive Aging

A consistent observation in the aging and cognition literature is a greater amount of variability in memory performance with increasing age. This finding is evident both when age is considered as a cross-sectional variable and when individual age trajectories are examined over time; some adults experience great amounts of cognitive decline while others experience relatively little. Increased variability suggests that there are moderators and mediators of cognitive aging. Two factors in particular, including cerebrovascular or cardiovascular risk and cognitive reserve, have received considerable attention as modulators that may account for some of the increased variability, and these are potential targets for intervention or prevention of cognitive decline.

Cerebrovascular or cardiovascular risk factors may mediate the relationship between chronological age and the neurobiological changes that underlie cognitive aging. Increased blood pressure is associated with reduced psychomotor speed, visuoconstruction ability, learning, memory, and executive functioning. Similarly, both insulin resistance and diabetes are associated with diminished cognitive abilities in later life. Hyperlipidemia has also been identified as a potential cerebrovascular risk factor that negatively impacts cognition in older adults. While it is still somewhat unclear by what mechanism cerebrovascular or cardiovascular risk factors impact cognition, it is likely that they interact with age to have a cumulative effect on cognition in later life. Furthermore, intervention studies that target the vascular system, such as cardiovascular fitness regimens, are associated with increased cognitive functioning among older adults.

Cognitive reserve is another factor that may account for the increased variability observed in cognitive aging. The cognitive reserve hypothesis stems from the observation that there is a disconnection between degree of brain pathology and its cognitive manifestation and suggests that the brain actively attempts to cope with brain pathology by using existing processing approaches or by recruiting compensatory networks. Although cognitive reserve is often applied to clinical entities, such as AD or stroke, it may be operative among the normal aged. That is, cognitive reserve may moderate the relationship between normal age-associated neurobiological changes and their cognitive outcome. Indeed, proxies for reserve, such as measures of education or literacy and IQ, are related to the degree of age-associated memory decline. Declarative memory scores of older adults with lower levels of literacy decline at a greater rate than do those with higher levels of literacy. Like vascular risk factors, interventions that target cognitive reserve may improve the course of cognitive aging.

Other factors, such as genes and nutritional exposure, could potentially impact the course of memory decline with normal aging. It is also important to note that the possibility of inclusion of individuals with insipient dementia may have contaminated some studies that attempted to elucidate the pattern of age-associated memory decline, and future studies of normal aging should focus on disentangling normal cognitive decline from pathological aging at the earliest point possible. With the powerful capabilities of neuroimaging techniques, we can begin to understand the complex relationships among normal aging, neurobiology, and cognition while defining potentially modifiable moderators and mediators of cognitive aging.

See also: Aging of the Brain; Aging of the Brain and Alzheimer's Disease; Aging and Memory in Animals; Basal Forebrain and Memory; Cognition in Aging and Age-Related Disease; Episodic Memory; Functional Neuroimaging Studies of Aging; Humans; Lipids and Membranes in Brain Aging; Metal Accumulation During Aging; Short Term and Working Memory.

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