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Memory and Language in Aging

How Their Shared Cognitive Processes, Neural Correlates, and Supporting Mechanisms Change with Age

David E. Warren, Rachael Rubin, Samantha Shune, and Melissa C. Duff

Key Points

- Memory and language are highly overlapping cognitive domains that share many neural correlates.
- Memory and language abilities are both subject to age-related changes which are most often detrimental and which can affect social and emotional status.
- The interactivity of memory and language processes deserves further study, especially in the context of healthy and nonhealthy aging.

Introduction

Memory and language are two quintessential human abilities that change over the course of our lives. Some of these changes are beneficial and may reflect accumulated experience and knowledge, while other age-related changes in memory and language are detrimental and reflect cognitive decline. Among older adults who are beyond their sixth or seventh decade, these declines can have profound consequences for social behavior, independence, and identity. This provides a compelling rationale for studying how memory and language change with age, and whether those changes are driven by unique or shared mechanisms. We will suggest that shared mechanisms play critical but poorly elucidated roles in age-related changes in memory and language by describing many specific changes in these cognitive abilities with age, and several important organizing theories relevant to these topics will also be discussed. Importantly, while much has been learned about these cognitive domains, much also remains to be discovered, and even the best available frameworks are inadequate to describe the full breadth of the changes in memory and language with age. Our goal is for this chapter to serve as a concise and targeted summary of the current state of an evolving field.

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Current research into the effects of age on memory and language abilities should be considered within our more general understanding of the aging process. This includes both universal trends such as changes in sensory function (e.g., visual and hearing loss; see chapters 15 and 16) as well as significant interindividual differences in the stability of cognitive performance with increasing age that may be attributable to lifestyle, genetic, or other factors (see chapters 29–31). While these are important considerations, extensive research has identified general principles that describe how memory and language abilities are predicted to change across the lifespan (independently and interactively).

At the broadest level, most everyday memory abilities decline with increasing age, but existing knowledge and skills are typically maintained or improved. In language, age-related changes appear less deleterious, yet alterations in both low- and high-level language processes may subtly alter verbal communication. And while memory and language are often studied separately, insight into interactions between the two sets of processes in cognitive aging can be gleaned from existing work. For example, positive age-related memory-language interactions are exemplified by steady improvements in vocabulary size throughout adulthood (i.e., learning and use of new words); negative age-related memory-language interactions are exemplified by word-finding difficulties later in life (i.e., failure to retrieve a word while conversing). The challenges inherent in studying complex interactions between memory and language are many, but these interactions reflect real-world challenges facing older adults beyond the laboratory. While many open questions remain in cognitive aging research focused exclusively on memory or language topics, we speculate that those independent domains have developed to the point that investigations targeting the intersections of memory and language have the potential to be especially informative.

This chapter is a selective consideration of important topics in memory and language within the literature of cognitive aging. First, we summarize cognitive aging findings focused on memory abilities, and following that section is a similar summary of cognitive aging findings addressing language abilities. Then we briefly present several relevant theories of cognitive aging that are applicable to the study of memory, language, or both. Finally, we conclude by discussing the promise of studies probing the intersections of memory and language through behavior, neuropsychology, and neuroimaging which point toward possible shared mechanisms.

Memory and Aging

Memory is the ability to encode, store, and retrieve information related to past experience. You possess memories of objects you have seen, conversations you have had, and skills you have learned. The processes that support memory rely on many other cognitive processes; similarly, the neural correlates of memory interact with many other brain systems. These systems are exercised when new information is first sensed and then perceived in order to invoke a high-level memory process such as a recollection that may guide subsequent behavior. For example, when a colleague asks whether you've completed the big project, you sense the auditory stimulus, perceive the words, comprehend the meaning, retrieve the status of the work, and decide to respond, "Not yet, but by the end of the day!" Thus, while memory can be conceptually separated from other cognitive abilities, it also depends on them. And while our example illustrates one type of memory, different memory systems exist throughout the brain and can support learning of very different types. This section will describe two distinct types of memory (declarative and non-declarative), the brain regions and networks that support these types of memory, and the way these brain systems change over the lifespan with a focus on age-related memory changes in older adults. Selected examples are provided to familiarize the reader with important paradigms used to study different types of memory.

Multiple memory systems perspective: Declarative and nondeclarative memory

Older adults often complain that their memory is worse than it used to be. While this sentiment suggests that memory is a single ability, age changes some types of memory more quickly than others. This section will review supporting evidence for the perspective that memory is not a single ability; rather, memory is made up of functionally distinct processes that rely on separable brain systems[1,2] (see Figure 14.1 for a taxonomy of memory). A high-level example of this functional separation is found in the difference between long-term memory (durable and long-lasting) and short-term memory (immediate but temporary).[3] Short-term memory has its own sophisticated taxonomy which distinguishes, for example, simple maintenance of information (short-term memory) from operating on the contents of different, sensory-specific short-term memory stores (working memory).[4] The literature of short-term and working memory is extensive,[5] but the remainder of this section will focus on distinguishing between different forms of long-term memory.

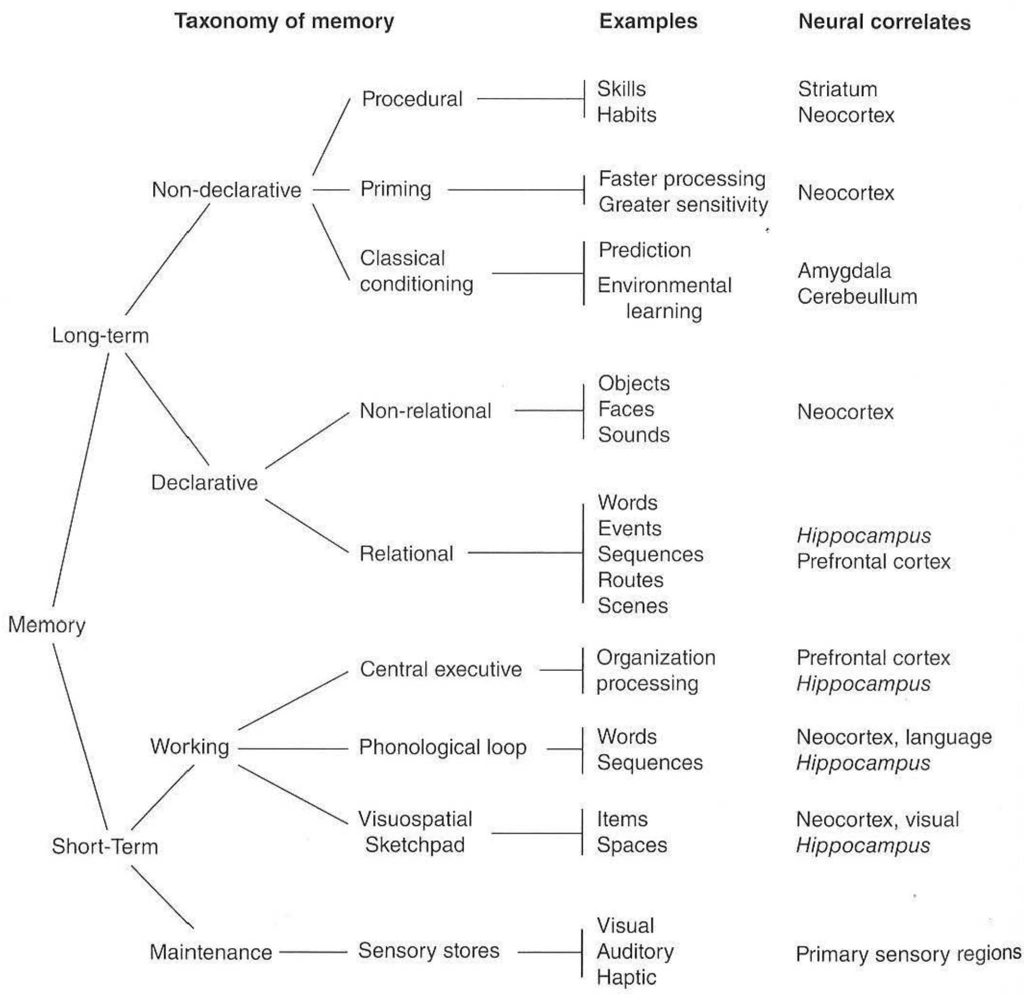

Figure 14.1 A taxonomy of memory to illustrate the organization of human memory systems as described in this chapter. The expanded role of the hippocampus in online processing or "memory-in-the-moment" is indicated by its inclusion (in italics) as a neural correlate of certain short-term or working memory processes. Many alternative modern taxonomies exist, each emphasizing a unique theoretical perspective and describing a unique hierarchy.[14–16] (Loosely based on Figure 1 in Squire and Zola[6]).

The *multiple memory systems* perspective describes a functional and anatomical separation of two types of long-term memory: declarative memory and nondeclarative memory (sometimes called "procedural memory"). The declarative memory system allows us to make *new*, *long-lasting* memories for facts and events (semantic and episodic memories, respectively). These memories are often expressed explicitly at the level of conscious awareness, hence the label "declarative." Declarative memory supports many abilities: the ability to access our personal histories, the ability to differentiate between similar experiences, and the ability to flexibly express stored information in support of other behaviors such as language use and decision-making.[2] Put another way, declarative memory is necessary for binding together relations among stimuli that we encounter throughout life, including information about the co-occurrences of people, places, and things as well as the spatial and temporal relations among them.[2]

Meanwhile, nondeclarative memory systems support the ability to incrementally acquire knowledge expressed through skilled performance. Nondeclarative memories are learned across many exposures as in the cases of priming, simple classical conditioning (e.g., stimulus–response associations), habituation, and probabilistic categorization.[1,6] Some forms of nondeclarative memory are expressed through physical actions or procedures (hence "procedural" memory) such as the canonical example of knowing how to ride a bicycle. When you ride a bicycle, you demonstrate memory for a complex motor pattern which coordinates your entire body and reflects the experience you gained on many previous rides. Not all expression of nondeclarative memory is so obvious, however; nondeclarative memory is often expressed implicitly (e.g., through faster or more accurate responses) rather than explicitly. The difference between these various types of learning and memory may now seem obvious, but empirical evidence for their separable nature was not obtained until about 60 years ago.

The seminal observations that support our current understanding of multiple, anatomically distinct memory systems emerged from the study of patients who developed amnesia as a result of brain damage. Findings from one profoundly amnesic person, patient H.M., were particularly influential. In 1953, H.M. underwent surgical resection of his bilateral medial temporal lobes (MTL) to alleviate intractable epilepsy. The surgery did reduce his seizure activity but left him profoundly amnesic.[7] In an era before high-quality neuroimaging data was routinely available, H.M.'s case provided researchers with a unique opportunity to study the memory of a living individual with well-characterized brain damage.

Laboratory tests showed that some of H.M.'s memory abilities were spared while others were impaired: H.M. was unable to form new memories for everyday events and performed very poorly on standard neuropsychological tests of long-term declarative memory; however, his short-term memory appeared intact. For example, H.M.'s ability to remember word lists and pictures was most impaired at long delays.[8] Similarly, his ability to form new semantic memories was impaired but previously acquired semantic memories were reportedly intact.[9] Additional research with amnesic patients revealed that MTL damage also seemed to spare nondeclarative learning for skills such as mirror reading as well as performance on tasks that stressed learning of repetitive responses.[1,10] More broadly, the non-mnemonic cognitive abilities of amnesic patients were generally thought to be intact,[7] although most researchers focused their efforts principally on the glaring declarative memory deficits. Based on these observations, a theory of multiple memory systems began to emerge. The theory suggested that there are different memory systems in the brain which support different memory processes such that forming new long-term declarative memories requires the MTL while forming new nondeclarative memories relies on other brain regions (see below).

In the decades following the seminal reports describing H.M. and other amnesic patients, the theory of multiple memory systems has been refined to provide a more detailed account of the neural correlates of memory. Findings from a wide variety of converging methods have driven this refinement, including functional neuroimaging of healthy and patient populations (see chapter 8), sensitive new neuropsychological paradigms (see chapter 7), experimentation with non-human animals (see chapter 3 and chapter 4), and molecular and cellular neuroscience among many others.[11,12] Results from studies using these advanced, complementary methodologies have continued to support the distinction between declarative and nondeclarative memory systems as well as the necessary role of the MTL for declarative memory.[11–13] In addition, the sensitivity and anatomical specificity of new methodologies have improved our understanding of how individual components of MTL contribute to memory.

The importance of MTL for memory processes is well-established, but the brain's declarative memory systems can also be considered at a finer grain within MTL as well as extending beyond MTL. Although MTL was once thought to be a homogenous functional unit, it is composed of several anatomically and functionally distinct components. These include the hippocampus, the perirhinal cortex, and the parahippocampal cortex (see Figure 14.2). Considering these MTL components in turn, the hippocampus supports the ability to form arbitrary relations among discrete elements of experience and to flexibly express those relations in service of memory. Meanwhile the surrounding regions—the perirhinal cortex and the parahippocampal cortex—support memory for individual items and contexts, respectively[2,14–16]. And while this discussion of the neural correlates of declarative memory has focused on the MTL, many important memory processes such as encoding, retrieval, and maintenance also rely on regions of the prefrontal cortex (PFC).[15,17]

Recent findings have extended the role of the hippocampus in relational memory to tasks that require relating arbitrary pieces of information across timescales and domains. The hippocampus is involved in binding information such as face-scene pairs or groups of objects at very short delays (e.g., a few seconds) or even when there is no interposed delay.[18–21] The involvement of the hippocampus has also been observed on tasks that place a high demand on relational processing outside of the memory domain, spanning abilities as diverse as navigation, imagination, creativity, decision-making, character judgments, establishing and maintaining social bonds, empathy, social discourse, and language use.[22] These findings complement the earlier perspective that MTL was necessary primarily for long-term declarative memory processes, and they suggest that when the MTL and its components are affected by age, associated cognitive functions including (relational) declarative memory will be affected as well.

While the neural correlates of declarative memory are relatively circumscribed, the neural correlates of nondeclarative memory are diffuse and highly distributed. From one perspective, what we have described as nondeclarative memory might be considered the manner in which most of the brain responds when repeatedly exposed to the same stimuli. This characterization makes declarative memory unique in two respects: its ability to bind together multisensory, multi-item information; and the limited anatomical extent of its neural correlates. Keeping that distinction in mind, the neural correlates of nondeclarative memory have been studied most thoroughly in the basal ganglia, the striatum, the cerebellum, and task-specific sensory cortical areas. Sensory cortical areas can support nondeclarative memory for previously experienced sensory information through, for example, more efficient processing of that information.[23] This is reflected in the gradual tuning and modification of neuronal populations in visual cortex during visual priming tasks. Similar tuning and refinement can be observed in the motor domain, and here the basal ganglia and striatum play important roles. The basal ganglia are associated with voluntary control of motor movements and the development of routine behaviors or habits such as the incremental learning of stimulus-response associations.[24] Dysfunction of the basal ganglia is seen in the disruption of coordinated motor movements in Parkinson's disease and Huntington's disease patients.[25] These diseases also affect nondeclarative memory selectively, disrupting learning of procedural tasks—including purely cognitive tasks that do not require coordinated movement—while largely sparing declarative learning.

In summary, the declarative and nondeclarative memory systems form two functionally and anatomically distinct systems in the brain. The extent to which these systems are differentially affected by age has implications for which memory abilities show the greatest age-related

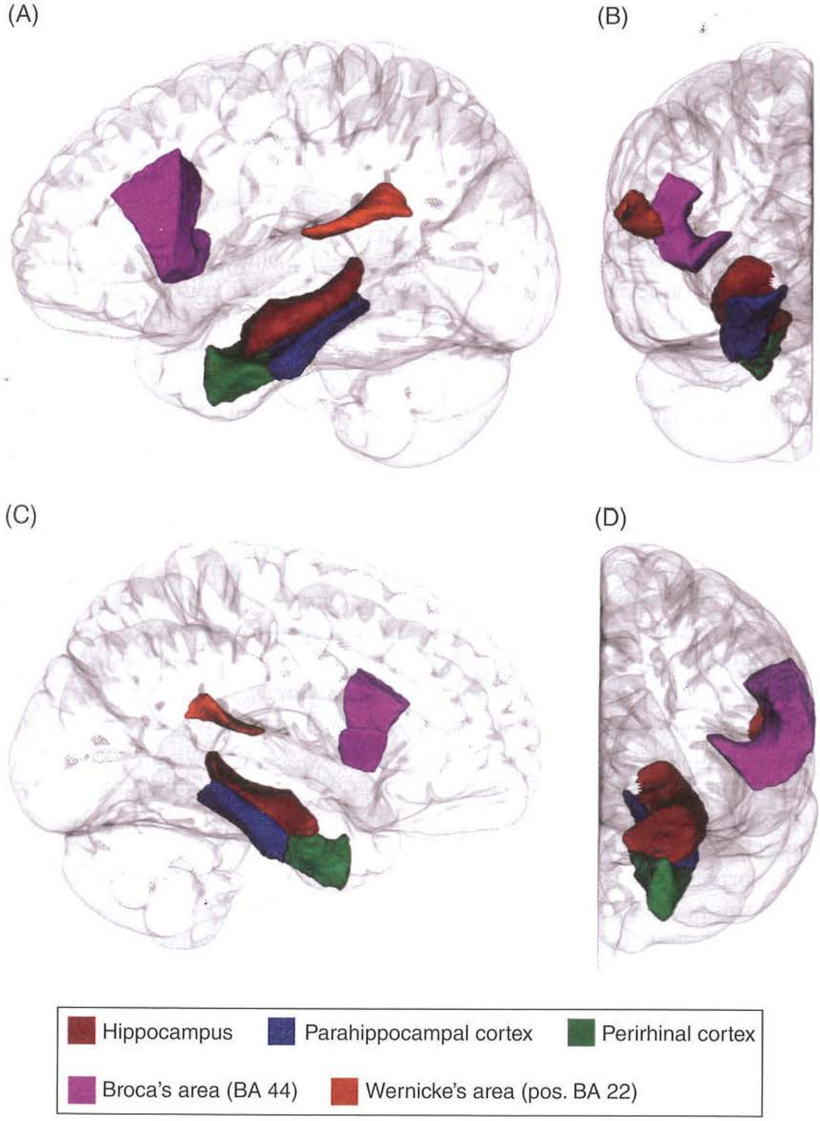

Figure 14.2 Neural correlates of memory and language processes. The neural correlates of memory and language systems are depicted as solid-color brain regions in the context of a template brain's left hemisphere (presented as a nearly transparent glass brain) from four perspectives (A: lateral, B: posterior, C: right medial, D: anterior). Brain regions supporting declarative memory are concentrated in the medial temporal lobe and include the hippocampus (red), parahippocampal cortex (blue), and perirhinal cortex (green). The hippocampus is necessary for relational memory binding together objects, places, and other information, while the perirhinal and parahippocampal cortex are necessary for memory of items and places, respectively. Brain regions supporting language are superior to the memory structures, and they include Broca's area (pink, Brodmann area 44) and Wernicke's area (orange, posterior portion of Brodmann area 22). Wernicke's area is necessary for interpretation and organization of language meaning, while Broca's area is necessary for language production.

changes. The next section reviews behavioral, neuroanatomical, and neuroimaging data examining declarative and nondeclarative memory changes in older adults. Unless otherwise specified, we will use the term older adults in reference to healthy individuals without pathology or cognitive impairment.

Changes in declarative memory

Memory complaints are common among otherwise healthy older adults such that up to half of older adults complain of decreased everyday memory function for episodic information.[26] These subjective complaints have been empirically validated and are particularly evident after the sixth decade.[27] Normative declines in episodic declarative memory function can be contrasted with the relative preservation of well-established, highly familiar knowledge including semantic and autobiographical information as well as nondeclarative or procedural memory for highly practiced skills.

In general, declarative memory for recently learned information appears to be the most disrupted memory ability in older adults. Older adults perform more poorly than younger adults on laboratory tasks requiring recall (i.e., *generating* studied information) and recognition (i.e., *identifying* studied information) regardless of stimulus type. For example, older adults are impaired relative to younger adults on memory tasks involving common laboratory stimuli such as single words or passages of text, spatial locations, pictures, faces, and activities, as well as more naturalistic stimuli, including items on a grocery list, people's names, and even golf shots (reviewed by[28]). Older adults also perform less well than younger adults when tested for memory of contextual details or so-called "source" information[29] meaning which of two or more possible sources were associated with information when it was learned.

Forming new memories places a high demand on a hallmark function of the relational declarative memory system—rapidly establishing new associative representations between individual, arbitrarily related elements of experience—and age-related memory deficits might reasonably be expected to correlate with age-related changes in the neural correlates of declarative memory. Consistent with this perspective, age-related declines in declarative and relational memory can be parsimoniously attributed to changes in cellular, morphologic, and volumetric aspects of the hippocampus and surrounding MTL structures.[30–32] The literature on age-related changes in the brain shows that the hippocampus and other brain regions comprising a cortical-hippocampal network are among the most affected by aging. Large-scale neuroimaging studies of regional brain volume almost uniformly report reductions in hippocampal volume associated with age.[33,34] Recent reports further suggest that hippocampal volume does not decline gradually with age; rather, hippocampal volume remains stable into the sixth decade and then decreases rapidly relative to other brain regions.[35] Of note, hippocampal volume loss found in healthy older adults is robust but still much less than that associated with neurodegenerative disorders such as Alzheimer's disease.[36]

The PFC also shows substantial age-related change and likely contributes to reduced memory performance through its bidirectional connections with the MTL. Longitudinal magnetic resonance imaging (MRI) studies that involve serial neuroimaging of the same older adults over several years find similar negative trajectories in PFC volume.[34,37] These decreases in PFC volume may be related to reduced source memory performance in older adults as discussed earlier. Other studies have empirically related age-related memory changes to a decline in PFC-mediated working memory abilities.[38–40] PFC-dependent changes have also been linked to reduced declarative memory performance and reduced processing speed in older adults.[41,42]

In addition to structural changes within the PFC and hippocampus, there is also evidence for functional age-related change in these regions.[39,43] For instance, studies using task-based functional magnetic resonance imaging (fMRI) have compared brain activation during memory task performance in older and younger adults. Older adults show reduced MTL activity despite successful memory encoding and retrieval.[44] These findings are consistent with a recent longitudinal neuroimaging study of older adults that measured the relationship between six-year intra-individual change in fMRI signal and change in declarative memory performance over two decades.[45]

The hippocampus, other MTL regions, and the PFC comprise a network of brain regions that are necessary for forming new declarative memories. Converging evidence suggests that the brain regions in this network exhibit age-related functional and structural changes that are related to decreases in declarative memory performance in older adults. Next, we consider changes in nondeclarative memory.

Changes in nondeclarative memory

While declarative memory is clearly susceptible to effects of age, nondeclarative memory may be less vulnerable. Most empirical findings indicate that nondeclarative memory is well preserved and that any declines are small relative to age-related reductions in declarative memory.[46]

While there exist many paradigms for assessing nondeclarative memory it is often conveniently assessed using tasks in which the initial presentation of a stimulus (e.g., a word or picture) later influences the speed or accuracy with which an individual responds to subsequent presentations of the same stimuli. Importantly, facilitation due to prior experience—called "priming"—is independent of declarative memory for the same stimuli. Several studies have found that older adults perform much like younger adults on a variety of repetition priming tasks such as word fragment completion,[47] speeded lexical decision,[48] and category exemplar generation.[49] Other studies that have examined implicit sequence learning have likewise found performance to be intact in older adults.[50] However, some exceptions have been reported such as age-related changes in nondeclarative memory for implicit sequence learning and priming tasks that require semantic or conceptual analysis.[51]

Another form of non-declarative memory that remains intact in older adults is perceptual-motor skill learning. In an exemplary longitudinal study, older adults showed retention of a mirror-tracing skill learned five years earlier without evidence of age-related changes in performance.[52] In another study that included measures of both declarative and nondeclarative memory, a dissociation between the learning rate on the declarative and nondeclarative tasks was found in younger and older adults: younger adults had a higher learning rate during the declarative task; but there were no group differences in learning rate during the non-declarative task.[53]

The behavioral preservation of nondeclarative memory performance in older adults is partially consistent with neuroimaging evidence showing volumetric stability in regions associated with nondeclarative processes. For example, cortical areas that are involved in sensory processing and repetition priming, such as primary visual cortex, show little volume loss across the lifespan.[34] In contrast, subcortical structures such as the basal ganglia and striatum often decrease in volume with age.[54] This between-region dissociation in volumetric changes with age suggests that task performance related to the different regions should show a similar dissociation, but empirical evidence does not clearly address this speculation. Structural neuroimaging therefore presents a complex relationship with age-related changes in nondeclarative memory.

Unlike structural neuroimaging, findings from several functional neuroimaging studies of age and nondeclarative memory are better aligned with the behavioral evidence. For example, Bäckman et al.[55] examined age-related differences between young and older adults on a nondeclarative word-stem completion priming task. There were no age differences in task performance, and younger and older adults exhibited similar patterns of brain activity in extrastriate cortex. This was congruent with neuroimaging results from a semantic repetition-priming task in which both young and older adults demonstrated repetition-based response time benefits and displayed similar changes in brain activation patterns.[56]

In summary, nondeclarative memory performance across a variety of tasks remains mostly intact in older adults, and this is broadly consistent with neuroimaging findings of structural and functional stability in the neural correlates of nondeclarative memory. Although certain empirical findings hint that nondeclarative memory performance may be altered by age, an important consideration is the potential contribution of declarative memory processes to, for example, rapidly learning the parameters of a new task. This caveat does not preclude process-pure measurement of nondeclarative memory performance, but it does illustrate the challenge of measuring those processes exclusively.

Conclusions

Memory problems are the most common cognitive complaint of older adults, whether it be misplacing their keys, misremembering the name of a new acquaintance, or forgetting to take their medication. Laboratory results confirm these ecological, subjective impressions of memory decline for certain types of memories. Declarative memory and its neural correlates comprising the hippocampal memory system are disproportionately affected by age relative to the nondeclarative or procedural memory system. Importantly, the normal, brain-wide changes found in healthy older adults are qualitatively different from pathological aging. New research also suggests that many behavioral factors such as education, fitness, and diet can positively influence the age-related trajectory of memory and other cognitive abilities.[33] (see chapter 29). In the next section, we consider age-related effects in another cognitive domain, that of language.

Language and Aging

Language is fundamental to our ability to communicate with others, and as such it is critically important to maintaining healthy relationships with friends and family across the lifespan. Language may also offer a buffer against other age-related changes by supporting positive social interactions.[57,58] For example, older adults who are more socially engaged have been shown to benefit through better mental health, better cognitive function, and longer lives.[58,59] On the other hand, declines in language abilities can make interpersonal communication more difficult. Older adults with impairments in language may negatively self-evaluate their own language competence and fear that their impairment will harm how others perceive them. As a consequence, older adults with language impairment might limit potentially beneficial social interactions[60] with consequences for their health and welfare. These examples illustrate the importance of learning more about age-related changes in language abilities both for basic science goals as well as practical aims such as devising interventions with the potential to improve older adults' health, socialization, and independence.

Even beyond social interaction, language is a complex ability that requires integration of concepts, goals, and context. This high-level integration is essential for successful use of language and includes consideration of individual intentions, prior experience, and social relations as well as integration of sensory information including ongoing auditory, visual, and proprioceptive inputs. The complexity of language abilities presents significant challenges to researchers, but that complexity also provides measures that are sensitive to cognitive aging and which have supported important theoretical developments.[61] And, just as healthy aging does not disrupt all types of memory equally, certain processes of language show age-related trends toward stability or even enhancement.[62] We detail many of these changes in this section.

Language: Basic properties and neural correlates

Much like the diffuse network of brain regions supporting memory processes, brain regions associated with language processes are widely distributed. And while certain memory and language processes require certain brain regions, neither memory nor language is exclusively associated with any single region. In the case of language, a selection of cortical and subcortical areas of the language-dominant hemisphere of the brain (the left hemisphere for most individuals) are necessary for normal language. Collectively, these brain areas make sense of incoming messages and execute plans for verbal responses. Traditionally, the anterior frontal lobe (Broca's area), the posterior temporal lobe (Wernicke's area), and cortical areas surrounding the supramarginal and angular gyrus regions in the left hemisphere have been considered the key hubs of a core language network (see Figure 14.2). Language processing requires that these hubs communicate with one another via neural signals thus allowing a listener to interpret incoming messages (comprehension) and formulate, plan, and execute outgoing responses (production/expression).

Focusing on the components of this language system in more detail, the comprehension of spoken language begins with the primary auditory cortex in the temporal lobe where the incoming message is first encoded and transmitted to Wernicke's area. Wernicke's area lies in the left temporal lobe, and it is necessary for the retrieval of concepts associated with the words in the message and the relationship between those words implied by syntax. Put simply, Wernicke's area is necessary for (re)construction of the message's meaning. After processing a message to determine its meaning, Wernicke's area transmits the processed information to other brain regions that support diverse cognitive processes such as valuation, decision-making, and memory. Wernicke's area also plays a critical role in the initiation of language production (both spoken and written). Specifically, Wernicke's area retrieves the words needed to express a message from a person's own store of word knowledge (i.e., the mental lexicon) and then identifies a sentence construction that conforms to the phonologic, syntactic, and semantic rules of the individual's language. This formulated message is then transmitted via a large bundle of neuronal axons (i.e., the arcuate fasciculus) to Broca's area.

Broca's area lies in the frontal lobe, and it is crucial for the planning and organization of speech movements. It translates neural activity representing a message into a programmatic plan that will be transmitted to and executed by the primary motor cortex, cranial nerves, and speech musculature. Importantly, other cortical and subcortical regions such as the association cortices, basal ganglia, cerebellum, and thalamus are also involved in the refinement and organization of motor movements supporting communication but are beyond the scope of our discussion. Finally, Wernicke's area monitors the message during motor production for language-based errors or inconsistencies between the intended and actual message.

This brain-based language system was developed over many decades of neurological observation and neuropsychological experimentation, and it captures many key attributes of language in the brain. However, much as theories of declarative memory have been greatly elaborated over the last several decades, language processing likewise has been described in greater detail by models that highlight the utilization of parallel distributed processing, broader brain networks, and the interaction of top-down and bottom-up influences.[61,63] In this *interactive activation model* of language, parallel top-down and bottom-up connections exist between representations of semantic, syntactic, and phonological/orthographic information (i.e., the various representations necessary to comprehend and produce language). The retrieval of information that is encoded in a given representation—for example, the retrieval of a word from the mental lexicon during speech production—requires excitation of the target representation.[64] Just as in the earlier discussion of memory processes, activation of language representations can be facilitated through *priming* that arrives via parallel top-down and bottom-up connections.[63] Both language comprehension and production processes rely on the system's ability to transmit priming across links connecting representations. Thus, the relationships described between the dominant language brain regions can also be viewed as a spreading of activation between the different representations, including conceptual, lexical, phonological, and sensory representations, and muscle movements.[63] As such, the simple cortical language circuit described earlier may be better appreciated as a complex and dynamic network that involves widespread brain networks. The sophistication of this more recent model addresses how distributed information processing can improve language representations.[65]

To summarize, language processing relies on a widely distributed set of brain regions that is normatively left-lateralized but also involves interhemispheric connections. Complex interactions between the components of this network support the comprehension and production of language (see Figure 14.3 for an illustration of the language processes described in this chapter). In the next section, we consider how language processes and the brain regions that support them are affected by age.

Age-related changes in language

Within the diverse set of language processes, it is recognized that some decline with aging while others do not.[63] One key example is that older adults have greater difficulty with language production than language comprehension.[66] This and other age-related changes in language processing reflect interactions of many factors from low-level sensation and muscle movement to high-level discourse, each of which may be differentially impacted by age. For example, visual and auditory perception are necessary for processing stimuli that could eventually support higher-level language processes, but basic perceptual processes steadily degrade across adulthood with consequences for the quality of language processing.[67] Perhaps to compensate for decreased quality of bottom-up perceptual input, language processing in older adults appears to be more influenced by top-down processes.[68] The scope of the language literature makes a broad survey impossible in the current format, so we will restrict our consideration of age-related effects on language to three key topics: lexical processing, sentence processing, and discourse processing.

Lexical processing

Recognition. Age-related sensory and perceptual changes in the auditory and visual systems have negative consequences for lexical processing.[69] In the auditory domain, age-related hearing loss (or presbycusis) particularly affects higher frequencies important for speech, and this loss can contribute to poorer syllable and word recognition even in quiet environments.[70] Beyond hearing acuity, other age-related changes in the auditory system also negatively impact speech recognition. For example, age degrades the temporal processing of spoken language that is essential for attending to the fine structure of real-time speech.[71] Associated deficits include loss of auditory temporal synchrony, the detection of temporal gaps, and temporal sequence detection.[72] Lacking good temporal processing, older adults often have difficulty differentiating voiced from voiceless sounds or distinguishing sounds that differ in voice-onset time.[73]

Reading is also affected by age-related sensory changes including reduced visual acuity. Older adults show reduced reading performance relative to younger adults when presented with challenging visual conditions such as small font sizes, low levels of contrast, or low room illumination.[74] These degraded inputs have been associated with impaired behavioral performance and reductions in brain activation,[75] as when decreased visual cortex activation in older adults was observed to accompany increased lexical decision latency.

Sensory loss therefore negatively impacts language comprehension in older adults, and they may compensate by relying more on top-down processes than younger adults. For example, older adults have been shown to make lexical decisions more quickly for high-frequency words than low-frequency words while younger adults do not. This suggests that older adults may be accessing high-level lexical information (i.e., top-down processing) in the service of visual language processing.[76] Perception and higher-order processes may also interact in the comprehension and

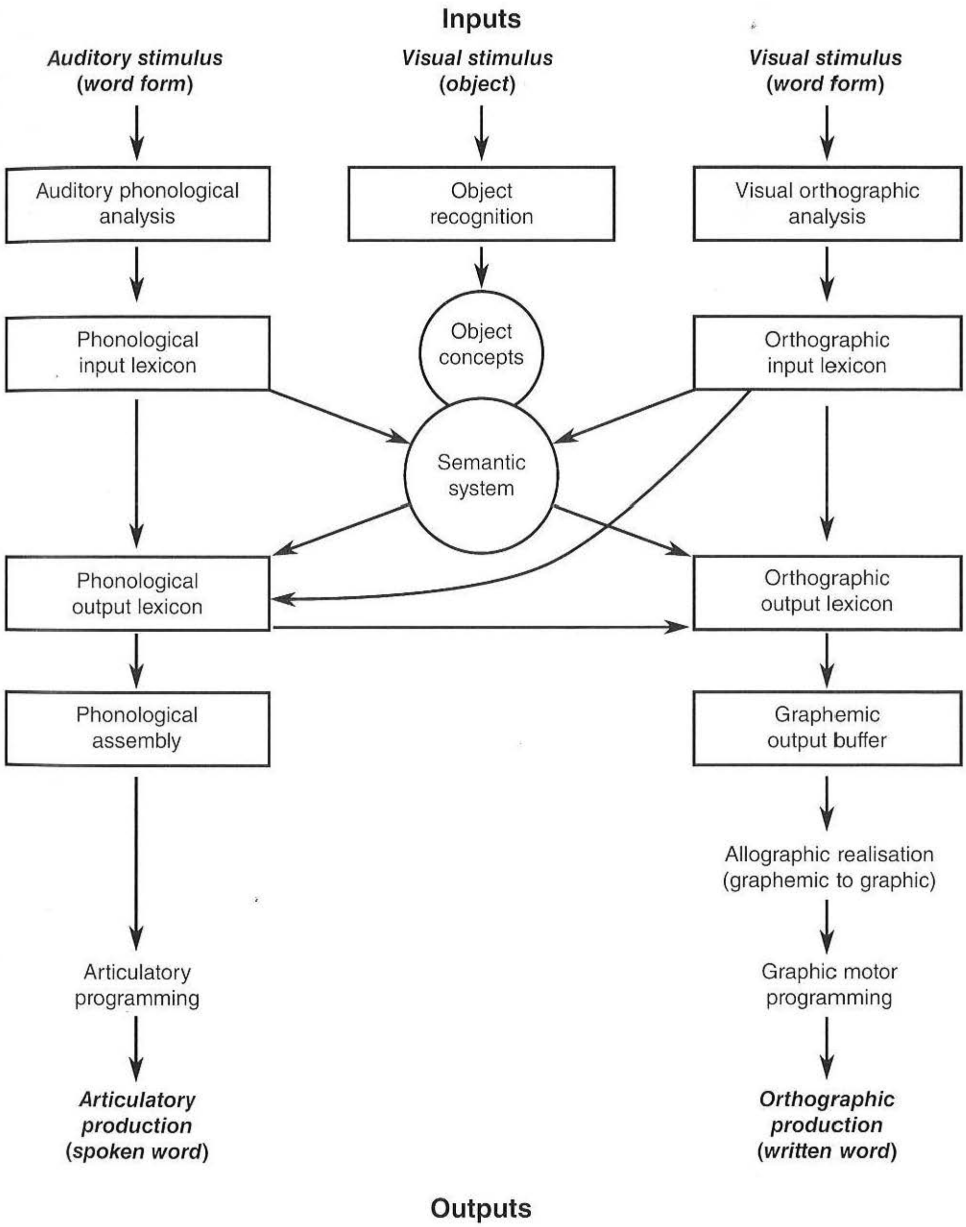

Figure 14.3 A taxonomy of language processes. Parallel and potentially intersecting processing streams are available for incoming auditory and visual information, while common semantic representations are used irrespective of the original source modality of the information. Production again diverges depending on the desired output—either speech or orthography. Adapted from Figure 1.1 in Whitworth et al.[146]

processing of speech. Speech perception under noisy listening conditions is frequently impaired in older individuals, and this remains true even when age-related differences in hearing loss are controlled.[77] Noise effects have been described as a consequence of both auditory[78] and cognitive[79] deficits. As with reading performance, older adults may rely on top-down processes to compensate for these degraded signals.

Perceptual deficits may also affect speech and word recognition in older adults by increasing their sensitivity to speech rate and phonological neighborhood density. Increased speech rates reduce speech perception among older adults[80] possibly by overwhelming degraded perceptual processes. At a higher level, older adults also show an age-related decline in accurate identification of words that share phonemes with many other words (and therefore have high "phonological neighborhood density").[79] Interestingly, this negative effect of neighborhood density is limited to phonology—age-related deficits have not been observed when semantic neighborhood density is high.[81] This implied dissociation between phonology and semantics may also be reflected in findings showing that older adults rely more on semantics and less on phonology than younger adults,[82] and these results are consistent with a recurring theme, that is, older adults rely on top-down processes to a greater extent than younger adults.

Retrieval. Word knowledge continues to develop across the lifespan, and older adults possess larger vocabularies than younger adults even when controlling for effects of education and cohort.[83] More specifically, semantic and lexical knowledge increase throughout adulthood and remain stable until declines in very old age.[84] Despite this evidence of continuous learning, age-related difficulties with word retrieval and the production of specific words (i.e., word finding failures) are rated by older adults as the most frequent and most vexing age-related change in their language abilities.[85] Studies of picture-naming, tip-of-the-tongue experiences, speech errors, and disfluencies have all shown age-related deficits in lexical and phonological retrieval that may contribute to word finding failures.

Studies examining the effects of age on picture-naming have found that older adults make more naming errors than younger adults.[86] This does not appear to be attributable to deficits in semantic access. Rather, errors in picture-naming reflect deficits in lexical or phonological access.[86] Notably, this deficit is found despite increased response times, and these increases in naming latency may longitudinally precede decreases in accuracy.[87] While the longer naming latencies slow the responses of older adults and might be expected to slow their speech production, older adults have not been found to experience "lexical traffic jams" when they produce long utterances.[88] This preservation may be attributable to adaptive strategies: older adults tend to speak more slowly than young adults, and slower speech has been hypothesized to allow more time for retrieval and thereby increase fluency while decreasing errors.[89] Converging findings have shown that older adults slow their speech further by producing more lexical and nonlexical fillers, word repetitions, and lengthy pauses than younger adults,[90] and each of these behaviors may also reflect conscious or nonconscious adaptation to address changes in retrieval speed or accuracy.

Retrieval deficits among older adults are also evident in studies of tip-of-the-tongue (TOT) states. TOT describes the temporary inability to recall a well-known word.[91] In a TOT state, a person can recall semantic and grammatical information about a target word but has difficulty describing the target's phonology.[92] Age-related increases in the rate of TOTs during speech has been shown in both laboratory settings and in spontaneous real-world speech.[92] TOTs may be unusually common for proper names, and consistent with this, older adults have more retrieval failures for proper names than younger adults.[92] Further, age-related increases in TOTs appear to be partially dissociable from age-related declines in declarative memory,[93] an intriguing distinction between age-related changes in memory and language.

Age-related changes in lexical processing and retrieval are common frustrations for older adults, but the evidence reviewed here suggests that increased top-down influences may partially compensate for the associated deficits. Next, we consider language processing at the level of sentences.

Sentence processing

Comprehension. Sentence-level processing that supports comprehension is negatively affected by age, and this change has frequently been attributed to age-related reductions in working memory capacity. Specifically, reduced working memory abilities in older adults have been hypothesized to underlie changes in their ability to comprehend (and produce) complex language constructs such as long, complicated sentences.[94] Consistent with this perspective, older adults have shown age-related reductions in recall of sentences that interact with sentence complexity.[95]

While declines in generic working memory capacity explain certain age-related sentence processing changes, some researchers have hypothesized that a specialized working memory system exists for the express purpose of automatically interpreting sentence meaning.[95] This perspective distinguishes between the putatively automatic online processing of sentences and offline measures of comprehension that require retention. Meanwhile, offline retention has been reliably associated with working memory measures, and there is empirical evidence of age-related effects in subsequent comprehension that are mediated by verbal working memory.[96] Intriguingly, working memory measures do not predict online comprehension or online syntactic processing[96]. Based on these findings, there appears to be a robust dissociation between age-invariant sentence *processing* and age-related declines in sentence *memory*.

Production. Older adults tend to produce less complex spoken and written language than younger adults. This age-related trend has been reported in cross-sectional and longitudinal investigations, and its common manifestations include decreased use of subordinate and embedded clauses.[97] Although many factors likely influence age-related changes in syntactic complexity, working memory capacity appears to be an important contributor.[98] Alternatively, age-related changes in sentence complexity during speech production (e.g., using simpler syntactic constructions) may also reflect top-down influences such as deliberate choices made by older adults about how to address listeners.[99] The decreased sentence complexity employed by older adults could also be driven by differences in effective cognitive load during sentence construction.[100] Finally, bottom-up processes could also play a role as reductions in the frequency of exposure to complex sentences may produce greater priming of simple syntax.

While age-related declines in sentence production have received the greatest scrutiny, certain sentence processing skills may be preserved in older adults. For example, laboratory tasks imposing fewer constraints on sentence construction have found that older adults can perform as well as younger adults in tasks that require participants to create sentences that include key words.[101] This suggests that older adults maintain the ability to utilize multiple grammatical options for increased efficiency during sentence production despite evidence of behavioral changes in more constrained laboratory tasks.

Age-related changes in sentence processing therefore include reduced comprehension and production of complex sentences. These changes have significant potential to influence the final topic that we will consider, discourse processing.

Discourse processing

Overview. Discourse processing is critical for high-level communication such as carrying on a conversation, and certain aspects of this ability change with age. The preceding sections have discussed important age-related effects on micro-level language phenomena, but in this section we will review literature which suggests that age-related changes in discourse may provide the most comprehensive, ecologically valid measures of how older adults use language. In support of this perspective, dissociations between *linguistic* (i.e., micro-level) and *communicative* (i.e., discourse-level) abilities have been observed in patient populations such as individuals with aphasia (i.e., impaired linguistic functioning in the presence of relatively preserved communication abilities) and traumatic brain injury (i.e., impaired communicative abilities in the presence of intact linguistic functioning).[102] Thus, analysis of discourse allows researchers to evaluate whether older adults can still communicate effectively despite underlying changes in their language abilities.

Comprehension. Presbycusis and other age-related auditory changes have clear implications for language processing at the lexical and sentence levels, but these auditory deficits also have consequences for discourse processing. While older adults can perform discourse tasks as well as younger adults when signal-to-noise ratios are controlled[78] typical social settings do not afford this luxury. Instead, ecologically valid communication settings often involve suboptimal listening conditions that compound auditory deficits (e.g., simultaneous conversations, environmental background noise, interrupted speech, and reverberation).[103] Presbycusis has a clear negative effect on phonemic processing and it may also negatively impact perception of so-called "paralinguistic" speech cues such as intonation, rhythm, and stress.[104] Deficits in processing these paralinguistic cues may be particularly harmful to comprehension for older adults who might otherwise benefit from paralinguistic information when it is accurately perceived.[105] Inability to use this adaptive strategy of increased reliance on paralinguistic cues may underlie changes in conversational styles that have been observed between young-old and old-old adults. Whereas young-old adults show a dynamic development of conversational topics marked by flexibility and balanced turn-taking, old-old adults show a rigid conversational style often involving a single dominant speaker.[103] One interpretation of this pattern is that old-old adults engage in longer conversational segments focused on the concerns of one partner at a time in order to decrease the need for more fine-grained interpretation of paralinguistic feedback.

Discourse comprehension requires the integration of multiple sources of information and language systems. These include interpreting bottom-up signals, storing concepts in working memory, and using semantic and episodic knowledge to shape overall comprehension. Representations of this complex, multidimensional communication context have been referred to as "situation models" which are hypothesized to be necessary for efficient discourse.[106] Situation models involve integrating existing knowledge while tracking newly introduced people and objects, causal sequences, spatial and temporal relationships, and emotional responses. Older adults continue to use and respect situation models in communication,[107] and they may rely more on situation models to support comprehension under certain conditions.[108] This would be consistent with the perspective that reliance on top-down processing benefits comprehension in older adults, and it offers an adaptive mechanism with some explanatory power for age-preserved discourse comprehension.

Production. While older adults frequently demonstrate decreased syntactic complexity, they show increased discourse complexity. Whether writing or speaking, the discourse of older adults typically includes multiple episodes, embedded episodes, and conclusions regarding moral lessons. Perhaps as a result, the discourse of older adults is often perceived as more interesting, informative, and clear than that of younger adults.[98,109] Older adults are also more likely to generate elaborated, integrative, lexically diverse, and rich responses during story interpretation, collaborative referencing tasks, and general conversation than younger adults.[62,110] Specific interactional discourse resources, such as verbal play, have also been found to be preserved in older adults. Older adults not only use these resources as frequently as younger adults, but they are also more likely to utilize these resources to promote the social nature of discourse.[111] This may mirror patterns in discourse comprehension; in both cases there is an increased focus on the discourse level variables and resources by older adults.

Unfortunately, not all aspects of discourse production benefit from age. While discourse content may be maintained or improved with age, older adults appear to express fewer ideas in the same volume of discourse and therefore reduce the density of their discourse content,[112] requiring more time to express the same quantity of information. Other changes in the discourse of older adults include decreased cohesiveness, reduced global coherence, less topical organization, and an increase in ambiguous references. The combination of these age-related changes in discourse production increase the difficulty of comprehension for communication partners.[113] Lower-level changes in speech production, discussed earlier, may also reduce the effectiveness of older adults' discourse.[114]

The ability to remain on topic by generating ideas consistent with the theme of current discourse also deteriorates with age.[115] While off-topic verbosities increase with age, they are more likely to occur during unstructured autobiographical storytelling than during goal-directed discourse.[116] In fact, high rates of off-topic verbosities only characterize a minority of older adults,[117] and most older adults appear able to monitor this behavior to respond to social cues such as an obviously bored listener.[117] These findings further emphasize the importance of considering more macro-level components of language, including pragmatics, and situating language within the context of interpersonal communication when characterizing changes in language and discourse practices associated with healthy aging.

To summarize, discourse comprehension and production change with age in positive and negative ways. Unlike the declines described in nearly all aspects of lexical and sentence processing, certain characteristics of discourse show age-related improvement. In fact, as described above, the discourse of older adults has been described as more interesting, clear, and informative than that of younger adults. This dissociation between age-related changes in linguistic and communicative abilities illustrates the complex nature of language processing across the lifespan. In the next section, we discuss several theories that address age-related change in language and memory processes.

Models of Cognitive Aging Applied to Memory and Language

Cognitive aging has been described by a great number of theories, many of which address age-related changes in memory and language. Our selective consideration of these theories will illustrate the diversity of potential mechanisms cited to explain cognitive aging effects in the domains of memory and language. Some of the age-related explanatory variables highlighted by these theories will include: inefficiency of cognitive processes; reduced quality of cognitive strategies; diminished processing resources; cognitive slowing; focal, longitudinal brain atrophy; and changes in socialization. We note that while these theories often successfully address a specific pattern of findings or targeted domain, there is no "grand unified theory" of cognitive aging with universal explanatory power. Even addressing the overlapping domains of memory and language with a single theory remains a significant challenge.

Given the strong evidence that cognitive abilities such as memory and language change with age, a key consideration for theories of cognitive aging has been one of resources. Specifically, do older and younger adults have access to the same cognitive resources, and do older and younger adults use the cognitive resources they possess in the same manner? This distinction was first addressed in the domain of working memory by Miller[118] and the principles are broadly applicable. Miller's key observation was that working memory had a relatively fixed capacity for information of a given type, thus distinguishing between a cognitive resource and how it is used in cognitive processing. For example, there is variability in how many random digits different individuals can remember, but the range of normal performance is small. However, the absolute quantity of information that can be remembered is radically altered for different stimuli. This seminal insight revealed that the apparent capacity of a limited resource could be magnified many times by changing the representation of the information. As a concrete example, memorizing two alphabets' worth of random letters would be daunting, but remembering a sentence of similar length such as, "She typed furiously to meet her editor's deadline for the chapter," is trivial. The increased efficiency achieved by utilizing higher levels of representation was described by Miller as "chunking," and this cognitive phenomenon has implications for theories of cognitive aging that apply to both memory and language.

It would be tempting to associate greater representational efficiency (i.e., better chunking) with increasing age and experience, but memory and language both show negative changes across adulthood on many laboratory tasks. Why is this? One class of theories has suggested that some aspects of cognitive aging may be attributable to failures of inhibition[119] with supporting evidence drawn from the domains of memory and language. For example, it has been observed that older adults are more likely than younger adults to misinterpret sentences with ambiguous meaning due to unusual sentence construction. Closer examination showed that even when older adults were correct, their behavior indicated that they maintained two possible meanings of the same ambiguous sentence longer than younger adults. These findings suggest that older adults do not inhibit competing representations in ongoing language processing, and this lack of inhibition may have negative consequences for comprehension. Similar findings are available in the domain of memory, such as the increased likelihood of false memory among older adults when recalling (or recognizing) word lists that deliberately exclude common associates[120] or inaccurate memory for the source of information.[121,122] These and other empirical results from memory and language show that failures to inhibit can have a significant effect on the performance of older adults.

Theories implicating failures of inhibition suggest that older adults may consider too much information when remembering or communicating, but other theories point toward an alternative culprit, namely broadly diminished cognitive capacity. Starting with observations in younger adults, Just and Carpenter[123] reported that individual performance on a measure of verbal working memory capacity ("reading span") was strongly correlated with other cognitive abilities. As the authors stated, "Cognitive capacity constrains comprehension, and it constrains comprehension more for some people than for others." From that starting point, they and other researchers observed that older adults typically show reduced reading span relative to younger adults, generating the hypothesis that cognitive aging might be directly related to changes in cognitive capacities such as verbal working memory. The appeal of this theory lies in its attribution of broad cognitive decline to a relatively simple, singular deficit. However, critics have shown that its key claims of unitary cognitive capacities for broad domains of cognition may be too strong. In particular, Waters and Caplan[124] have provided evidence that verbal working memory may be modular, and more specifically, that syntactic processing may be dissociable from other forms of verbal working memory processing. Critically for the current discussion, Waters and Caplan suggested that syntactic processing is essentially unaffected by age. While this line of criticism may reduce the appeal of theories describing broad cognitive declines due to reductions in unitary capacities – for example, working memory –[123] the underlying theme remains influential.

Yet another class of theories addressing cognitive aging identifies a different unique explanatory variable, specifically, slowing of cognitive processing.[125] Some of the findings cited in this literature are particularly compelling, such as the observation that the response times of older and younger adults on many distinct tasks are often linearly related, meaning that older adults require proportionally more time to achieve the same goal as a function of age.[126] The implications of this relationship are substantial because any context that implicitly imposes a deadline on processing would be expected to reduce performance in older adults. Thus, whether in the laboratory or in the real world, the fleeting availability of information including speech, facial expressions, and many other important environmental stimuli may cause disproportionate difficulty for older adults.

The theories discussed to this point emerged from the traditions of cognitive psychology and focused principally on behavioral rather than neuroanatomical changes. The potential power of incorporating knowledge about age-related changes in the brain was demonstrated by West[127] in an era of burgeoning structural and functional neuroimaging. As discussed earlier in this chapter, the volume of many brain regions is reduced with age, and those reductions are not uniform across the entire brain.[37] The reduction in the volume of the PFC is particularly striking because the PFC is a very large region of association cortex that is related to many higher cognitive abilities. West's prefrontal cortex function theory of aging suggests that many of the age-related changes in memory abilities are directly attributable to volumetric change in the PFC. West proposed that PFC is necessary for temporal integration of information, that is, organizing thought and behavior across time to support goal-directed behavior. Temporal integration is in turn supported by four key memory processes that change with age and have been related to PFC: two processes that are key elements in other theories of cognitive aging discussed earlier, interference control and inhibition functions; as well as two further processes including prospective memory (memory dictating behavior in the future) and retrospective memory (online retrieval and maintenance of information appropriate to the current context). By incorporating elements of other well-established theories and relating them to neuroanatomical findings, West provided an impressively inclusive and powerful framework for interpreting age-related changes in memory. The impact of what has been called the "frontal lobe hypothesis" is still evident 20 years after its debut, and while the theory has received significant scholarly critique, it remains highly influential.

Theories addressing cognitive aging can also have implications for memory and language even when the primary domain under consideration is quite different. One example is socioemotional selectivity theory[128] which primarily focuses on describing putative changes in the socialization of older adults in terms of emotional rewards. Specifically, an age-related trend in social behavior has been observed across different phases of adult lives: during childhood, a few close social relationships dominate; during adolescence, more social relationships are sought and developed; and during middle and late adulthood, fewer social relationships are maintained. Socioemotional selectivity theory addressed this trend with the suggestion that the emotional utility of new social relationships changes with age, and this change in utility is hypothesized to drive differences between the perceived reward value of new and existing relationships. Greatly simplified, the theory suggests that in later adulthood new relationships will have less emotional utility than existing relationships. Carstensen's theoretical perspective has substantial explanatory power for socialization across the lifespan, and could potentially inform issues in memory and language. For example, researchers studying language ability in older adults often do not account for the fact that older adults communicate most with already-familiar communication partners, but this limited pool of communication targets may profoundly affect the variety, efficiency, and content of their language use. Similarly, day-to-day memory demands may be reduced in the context of smaller social networks in ways that mask evidence of age-related declarative memory changes. Importantly, the relationship between the social and cognitive domains is not unidirectional: memory and language abilities are influenced by socialization and may in turn influence socialization (also see chapter 5 and chapter 20). Whether at a general level or in its specifics, socioemotional selectivity theory offers important considerations for studying cognitive aging in memory and language that complement other theories in this domain.

In summary, the proliferation of theories describing age-related cognitive changes in memory, language, and other related domains implicitly acknowledges the salience of changes in these abilities for older adults, but no single overarching variable such as efficiency, slowing, volumetric reductions in PFC, or socialization can explain all of the reported changes. As demonstrated by some of the more recent, more inclusive entries[127] many of the factors favored by specific theories are not mutually exclusive: older adults may simultaneously have deficits in inhibition, processing speed, and processing capacity as well as different utility functions for social behavior. The complex interactions of these individual and environmental variables are difficult to disentangle, and the tools of cognitive neuroscience may benefit theories of cognitive aging by offering constraint based on changes in brain structure or function. As this brief summary shows, no theory adequately addresses all components of cognitive aging in memory and language, but promising explanations of more limited scope are available and continue to be refined.

Interactions Between Memory and Language

Memory and language are often studied as unique cognitive abilities with distinct methodologies, theories, and investigators, and this is no less true in the domain of cognitive aging than elsewhere. Important historical reasons exist for this division, but cross-pollination between the disciplines of memory and language has proved fruitful on many occasions. Conceptual models of associative memory organization and activation have been highly influential in the literatures of both memory and language.[129] Similarly, explicitly computational models have spanned the domains of memory and language,[130] and at least one prominent theory of memory has been transplanted to the language literature with some success.[131] These intersections between the study of memory and language make sense: clearly, certain processes and phenomena straddle the two domains such as semantic memory, word learning, acquisition of new languages, and more. Furthermore, while the neural correlates of memory and language might once have been believed to be perfectly dissociable, new neuropsychological and neuroimaging data now reveal their complex interactions. In this section, we describe several investigations at the intersection of memory and language that exemplify the potential benefits of studying these abilities in tandem and which we believe motivate their joint study in older adults.

Earlier in this chapter, we briefly outlined two model brain systems supporting memory and language processes, respectively. Our presentation accurately represented an important assumption underlying both models which is the view that memory and language are discrete cognitive abilities with dissociable neural correlates (Figure 14.2). This perspective is firmly established in the literature and has prevailed for several decades. Despite this prevalence, there is significant recent evidence indicating that brain regions generally thought to be responsible for memory processes also contribute to language,[132] and the reverse may also be true. Given the age-related changes that are known to occur in the hippocampus, PFC, and other brain regions associated with language abilities and declarative memory performance,[37,133] these findings have strong implications for theories of cognitive aging in language as well as memory.

Language processing has often been differentiated from memory by certain key characteristics. In particular, language processing requires the rapid processing, maintenance, and generation of new information. Historically, the speed of these processes might have been thought to rule out significant contributions of the declarative memory system which was not generally believed to operate in real-time cognitive processing beyond encoding information.[12] However, many reports from the last decade are not consistent with this perspective. For example, individuals with focal, circumscribed damage to the hippocampus have been shown to have deficits in many aspects of language processing.[132] These deficits range across several different levels of language processes, from semantics to discourse to sentence processing. Specific findings include evidence that patients with hippocampal damage are less likely to engage in verbal play during discourse, less likely to use definite articles when identifying familiar objects to a communication partner, less likely to appreciate contextual constraints on the comprehension of a communication partner, and less likely to correctly interpret ambiguous pronouns.[134–137] These findings are at odds with the perspective that the brain's memory and language are perfectly dissociable, and also contribute to the emerging view that the processes of relational declarative memory play an important role in real-time processing of information in addition to their well-characterized roles in memory[18,21,132,138].

Another important rationale for combined study of memory and language lies in their overlapping neural correlates and the age-related changes to those brain regions. Early neuropsychological work indicated the opposite: patients with damage to certain brain regions showed deficits in speech comprehension or production;[139] patients with damage to other brain regions showed deficits in the ability to remember new declarative information.[7] These findings suggested a double dissociation in the neural correlates of memory and language and may have reinforced existing divisions between research in the two domains. However, more recent neuropsychological and neuroimaging findings suggest that some of the neural correlates of memory and language are in fact shared, and that the interplay between memory and language systems is the norm rather than the exception. Neuropsychological evidence consistent with this perspective was described previously,[132] and functional neuroimaging studies have also shown that language and memory can produce activation in similar sets of regions under appropriate circumstances.[140]

Word learning is another example of interactions between memory and language processing. Incorporating a new word into a lexicon first requires binding together arbitrarily related phonology, orthography, and conceptual information. Without the ability to perform this binding, the separate components would be isolated from one another: perceived phonology would not map to concepts or orthography, concepts would not be expressed phonologically through speech, and the segregation of these representations would render them useless for language. Word learning is an important part of early language acquisition, but the same skills remain useful and necessary throughout life. While older adults already have large vocabularies, the addition of new words to a language through cultural mechanisms mandates continuous—albeit slow—updating of word knowledge. Consistent with this, older adults have been shown to have larger vocabularies than younger adults.[83] There is neuropsychological evidence indicating that the hippocampus is necessary for word learning by adults in explicit and implicit learning conditions,[141] and known changes in the function and volume of the hippocampus with age may affect word learning in older adults.

Word learning reflects distributed contributions to semantic representations, and semantic knowledge is another example of functional overlap between memory and language that is especially relevant to cognitive aging. Semantic memory is generally thought to be stable almost throughout adulthood[142] because significant semantic failures appear to occur most often in very old age or in pathological conditions. However, there is recent evidence that the hippocampus may play a necessary role in semantic memory processes.[143] Individuals with focal hippocampal damage were impaired on sensitive tests of semantic memory, which they demonstrated by generating fewer features and senses of common words. This finding has strong implications for semantic memory in healthy older adults because of the rapid changes in hippocampal volume later in life. It is possible that the previously mentioned semantic memory failures of very old age may be attributable in part to associated decreases in hippocampal volume,[34] but this is an open question that will require further study.

Memory and language are heavily intertwined and studying the intersection between these cognitive abilities has recently become more popular. New insights from cognitive neuroscience have revealed previously unappreciated brain-behavior relationships that span the two cognitive domains. We suggest that new theories of language and memory will continue to benefit from considering both domains simultaneously[132,144,145] rather than honoring a historical separation that is increasingly understood to overstate the dissociation between memory and language systems.

Conclusion

In closing, memory and language both change with age, and not all of the changes are negative. However, many age-related changes in these domains do present difficulties for older adults, and so improving upon our current understanding is essential. Researchers from the domains of linguistics, communication disorders, cognitive science, cognitive neuroscience, and others all have the potential to contribute important converging evidence to support an improved understanding of how memory and language change with age. Further study of the processes of memory, language, and their interactions have the potential to yield interventions that could help older adults to preserve their social networks, their autonomy, and their identity. For this reason, we suggest that substantial rewards await researchers willing to overcome the challenges involved in studying memory and language together in older adults.

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