

Memory is one of the most widely studied and best understood facets of cognition. Investigations of memory have also played an important role in developmental psychology and have contributed to the evolution of life-span developmental psychology (e.g., Baltes, 1987). We cover the major topics of relevance for understanding the development of memory, acknowledging that our coverage will inevitably be both selective and incomplete.

■ THEORETICAL CONCEPTS OF MEMORY

We begin with a brief overview of foundational concepts regarding memory and its development. After considering some basic concepts, we then review in detail what is known about memory development across the human life span.

Our perspective, grounded in experimental cognitive psychology, emphasizes memory in terms of how different cognitive processes and procedures affect learning and remembering (e.g., Craik, 2002; Hunt, 2003; Roediger, Rajaram, & Geraci, 2007). For example, remembering information is in large part an outcome of how one attends to that information when it is first encountered. Memory can occur incidentally, as a by-product of attending to and thinking about information, or intentionally, because one has engaged a goal of learning new information.

There are multiple types of memory. The distinction between episodic and semantic memory has special developmental relevance. Semantic memory is defined as declarative knowledge about the world, culture, and one's own environment. It grows during childhood as a function of a child's exposure to information, and it is affected by environmental context, acculturation, social status, and schooling. Knowledge and access to knowledge is well preserved in adulthood. It declines rather late in life, more precociously with pathologies of memory than with normal aging.

Episodic memory is defined as memory for specific instances, events, or episodes in one's life. Some aspects of episodic memory (e.g., recognizing objects such as toys or the faces of adults) seem to develop relatively early in childhood. Other aspects, such as the ability to successfully organize information to facilitate remembering, continue to develop and improve into early adolescence. Unlike semantic memory, performance on at least some kinds of episodic memory tasks begins declining in middle age, with the rate of memory decline accelerating in later life. However, whether specific children or adults show typical or atypical patterns of development depend on a number of factors, and there are reliable individual differences in the rates of memory change in adulthood and old age. A full understanding of memory development, then, requires an appreciation for different ways in which relevant

processes—such as the allocation of attention—can influence memory, and how development influences these processes across the life span.

Stages of Memory Processes

The temporal context of learning and remembering is often divided into encoding, storage, and retrieval. Encoding involves perceiving, attending, and comprehending new information. Concentrating on the meaning of new information results in greater memory strength and a higher likelihood of remembering than superficially noticing it, or processing superficial stimulus features (e.g., Craik, 2002). Comprehension (the process of understanding) carries special advantages and benefits for later remembering (Kintsch, 1998).

Memory storage and binding processes integrate information into coherent episodes as a more or less integrated ensemble, preserving them for later access (e.g., Treisman, 1996; Zimmer, Mecklinger, & Lindenberger, 2006). Often, the process of binding includes information about what happens and when it happens; the binding process associates features of events, including how they are interpreted in light of what one already knows, with the temporal context in which events happen (e.g., Polyn, Norman, & Kahana, 2009).

Remembering occurs when previously processed information is retrieved. Retrieval can be incidental (e.g., when perceiving something in the environment reminds us of something else) or intentional (e.g., trying to remember where one put one's keys). Retrieval is not an all-or-none process, in which all elements of an episode are accessed once the episode has been brought to mind. To the contrary, remembering is often reconstructive. One remembers fragments of past events and attempts to reconstruct other aspect of those events by inference or further, guided retrieval attempts (Johnson, 2006). For this reason, and others, individuals are susceptible to a variety of memory errors (Schacter, 2001), such as believing that two different memory fragments they have retrieved are part of the same episode.

Whether information that is available in memory is accessible (can actually be retrieved; Tulving & Pearlstone, 1966) depends on complex interactions involving mechanisms from all three stages of remembering. For example, retrieval is most likely when it is aligned with the type of process used at encoding (transfer-appropriate processing; Morris, Bransford, & Franks, 1977). Retrieval is less likely when encoding results in generalized memory representations, lacking distinctive detail, that are weakly bound to the specific context and contextual cues.

Implicit Versus Explicit Memory

Explicit memory is defined as remembering under the explicit goal of doing so. Implicit memory refers to remembering without intent or awareness, often in the service of some other cognitive processing goal. We have chosen to focus this chapter on explicit memory. Nevertheless, implicit memory is affected by development. It has different patterns of early development, depending on whether it is perceptual or conceptual in nature (Schneider, 2011). In adulthood, implicit memory, whether based on repeated physical features or conceptual features, is relatively spared by aging (see Light, Prull, La Voie, & Healy, 2000). Likewise, procedural memory, remembering

how to do things, is relatively spared in old age (e.g., Fraser, Li, & Penhune, 2009), especially if the skill was originally well learned (Krampe & Ericsson, 1996).

■ LIFE-SPAN THEORIES OF EPISODIC MEMORY DEVELOPMENT

An inverted U-shape function describes many aspects of cognition, including episodic memory (Dempster, 1992; Kail & Salthouse, 1994). As children grow older, their episodic memory improves. In later adulthood episodic memory begins to wane. Nevertheless, old age is not merely the reversal of child development, because different constellations of mechanisms influence cognitive changes at each end of the life span (Baltes, Lindenberger, & Staudinger, 2006; Bialystok & Craik, 2006). Early memory development is influenced by selection and optimization processes that produce individual differences in knowledge relevant for memory encoding and retrieval. Semantic memory development over the life span supports episodic remembering, as discussed in more detail later in the chapter. Individuals gain specific skills and knowledge in domains of interest that they themselves select or those that are selected for them (e.g., Ackerman, 2000). On the other hand, compensatory mechanisms for cognitive loss may be important in old age. Compensation can occur at the neuronal (Park & Reuter-Lorenz, 2009) or behavioral levels (Hertzog, Kramer, Wilson, & Lindenberger, 2009). Compensation can maintain everyday memory functioning in old age, despite decline in underlying memory mechanisms (Bäckman, 1989).

Life-span views embrace the joint influences of multiple factors on memory development, including the important roles of heredity–environment interactions at different stages of the life course (Gottlieb, 1991). Context also plays an important role (Hess, 2005), for example, in terms of history-graded cohort differences in the content relevant knowledge structures (Hultsch, Hertzog, Dixon, & Small, 1998; Schaie, 2005). Moreover, different contexts may be relevant in different ways at different points in the life span (e.g., parental and peer influences on acculturation in childhood, intimate partnership, friendship and occupational-peer networks in adulthood, and family and peer network support structures in old age).

The specific mechanisms that drive developmental changes in memory functioning in childhood and aging have rarely been examined in conjunction (but see Craik & Bialystok, 2006). The life-span theoretical framework of episodic memory development proposed by Lindenberger and colleagues (Shing, Werkle-Bergner, Li, & Lindenberger, 2008; Werkle-Bergner, Müller, Li, Lindenberger, 2006) is an important exception. According to this framework, the ontogeny of episodic memory builds on the interaction between two components: (1) the *strategic component*, involving control operations that aid and regulate memory processes at both encoding and retrieval; and (2) the *associative component*, involving mechanisms that bind memory content into coherent representations.

The two-component framework builds upon neural models that postulate the involvement of prefrontal cortex (PFC) to support the strategic component, mediotemporal lobe (MTL)—particularly the hippocampus—to support the associative component (e.g., Moscovitch, 1992; Simons & Spiers, 2003), and interactions between PFC and MTL regions during encoding and retrieval (Paller & Wagner, 2002). These brain regions undergo substantial alterations across the life span (e.g., Buckner, 2004;

Nelson, 2001). PFC continues to mature well into adolescence, whereas MTL matures earlier in development (e.g., Gogtay et al., 2006; Ofen et al., 2007). In older adults, accelerated decline is observed in both PFC and MTL (e.g., Raz et al., 2005). The life-span framework of episodic memory development postulates that children's difficulties in episodic memory primarily originate from low levels of strategic operations, reflecting the protracted development of the PFC. Deficiencies in episodic memory functioning among older adults, on the other hand, originate from impairments in both strategic and associative components, reflecting senescent changes in the PFC and the MTL.

■ WORKING MEMORY

Working memory (WM) refers to the ability to flexibly process, transform, and maintain information in a state of heightened accessibility and awareness (Cowan, 1995). Some theorists consider WM to be more or less akin to activation of long-term memory in a state of heightened accessibility (Cowan, 1995; Ericsson & Kintsch, 1995; Unsworth & Engle, 2007). Because WM capacity is an important variable to consider in the context of encoding and retrieval mechanisms, we consider its development first.

The processes relevant to maintaining information in WM can be regarded as a subset of executive functioning or cognitive control. Controlled processing modes are generally conceptualized as requiring attention and effort, and are often (but not always) executed with awareness. Models of WM include multiple executive processes (Shah & Miyake, 1996), such as selection, updating, and resisting interference (Kane & Engle, 2003). Theories of cognitive control have been informed by neuroscience (e.g., Braver, Paxton, Locke, & Barch, 2009). For instance, dopaminergic systems connecting areas of basal ganglia and PFC are involved in goal-directed strategies, pursuit, and the evaluation of reward and punishment (Miller & Cohen, 2001).

The concept of WM capacity has played a critical role in developmental theory about cognitive development in childhood (e.g., Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999; Pascual-Leone, 1970). The ability to retain information for brief periods of time develops early in childhood and shows continuous improvement with age after preschool (e.g., Davidson, Amso, Anderson, & Diamond, 2006; Dempster, 1981; Pascual-Leone, 1970). Recent longitudinal work with participants from age 4 to 23 showed continuous span increases until the age of 18, but no increases thereafter (Schneider, Knopf, & Sodian, 2009). Cowan et al. (1999) found that the average span of apprehension (the amount of information that people can attend to at a single time) increased significantly with age, from childhood to young adulthood, reflecting developmental difference in the short-term storage capacity.

Case's developmental theory proposed that limited WM capacity must be shared between storage and processing functions (e.g., Case, Kurland, & Goldberg, 1982). With increasing age across childhood, the processing function of WM gains more efficiency, resulting in more capacity for storage function and further remembering (for alternatives, see Hitch & Towse, 1995; Pascual-Leone & Baillargeon, 1994). Baddeley's WM model has at least three subcomponents, including the central executive, the visuospatial sketchpad, and the articulatory or phonological loop (Baddeley, 1986). Gathercole, Pickering, Ambridge, and Wearing (2004) suggested that this basic structure of WM is present from 6 years of age, possibly earlier.

WM capacity declines in adulthood, as observed in both cross-sectional (e.g., Salthouse & Babcock, 1991) and longitudinal studies (e.g., Hertzog, Dixon, Hultsch, & MacDonald, 2003). One of the major sources of changes in WM capacity in adulthood appears to be the buildup of proactive interference, where information currently or previously held in memory reduces access to other information (e.g., Lustig, Hasher, & May, 2001; Zeintl & Kliegel, 2007). Older adults are also more susceptible to retroactive interference (where recently processed information reduces access to information learned earlier) in the short lists used in span tasks Hedden & Park, 2003 attributed that effect to confusion about sources (different lists) rather than degraded inhibitory functioning. Oberauer (2005) found that older and younger adults could temporarily disregard information that was designated as irrelevant, reactivating it later as needed, in memory updating tasks. He argued that older adults possessed preserved ability to move information in and out of the focus of WM, but showed difficulties in building and maintaining bindings between different representations in WM.

■ EPISODIC MEMORY

Episodic memory improves throughout childhood (see Schneider & Pressley, 1997). Figure 12.1 shows longitudinal data of episodic memory performance from children of age 4–12 (Knopf, 1999). Longitudinal and cohort-sequential studies in adulthood show that verbal and visual episodic memory declines in old age, even in individuals who are healthy and show no signs of dementing illness (e.g., Hultsch et al., 1998; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Schaie, 2005; Zelinski & Stewart, 1998; see Figure 12.2).

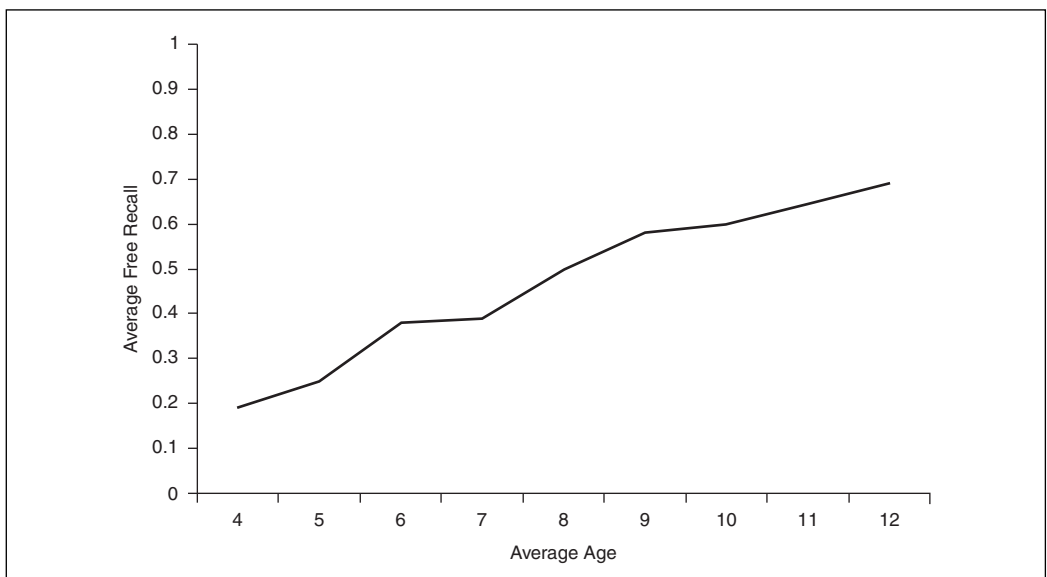


FIGURE 12.1 Developmental function for free-recall performance based on longitudinal data. *Source:* Data adapted with permission from Knopf (1999).

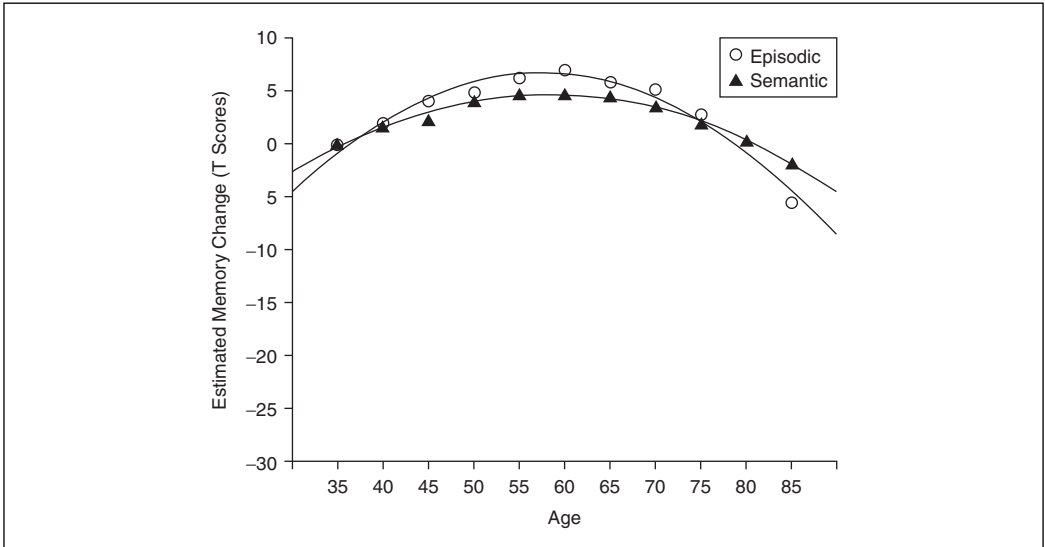


FIGURE 12.2 Estimated episodic and semantic memory changes across age (T scores) on the basis of longitudinal data. *Source:* Data adapted with permission from Rönnlund et al. (2005).

There are a number of qualifications of these broad generalizations. First, there is at least some evidence of cohort effects on memory performance, such that memory performance may improve for more recently born generations. The magnitude of these effects may be small relative to other types of cognitive ability (e.g., Rönnlund et al., 2005; Schaie, 2005; Zelinski, 2009). Cohort effects imply that historical and contextual events play a role in determining level of function; hence one should not presume that observed cross-sectional age differences in episodic memory are in some sense a pure reflection of ontogenetic aging. Second, the extent of episodic memory decline varies with the type of memory task. For instance, declines in memory for content of narrative texts shows smaller effect sizes of age than paired-associated recall or free recall of word lists (e.g., Hultsch et al., 1998). Third, there are individual differences in memory change in late life, arguing that some individuals experience greater memory decline than others (e.g., Hertzog et al., 2003).

Encoding

Tests of incidental encoding instruct an individual to process information in a certain way. On its surface, this orienting task has nothing to do with memorization per se (e.g., one might be instructed to judge properties of words, such as object size relative to a standard, or its consistency with a concept). Memory for the incidentally encoded information is then evaluated with a surprise memory test. Young children have excellent memory for recent events that have been coded incidentally (Schneider & Pressley, 1997). Memory for incidentally encoded information declines during adulthood (see Kausler, 1994). This contradicts the simple hypothesis that encoding deficits are primarily responsible for aging effects on memory, contrary to the early expectations of levels-of-processing theory (e.g., Craik, 2002), although

there has been debate about this issue (e.g., Light, 1991). Age differences in memory following incidental encoding can be reconciled with an encoding deficit by appeal to additional, elaborative encoding by younger adults—in effect, when individuals process information in a manner that enhances or supplements the surface requirements of the orienting task (e.g., Luo, Hendriks, & Craik, 2007).

Intentional encoding of new information involves strategic or reflective activity that aids the formation of new memory traces. This may take the form of organizing and/or elaborating on the to-be-learned information, often by making use of one's semantic knowledge to relate different features of an episode. For example, memory for new associations is aided by the use of verbal and imagery mediators (e.g., Richardson, 1998).

In the child developmental literature, episodic memory development has been tied to age changes in encoding strategies (Pressley & Hilden, 2006; Schneider & Pressley, 1997). Flavell's (1970) seminal work observed that rehearsal and organization develop as memory strategies between 5 and 10 years of age. Strategy use is often examined in sort-recall type of memory tasks in which items can be organized into semantic categories. Children's organization of items during study (assessed with sorting tasks) and recall (assessed by clustering like items in the recall sequence) develops rapidly throughout the elementary-school years (see Bjorklund, Dukes, & Brown, 2009; Schneider & Pressley, 1997). Kindergarten and early-grade school children do not spontaneously display strategic organizational behavior. However, when given instructions to use a strategy, they do so, pointing to an initial *production deficiency* of strategy use that can be overcome (Bjorklund et al., 2009). A *utilization deficiency* refers to spontaneous use of strategic behavior (e.g., selective attention) but without major benefits to memory (Bjorklund, Miller, Coyle, & Slawinski, 1997; DeMarie-Dreblow & Miller, 1988), implying inefficient or ineffective use of strategies, possibly due to limitations in WM (Schneider, Kron, Huennerkopf, & Krajewski, 2004) and metamemory (DeMarie, Miller, Ferron, & Cunningham, 2004). Development into young adulthood is characterized by increasing effectiveness of strategy use, which may be related to optimal selection of strategies to match item characteristics. Recent studies reveal that the use of multiple strategies can benefit children's later recall (e.g., DeMarie et al., 2004; Schneider, Kron-Sperl, & Hünnerkopf, 2009; Shin, Bjorklund, & Beck, 2007).

In adulthood, age differences in encoding strategies can reflect production deficiencies (Kausler, 1994; Verhaeghen & Marcoen, 1994), with older adults not spontaneously engaging in effective mnemonic strategies. Craik (1986) posited that successful remembering involves some mixture of externally driven "environmentally support" and internally guided "self-initiated activities." He argued that aging is associated with a decline in self-initiated processing, with older adults relying more on environmental support (see also Bäckman, 1989). One way of providing support is to instruct older adults to use mnemonic strategies, which benefits adults' learning (Kausler, 1994; Verhaeghen & Marcoen, 1994; Verhaeghen, Marcoen, & Goossens, 1992).

However, age-related production deficiencies are not an important explanation of aging effects on episodic memory. Dunlosky and Hertzog (2001) used item-level strategy reports to specify age differences in patterns of mediator use. In a paired-associate memory task, participants were instructed to use imagery or any strategy and were asked to report the strategy produced for learning each item. Small age differences in reported strategy production were only observed when people were not

informed about mediational strategies, and this difference did not account for large proportions of variance on older adults' recall. Spontaneous strategy use accounts for a substantial proportion of variance (individual differences) in WM and recall of newly learned associations, but little of the age-related variance in those variables, implying that factors other than a production deficiency are responsible for age differences in memory (e.g., Bailey, Dunlosky, & Hertzog, 2009).

The nature of memory representations created during encoding appears to undergo developmental changes. The fuzzy-trace theory by Brainerd and Reyna (1990) posits that memory representations can be aligned on a continuum ranging from literal, verbatim traces to fuzzy, gist-like traces. Verbatim traces correspond to representations constrained to the surface form of memory content. Gist traces, on the other hand, correspond to generalized representations, such as semantic meaning of memory content. In terms of developmental differences, during the preschool and early elementary-school-years an initial improvement in verbatim memory can be noted. Gist memory, on the other hand, tends to lag behind in development (e.g., Brainerd & Gordon, 1994). Overall, children experience a shift from relying on context-specific to gist-like representations over developmental periods (Brainerd & Reyna, 2004). The higher interference susceptibility of verbatim traces may, thereby, contribute to lower memory performance in younger children. There have also been some suggestions in the adult literature that older adults' self-generated cues are less stable and less distinct than younger adults, contributing to subsequent memory failure (e.g., Mäntylä & Bäckman, 1990), and that they encode general meaning information over specific details in text processing (e.g., Adams, Smith, Nyquist, & Perlmutter, 1997; Stine-Morrow, Miller, & Hertzog, 2006).

Binding and Storage

Binding refers to a set of cognitive processes that associate features within a memory trace or several memory traces among each other (Cohen & Eichenbaum, 1993; Polyn et al., 2009; Zimmer et al., 2006). In one of the few developmental studies that examined binding in childhood, Sluzenski, Newcombe, and Kovacs (2006) showed children and young adults' pictures of animals against arbitrary backgrounds, later testing them on their memory for the animals, the backgrounds, or both. Their results indicate that the quality of binding may progress significantly around 5–6 years of age (see Oakes, Ross-Sheehy, & Luck, 2006 regarding early development of binding in visual short-term memory). Memory for individual features appears to progress at a faster rate during childhood than the trajectory of memory for associations, which may also help to explain preschoolers' difficulty in source monitoring (Sluzenski, Newcombe, & Ottinger, 2004).

Binding may be implicated in greater age-associated impairments in remembering the context and the specific details of memory episodes than in remembering the content itself (see Spencer & Raz, 1995). The *associative deficit hypothesis* postulates that this effect is due, at least in part, to difficulties in binding information into cohesive memory representations. Chalfonte and Johnson (1996) compared age-related differences in memorizing individual features with binding of those features. Older adults' memory for object identity and object color was not worse than younger adults' memory (but feature memory for location was impaired). However, older adults manifested a disproportionate reduction in memory for bound item and

location information and bound item and color information. Older adults are disproportionately impaired at encoding and retrieving associations among items, such as associative pairings of two words (Old & Naveh-Benjamin, 2008), relative to the individual words themselves (see also Castel & Craik, 2003).

A recent life span study by Cowan, Naveh-Benjamin, Kilb, and Sauls (2006) indicates that memory binding develops early in childhood and declines faster than other aspects of memory. They investigated age differences in the ability to keep the association between a visual object (colored squares) and its spatial location in WM using a change-detection paradigm. Older adults often failed to notice changes in the conjunction of features. The two groups of children (aged 8–10 and 11–12 years) showed lower performance levels than younger adults on both kinds of trials. However, they were not as affected on the feature-conjunction trials as the group of older adults.

Retrieval and Accessibility

Like encoding, retrieval can be viewed as incidental or intentional. Incidental retrieval occurs when environmental cues or mental thoughts activate retrieval of information without explicit goal-directed search for the information. Recognition memory can generically be viewed as involving a passive retrieval process, in which activities or objects in the environment are subjected to comparator processes that match what is perceived to what is known or previously encountered. The phenomenology of recognition has been increasingly important in memory theory. Two-process views of memory retrieval (e.g., Jacoby, 1999) argue that individuals encountering old information experience either recollection (including activation of specific information about the original encounter) or familiarity, recognition of information as something encountered before, but without access to specific details about the encounter. Either type of experience can be illusory—in the Deese–Roediger–McDermott false memory paradigm, individuals report vivid recollection of a semantic category lure that was actually never presented to them (Roediger & McDermott, 1995). Nevertheless, familiarity experiences are more likely to be based on spontaneous retrieval of information that can be misattributed to one source as opposed to another (Dodson & Schacter, 2002).

Incidental retrieval seems in some respects relatively well preserved in adulthood. Older adults fare better on recognition tests than recall tests (e.g., Macht & Buschke, 1983; McDowd & Craik, 1987), especially if the criterion test is “yes/no” recognition that mixes old with new information and simply requires discrimination of each. From a two-process perspective, such outcomes are consistent with the claim that mechanisms supporting familiarity of specific information, such as individual items from a list, are spared by aging (Light et al., 2000). Conversely, older adults show declines in recollection during recognition tests, whether assessed by process-dissociation tasks (e.g., Jennings & Jacoby, 1997) or self-reports of recollection versus familiarity (e.g., Perfect & Dasgupta, 1997). The pattern of adult age deficits in recollection, coupled with relatively intact familiarity, has been demonstrated in a number of studies. For example, Jennings and Jacoby’s (1997) repetition-lag paradigm presented people with a series of items at encoding that they would be subsequently asked to recognize from among a set of novel items. During the recognition test, novel items were also repeated at varying lags, and participants were instructed to either exclude (say “no”) or include (say “yes”) repeated novel items at

test. Responding “no” to an exclusion trial required that participants be able to recollect the prior presentation of the item, whereas a “yes” response would likely be a product of context-free familiarity. Jennings and Jacoby’s results showed differences in recollection-based processing as a function of age, but they found no age effect on familiarity. Older adults are also more susceptible to familiarity-based memory illusions, such as ironic effects of repetition (Jacoby, 1999), in which repeated lures during a recognition memory test are mistaken for word originally presented during encoding.

Intentional retrieval, on the other hand, involves a goal-directed search for desired information (e.g., “where did I leave my keys?”). It relies on mechanisms of cognitive control, as well as metacognition that influence decisions about whether to stop searching, how to use processes of reconstruction, how to evaluate the products of retrieval, and so on. Cued recall tasks assess externally (experimenter) directed retrieval; self-initiated retrieval may be linked to concepts rather than percepts, and hence its success may hinge on how the desired information is construed at the time retrieval is initiated.

Many recognition memory tasks evoke both incidental and intentional retrieval mechanisms. After having people study paired-associate items, one can test associative memory by asking people to identify intact pairs and reject rearranged pairs (new combinations of unpaired words that were part of the pairs originally studied). Good performance on associative recognition tests of this kind benefit from the use of recollection-based intentional retrieval strategies, such as the use of recall-to-reject strategies in associative recognition tasks (Cohn, Emrich, & Moscovitch, 2008; Light, Patterson, Chung, & Healy, 2004). With this strategy, specific recollection that one element of a rearranged pair was actually paired with a different word when originally studied allows one to reject the rearranged pair as not being part of the original list.

Manipulation of intentional retrieval through memory test formats reveals differential rates of development in children, with smaller age differences being found in recognition memory than in cued or free recall (e.g., Perlmutter & Lange, 1978). Emerging evidence suggests that the development of recollection extends into adolescence, whereas familiarity matures earlier during childhood (e.g., Brainerd & Reyna, 2004; Ghetti & Angelini, 2008). These results support the notion that increasingly efficient inhibitory processes—including deliberate suppression of irrelevant information—contribute to improved memory performance that occurs with age across childhood (e.g., Bjorklund & Harnishfeger, 1990; Harnishfeger & Pope, 1996). Research from eyewitness memory further reveal that memory recall of children until at least 7 years of age is generally low (e.g., Poole & Lindsay, 1995), accompanied by an increase in the number of inaccurate responses. However, with appropriate interview procedure (e.g., motivated to screen out wrong answers by choosing “I don’t know”), even young children can enhance the accuracy of their testimony (Roebbers & Schneider, 2005).

There are several lines of evidence arguing that self-initiated retrieval becomes less effective as adults get older. Older adults’ cued recall differs more from young adults’ cued recall, relative to age differences in recognition memory (e.g., Macht & Buschke, 1983). Older adults, under instructions, are equally likely to generate effective mediators at encoding, but they are much less likely to be able to retrieve and report these mediators at test when asked to do so (Dunlosky, Hertzog, & Powell-Moman,

2005). This apparent retrieval deficit appears, in part, to be attributable to a failure to spontaneously use effective retrieval strategies to reconstruct the memory from available evidence (Naveh-Benjamin, Brav, & Levy, 2007).

Access to information during self-initiated retrieval searches depends in part on the extent to which that information has competition for access to retrieval mechanisms. Proactive interference during retrieval is increased in old age (e.g., Ikier, Yang, & Hasher, 2008; Lustig, Konkel, & Jacoby, 2004). The study by Ikier et al. (2008) used word fragment completion for items where one or two competitors had been previously presented that could be relevant completions of the fragment. Only younger adults implemented a controlled retrieval strategy to overcome this interference. Jacoby, Shimizu, Velanova, and Rhodes (2005) showed that older adults engaged in less depth of processing of foils presented at test in the context of words that had been deeply processed at study. The depth of retrieval was revealed by a later recognition test for foils. Jacoby et al. argued that control over retrieval depends on matching test behaviors to benefit from encoding quality.

Automatic inhibition of information at the time of retrieval appears to be intact in older adults (e.g., Holley & McEvoy, 1996), whereas controlled use of inhibition may be affected (Andres, Guerrini, Phillips, & Perfect, 2008). However, not all studies find age-related inhibition deficits during memory retrieval. The list-based method of directed forgetting instructs people to recall information from one of two studied lists, omitting items from the other list. Directed forgetting is relatively intact in older adults (Sego, Golding, & Gottlob, 2006; Zellner & Bäuml, 2006), as it is in older children (Zellner & Bäuml, 2005). When directed forgetting effects are found, they may be due to older adults failing to engage inhibitory strategies when encoding a second list so as to enable effective selective retrieval from the second list, but not the to-be-forgotten first list (Sahakyan, Delaney, & Goodmon, 2008), a problem with strategic processing, not inhibition per se.

Another phenomenon relevant to inhibition is retrieval-induced forgetting, in which retrieving some information from an inter-related set reduces likelihood of retrieving other information in the set. Older adults show similar retrieval-induced forgetting in a task requiring retrieval of exemplars from categories, in which retrieving some members of a category makes it more difficult to retrieve others (Aslan, Bäuml, & Pastötter, 2007). They also show similar part-set cueing effects (Andres, 2009; Marsh, Dolan, Balota, & Roediger, 2004). These studies argue against a general controlled inhibitory deficit concerning memory retrieval, indicating instead that older adults manifest some production deficiencies in retrieval control strategies (Naveh-Benjamin et al., 2007; Sahakyan et al., 2008).

Other phenomena have been used to argue for an increased susceptibility to interference at retrieval as people grow older. The fan effect occurs when a single cue may be associated with multiple targets, which reduces the likelihood of competing targets. Older adults show greater fan effects, in the form of increased errors or slowed response times as the number of elements mapped to a cue increases (Gerard, Zacks, Hasher, & Radvansky, 1991). However, the fan effect may not necessarily reflect interference effects alone. Buchler, Fauce, Light, Reder, and Gottfredson (2009) crossed fan mappings with repetitions of stimuli, using a complicated 5-choice associative recognition test. Repetitions provided both item and associative strengthening for both age groups. Fan-related interference was not greater for older adults, and they showed substantial and equivalent repetition benefits. Buchler et al. argued

that older adults manifest a retrieval deficit associated with weak memory strength from a single repetition, as well as a reliance on associative familiarity and item familiarity.

In sum, there is substantial evidence of age-related changes in retrieval effectiveness that may be due to multiple mechanisms. Studies of individual differences in memory and aging also support the hypothesis that age changes in retrieval mechanisms may be responsible for age-related changes in memory performance. Hultsch et al. (1998) and Hertzog et al. (2003) showed that older adults decline longitudinally in world knowledge tests. Such changes suggest reduced or impaired accessibility to knowledge. These changes also correlated highly with changes in WM and episodic memory, possibly implicating age-related problems in retrieval of information as a common influence on rates of episodic and semantic memory change in adulthood.

Encoding-Retrieval Interactions

One reason that it is difficult to separate encoding effects from retrieval effects is that the two sets of processes are interleaved, relying upon one another. Successful remembering requires both kinds of processes. The work by Jacoby et al. (2005) is an important example of encoding-retrieval interactions. The age difference in retrieval depth reported in those studies depends on the nature of encoding at test. Another example is the work on distinctiveness as a means of avoiding source memory errors. Dodson and Schacter (2002) argued that older adults are less likely to use distinctive details that are accessible at test to avoid misattributing what is familiar to the wrong source (see also Jacoby & Rhodes, 2006). Changes in test formats may encourage use of the distinctiveness heuristic, thereby lowering source memory errors. Likewise, the recollection training paradigm of Jennings and Jacoby (2003) trains individuals to avoid effects of repeating lures in a recognition test for items studied on an earlier list. By learning to engage in more effective encoding strategies, older individuals can learn to use recollection of the original words' features at encoding to discriminate them from the repeated lures (see also Lustig & Flegal, 2008).

■ METAMEMORY AND COGNITIVE CONTROL

Metamemory can be seen as a set of processes that involve self-reflection and evaluation (Wellman, 1983). It provides feedback to control processes on whether current actions are likely to achieve processing goals (Flavell, 1979; Nelson, 1996). Metamemory also involves declarative knowledge—such as knowing different processing strategies—and beliefs about one's own memory capabilities (Hertzog & Hultsch, 2000).

Memory Monitoring

Monitoring can occur with respect to multiple aspects of memory, and can be measured by multiple types of judgments (Nelson & Narens, 1990). Effective monitoring aids the control of learning and remembering. The major question is whether individuals' judgments have good resolution (relative accuracy). Resolution is assessed by within-person correlations of metamemory judgments with memory performance.

Judgments of learning (JOLs) assess monitoring whether information has been sufficiently studied to support later remembering. Schneider, Visé, Lockl, and Nelson (2000) found that JOLs have equal resolution in children from age 5 onward. Moreover, their children showed a delayed-JOL effect, in which the resolution of JOLs after a delay is considerably higher than that of JOLs given immediately after an item is studied (due in large part to the diagnosticity of a retrieval attempt for subsequent test recall). The equivalent resolution of immediate JOLs and delayed-JOLs suggests equivalent item-level monitoring of encoding and retrieval processes. However, Koriat, Ackerman, Lockl, and Schneider (2009) reported an increase from age 7 to age 12 in resolution of children's immediate JOLs, tying it to an age-related increase in reliance on the cue of memorization effort as a basis for making JOLs.

There is evidence that the monitoring of encoding is relatively unimpaired by aging (e.g., Connor, Dunlosky, & Hertzog, 1997; Hertzog, Kidder, Powell-Moman, & Dunlosky, 2002). Connor et al. (1997) also showed that equivalent delayed-JOL effects on resolution for older and younger adults. Recently, Hertzog, Sinclair, and Dunlosky (2010) examined JOLs in an adult cross-sectional sample, showing that JOLs were influenced by both item relatedness (the pre-existing association of word pairs) and the strategy used to encode the word pairs, and that this relationship was invariant over the adult life span.

Feeling of knowing (FOK) judgments assess the ability to forecast correct recognition after cued recall fails. Butterfield, Nelson, and Peck (1988) found a difference favoring younger children over older children in FOK accuracy. Lockl and Schneider (2002) also found no evidence of improved FOK resolution from kindergarten to adulthood. Hence monitoring retrieval appears to develop early in children. In adulthood, there is some controversy regarding the resolution of FOKs. It does not differ for items held in semantic memory (such as facts or world knowledge; e.g., Butterfield et al., 1988), but has been reported to be poorer in old age for FOKs about newly learned information (e.g., Souchay, Moulin, Clarys, Tacconat, & Isingrini, 2007). However, recent studies have indicated age equivalence in episodic FOK resolution in predicting both recognition accuracy and for recollection during the recognition test (Hertzog, Dunlosky, & Sinclair, 2010; MacLavery & Hertzog, 2009). The discrepancies in the literature have not yet been explained.

In some cases older adults have been found to be falsely confident about the accuracy of their recognition memory. Kelley and Sahakyan (2003) showed that older adults' recognition confidence judgments (CJs) were overconfident about responses to misleading lures in the Jacoby (1999) ironic effects paradigm. Older adults had poorer resolution of CJs for misleading items, but not in a test lacking them (see also Kelley & Rhodes, 2005). Likewise, Dodson, Bawa, and Krueger (2007) found that when older adults made commission errors in source recognition or in cued recall for related items, they tended to be overconfident, relative to younger adults, in the accuracy of their errors. Shing, Werkle-Berger, Li, and Lindenberger (2009) also reported that older adults manifested high-confidence errors in associative recognition, whereas children 10–12 years old did not show such pattern.

Some argue that this kind of "misrecollection" (Dodson et al., 2007) is due to the poor performance of a subset of older adults who manifest low scores on neuropsychological tests of frontal function (Butler, McDaniel, & Dornburg, 2004; Geraci & Roediger, 2007). Similar arguments have been made regarding reported age-related deficits in resolution of episodic FOKs (e.g., Souchay & Isingrini, 2004) and source

attributions (Henkel, Johnson, & DeLeonardis, 1998). These phenomena may reflect a failure to engage in controlled search for disconfirming evidence—what can be viewed as a failure of monitoring-guided control.

Monitoring latency or duration of cognitive processes, as opposed to their accuracy, is more influenced by aging. Old and young adults alike are moved by fluent encoding (rapid production of an image) to forecast later remembering in their JOLs, even when such fluency has no effect on actual memory (Robinson, Hertzog, & Dunlosky, 2006). There are also age deficits in monitoring elapsed time during memory task trials, such as in estimating how long it takes to retrieve information (e.g., Craik & Hay, 1999; Hertzog, Touron, & Hines, 2007). Hines, Touron, and Hertzog (2009) showed that older adults were less accurate in estimating recognition retrieval times and this was an apparent cause of lower resolution in their CJs.

Metacognitively Guided Control

Self-regulated learning (Winne, 1996) requires the use of monitoring to optimize learning. For example, self-testing determines how well information has been learned, aiding in the identification of items that need additional study, or a revised study strategy (Dunlosky & Hertzog, 1998).

Children between the ages of 7 and 12 show substantial improvement in the use of monitoring to guide selection of items for study, allocation of effort and study time, and adjustment of strategic behavior (Schneider, 2011). Children above the age of 7 do relatively well in setting thresholds for making or withholding recall responses (Roebbers, 2006). In multitrial learning tests, allocation of study time based on JOLs shows developmental improvement from age 7 upward (Dufresne & Kobasigawa, 1989; Koriat et al., 2009). Developmental improvements in strategic regulation of encoding reviewed earlier seem to be accompanied by improvements in what Schneider and colleagues call procedural metamemory—that is, on-line use of monitoring to guide effective control (e.g., Koriat et al., 2009; Roebbers & Schneider, 2005).

Older adults have been reported to show deficits in spontaneous self-testing to regulate recall readiness (e.g., Murphy, Schmitt, & Caruso, 1987), although this production deficit was redressed by informing older adults of the self-testing method. Dunlosky and Connor (1997) found that younger adults were more likely than older adults to base subsequent study time allocation on the basis of accurate delayed-JOLs, allocating more time to less well-learned items. However, older adults could have been engaging in extra elaborative rehearsal of recalled items that could be beneficial to their retention. Moreover, Hines et al. (2009) found equivalent influences of recognition memory accuracy and CJs on older and younger adults' next study time allocation, a finding in apparent conflict with Dunlosky and Connor (1997). Older adults have also been found to exhibit similar item selection behaviors, choosing items for study that they have not yet learned over ones they have learned (Dunlosky & Hertzog, 1997). Price, Hertzog, and Dunlosky (2010) found that older adults were similar to younger adults in selecting foreign language vocabulary items for study, although they tended to avoid the most difficult items in restudy. Older adults have also been reported to be flexible in selective learning recall of items designated by experimenters to have higher value (e.g., Castel, Farb, & Craik, 2007). Hence, the evidence is mixed regarding age deficits in metacognitively guided control, possibly

indicating that age differences depend on task demands and characteristics of the individuals.

Metamemory Beliefs

Beliefs people have about memory and cognition can play a role in memory development (Hertzog & Hulstsch, 2000; Schneider, Korkel, & Weinert, 1987). Young children develop around the age of 4 a theory of mind that accurately reflects the fact that internal thoughts are not accessible to others, including one's parents (Wellman & Gelman, 1992). Later, implicit theories about causes of cognitive success and failure appear to influence how children engage in, react to, and interpret success and failure in testing situations (e.g., Dweck & Leggett, 1988). Metamemory researchers have emphasized the importance of declarative knowledge about strategy effectiveness and its development in guiding self-regulated learning and remembering (Schneider, 2011).

Older adults, like younger adults, believe that episodic memory declines in adulthood (see Hertzog & Hulstsch, 2000; e.g., Lineweaver & Hertzog, 1998; Ryan & See, 1993). Although older adults perceive less decline and later decline than younger adults, the fact that they are experiencing late-life effects of aging may make them more vulnerable to negative stereotypes, in terms of stereotype threat (Hess, Auman, & Colcombe, 2003) or implicit activation that harms memory performance (Levy, 1996). Some stereotypes about aging and cognition are positive. Lineweaver, Berger, and Hertzog (2009) showed that reading person descriptions that contain positive stereotypes, such as being active in old age, led younger and older people to predict less memory decline for those persons, relative to persons who had negative attributes. Hertzog, McGuire, Horhota, and Jopp (2010) found that older adults' implicit theory about control over memory was likely to involve lifestyle variables such as exercising the mind and memory, good nutrition, as well as positive motivation. Younger adults rarely mentioned staying active as an influence on memory, instead being more likely to talk about aspects of metacognitive self-regulation.

Older adults typically rate themselves as lower in memory ability and control over memory, and these beliefs often correlate only weakly (about .2) with episodic memory performance in older samples (e.g., Hertzog, Dunlosky, & Robinson, 2009; Lachman, Bandura, & Weaver, 1995). Thus, memory beliefs may not be very accurate. Low memory self-efficacy has been linked to lower memory performance in older adults, as well as less effective strategy use (Berry, 1999). Price et al. (2010) showed that avoidance of difficult items by older adults correlated with memory self-efficacy beliefs. Likewise, lower perceived control over memory is associated with lower levels of strategic encoding behavior in memory tasks (Hertzog, Lineweaver, & McGuire, 1999; Hertzog et al., 2009; Lachman, Andreoletti, & Pearman, 2006). Recently, West, Dark-Freudeman, and Bagwell (2009) showed that a measure of general memory self-concept interacted with a goal-setting manipulation in influencing the amount of older adults' performance improvement on a second exposure to a grocery list. Memory beliefs had no impact on younger adults' performance improvements.

Interventions that target memory self-efficacy and control beliefs have been shown to be effective in raising levels of self-efficacy and control, and in some cases, memory performance (e.g., West, Bagwell, & Dark-Freudeman, 2008). West et al.

(2008) engaged in a comprehensive self-efficacy intervention focusing on mastery experiences, persuasion, and skill-modeling that persisted through training. They found differential benefits of self-efficacy training on strategy use and recall performance on multiple tasks—training benefits were larger and more durable than those seen in earlier studies that implemented more modest belief-restructuring interventions.

Role of Training/Testing Limits in Evaluating Memory Change

Various theories in the field of developmental psychology have emphasized the notion of plasticity, that is, the modifiability of an organism in adapting to changing constraints and opportunities afforded in the developmental context (Baltes, 1987). In this vein, intervention and training studies play an important role in exploring the range and modifiability of cognitive functioning across different age periods (see Hertzog, Kramer et al., 2009, for a recent review). A specific paradigm that plays an important role in episodic memory training studies, particularly in aging, is the *testing-the-limits* procedure (Lindenberger & Baltes, 1995). Its aim is to approximate the upper limits of memory performance potential by providing strategic instruction and extensive practice, often combined with systematic variations in task difficulty.

A robust finding from the testing-the-limits literature is that memory plasticity remains in cognitively healthy older adults (Baltes et al., 2006; Shing, Brehmer, Li, 2008). Instruction and/or practice in a memory technique lead to robust performance improvements in healthy older adults. For example, Kliegl and colleagues (Kliegl, Smith, & Baltes, 1989, 1990) showed that after multiple sessions of training and practice in using the Method-of-Loci strategy, both younger and older adults improved their memory performance. This finding converged with evidence from other intervention studies (e.g., Ball et al., 2002; Derwinger, Neely, Persson, Hill, & Bäckman, 2003; Verhaeghen & Marcoen, 1996; Verhaeghen et al., 1992), indicating continued existence of memory plasticity in old age. Nevertheless, Kliegl et al. (1990) also found that extensive training resulted in a widening of the age difference in memory performance, with all younger adults outperforming older adults after training. Thus, the testing-the-limit paradigm demonstrated age-related differences in upper limits of memory performance (see also comparison to children in Brehmer, Li, Müller, von Oertzen, & Lindenberger, 2007), and these limits are more bounded in very old age (Singer, Lindenberger, & Baltes, 2003).

■ SEMANTIC MEMORY/KNOWLEDGE

It has long been known that tests of semantic memory show continuous growth in childhood and relative maintenance in adulthood, declining only late in life (e.g., Schaie, 2005). The maintenance of knowledge and knowledge access fueled theoretical distinctions on intelligence throughout the 20th century, as in the fluid-crystallized theory of Cattell (1971) and Horn (e.g., Horn, 1968), and Baltes and colleagues' emphasis on pragmatics versus mechanics from a life-span perspective (e.g., Baltes et al., 2006). Knowledge and expertise can be construed as a return on investment of time and effort (Ericsson & Charness, 1994), as well as an application of fluid intelligence to learning (Ackerman, 2000; Cattell, 1971). This investment that

leads to new knowledge structures, characterized by fast and fluent access to and retrieval of information as it is needed for comprehension, evaluation, and inference (Ericsson & Kintsch, 1995).

A large number of developmental studies have demonstrated that the amount of knowledge in a particular domain determines how much new information from the same domain can be stored and retrieved (see reviews by Bjorklund & Schneider, 1996; Chi & Ceci, 1987). As demonstrated in expert studies of various domains including chess, physics, and sport, domain knowledge is a powerful determinant of memory and learning. It increases steadily from infancy to adulthood and contributes to the development of memory competencies (e.g., Schneider & Pressley, 1997). For example, children's recall of categorically related material over the school years can be attributed to age-related increases in the relatively automatic activation of semantic memory relations (e.g., Bjorklund & Harnishfeger, 1987; Hasselhorn, 1995). The importance of interactions among these factors for memory development was highlighted in the "model of good information processing" (see Schneider & Pressley, 1997).

Knowledge and skills learned long ago persist, in at least partially accessible form, for long periods of time. Bahrick (1984) demonstrated that middle-aged adults had some level of recognition vocabulary for Spanish words they had studied years before in high school. Bahrick and colleagues have extended this work to other domains (e.g., Bahrick & Hall, 1991), and formulated the concept of *permastore*—the idea that once information entered semantic memory it stayed there, with the only issue being whether it could be accessed.

Increasing age appears to be accompanied by changes in both accessibility and the dynamics of accessibility to information held in semantic memory (Craik & Bialystok, 2006). Deliberate search for information in semantic memory according to arbitrary rules, such as word fluency, declines with age (Schaie, 2005). Older adults have difficulty learning and remembering proper names (e.g., James, Fogler, & Tauber, 2008; Seidenberg, Guidotti, & Nielson, 2009), and are generically more susceptible to tip-of-the-tongue effects (Burke, McKay, Worthley, & Wade, 1991; Maylor, 1990). Word finding problems increase with old age, and are particularly associated with some forms of dementia (Laws, Adlington, & Gale, 2007). Even when retrieval from semantic memory is routinely successful, such as in comparative judgments of category typicality or synonym meaning, access is often slowed (e.g., Hertzog, Raskind, & Cannon, 1986), albeit less than slowing of other types of cognitive operations (Hale & Myerson, 1996; Laver & Burke, 1993). Slowed or blocked access is cited by older adults as a cause of loss of control over memory (Hertzog et al., 2010). It could be related to longitudinal changes in world knowledge performance of older adults found in the Victoria Longitudinal Study (Hertzog et al., 2003).

■ AUTOBIOGRAPHICAL MEMORY

Autobiographical memory refers to memory of past events from one's own life. According to Rubin and colleagues (e.g., Rubin, 2006), autobiographical memories are not single entities but consist of information stored in component processes, with each process occurring in a separate behaviorally and neurally defined system. In

this view, the construction and recall of autobiographical memory may involve integrating both episodic and semantic contents (among other domains).

Autobiographical memory research in child development often focuses on childhood amnesia, which refers to the inability to consciously access memories from the earliest years of life. Explanations of childhood amnesia have assumed that early memories are qualitatively different from later memories until the child crosses the so-called "childhood amnesia barrier" (see Bauer, 2006). However, even infants are able to recognize and recall aspects of specific experience and retain these memories over extended period of time (see also Hayne, 2004; Rovee-Collier & Shyi, 1992). Maturation of medial temporal structures shifts the locus of forgetting from the initial phases of memory trace construction to the later phases of trace retrieval (Bauer, 2006). With development, richer and higher-quality traces are more available for retrieval and contribute to an increase in the number of memories that feature autobiographical elements. Furthermore, children begin to verbally communicate past events soon after they begin talking, allowing for rehearsal and reorganization of the memory into a more coherent narrative form (e.g., Fivush, Haden, & Reese, 1996).

At the other end of the life span, the reconstruction of autobiographical memory through episodic and semantic components undergoes changes in aging. Investigations of autobiographical memory recall (e.g., Holland & Rabbitt, 1990; Levine, Svobada, Hay, Winocur, & Moscovitch, 2002) suggest that older adults show greater decline on episodic components of autobiographical memory, but preserved or enhanced recall of semantic components (e.g., Cabeza & St. Jacques, 2007). Another important finding concerning autobiographical memory and aging is the so-called reminiscence bump. In general, regardless of age, we tend to recall recent memories more often than remote memories. Beyond this, middle-aged and older adults experience a peak in the recall of memories of events that occurred when participants were in early adulthood, between approximately 10 and 30 years of age (Rubin, 2000). This reminiscence bump has been repeatedly reported in the literature, although the exact age range of the bump varies across studies (e.g., Chu & Downes, 2000), and the causes of the bump are still a matter of debate.

■ PROSPECTIVE MEMORY

Prospective memory (PM) is remembering to do something in the future. Perhaps the most salient feature of PM is how contemporary psychological theories interweave other psychological processes such as attention and monitoring (Smith, 2003), motivation, intention formation (e.g., Goschke & Kuhl, 1993), and goal neglect to account for PM successes and failures (see Kliegel, McDaniel, & Einstein, 2008). PM research has also attended to similarities and differences between laboratory tasks assessing PM and PM as it occurs in everyday life. McDaniel and Einstein's (2000) multiprocess view of PM embraces these influences, and more, in a comprehensive account of PM. Two basic types of PM are distinguished in the literature, although these types may blend when discussing prospective remembering in everyday life: event-based and time-based PM. Event-based PM refers to contingent enactment, doing something when environmental circumstances warrant or allow it. Time-based PM involves acting at a specific point in time.

Ceci and Bronfenbrenner (1985) were among the first to evaluate time-based PM in children. In their study, children were instructed to perform future activities after waiting 30 minutes. Children's strategic time monitoring during the waiting period was found to occur less frequently in the laboratory than in the home. In other words, at least when in their familiar environment, children as young as 10 showed relatively well-developed time monitoring for prospective event. In more recent event-based PM studies, results also tend to suggest that, in comparison to retrospective memory, PM skills develop at a relatively early age (e.g., Kurtz-Costes, Schneider, & Rupp, 1995; Kvavilashvili, Messer, & Ebdon, 2001). However, at least modest effect of age was found in a few studies that employed wider age ranges (e.g., Kerns, 2000), calling for the need for more comprehensive investigation.

In adulthood, there is a major discrepancy between studies of PM in the natural ecology and PM in the laboratory. Older adults often do quite well with PM tasks in everyday life, such as remembering to take medications (Park et al. 1999), or remembering to phone the laboratory at a specific time (West, 1988). Older adults often use an organizational system or a routine to support everyday action, rather than relying on remembering their intentions. In laboratory tasks, older adults are clearly impaired in time-based PM (Einstein, Richardson, & Guynn, 1995), and impairments in time monitoring may contribute to this deficit (Park, Hertzog, & Kidder, 1997).

Einstein and McDaniel (1990) created a dual-task laboratory procedure assessing event-based PM. An ongoing activity (e.g., a continuous memory task) is paired with a secondary PM task, for which an occasional primary task event cues a different action (e.g., press a key when an animal name is presented). They found no age-related impairments in event-based PM. A published meta-analysis (Henry, MacLeod, Phillips, & Crawford, 2004) argued that there was a deficit, but a smaller one, for event-based PM relative to time-based PM. Smith and Bayen (2006) localized age deficits in event-based PM to the attentional demands of prospective monitoring during a concurrent task. Age differences are larger in successful PM for cues outside the immediate focus of attention, especially under attentional load (Rendell, McDaniel, Einstein, & Forbes, 2007)—findings broadly consistent with a monitoring deficit. McDaniel, Einstein, Stout, and Morgan (2003) demonstrated that delayed enactment (i.e., when the action must be deferred after detecting the PM cue) is also sensitive to age differences, possibly owing to age deficits in maintaining intentions in WM while performing other actions. Thus, although age differences may be larger in time-based PM, event-based PM differences will be found when additional processing is required to detect a cue or maintain an intention in the face of distraction and intervening events.

■ INFLUENCES ON LIFE-SPAN MEMORY DEVELOPMENT

We have already mentioned several factors that influence memory development, such as changes in the brain regions envisioned by Lindenberger and colleagues (e.g., Shing et al., 2008) in their life-span theory of memory development. Although space precludes a detailed treatment of other influences, we treat briefly two other aspects: a psychological account of memory development based on the concept of cognitive resources, and the influence of pathological memory change in later life.

Cognitive Resources

By some accounts, basic processing mechanisms can be viewed as resources that can be flexibly allocated in service of achieving cognitive goals. Here, we selectively discuss two basic cognitive resources (i.e., WM and processing speed) that received considerable attention in both fields of cognitive development and aging. WM is a critical resource for encoding information into episodic memory, as well as other higher-order forms of cognition such as inductive reasoning (e.g., Kyllonen & Christal, 1990; Hulstsch et al., 1998; Salthouse, 1991). Developmental changes in WM have been cited as a major cause of higher cognitive development in children (Gathercole, 1998) and as a cause of age-related decline in episodic memory (Salthouse & Babcock, 1991; Stine-Morrow et al., 2006). WM changes are highly associated with episodic memory changes in adulthood (Hertzog et al., 2003; Hulstsch et al., 1998).

Theories of cognitive development emphasizing the role of processing speed have also been formulated for both ends of the life span (Birren, 1965; Kail & Salthouse, 1994; Salthouse, 1996). For instance, Kail and Park (1994) showed that there is a relationship between processing speed and memory span mediated by articulation rate. In aging, cross-sectional studies have found that between 44 and 80% of cross-sectional age variance in memory task was associated with psychometric tests of perceptual speed (Salthouse, 1996; Verhaeghen & Salthouse, 1997).

However, reduced resource explanations of aging have been challenged on several grounds, including (1) the measurement properties and cognitive constituents of tests of processing speed (e.g., Hertzog, 1989; Lustig, Hasher, & Tonev, 2006); (2) whether one of these information-processing constructs is more basic than the variables they are used to predict (Deary, 2001; Light, 1991); and (3) methodological problems with regression-based estimates of resource-determined age-related variance using cross-sectional data (Hofer, Flaherty, & Hoffman, 2006; Lindenberger & Pötter, 1998). For example, longitudinal data typically show smaller effects of changes in speed and WM on changes in episodic memory performance (Hertzog et al., 2003; Hulstsch et al., 1998).

Normal and Pathological Changes in the Central Nervous System

Major memory loss is associated with brain pathologies such as dementia of the Alzheimer's type, frontotemporal dementia, Parkinson's disease, exposure to environmental toxins, and HIV infection. In practice, it can be difficult to separate such effects from normal aging in psychological studies of memory, because of a lack of information about neurological status, neuropsychological evaluation, and postmortem evaluation of brain function. Although memory decline is considered a part of normal aging, it can also be a leading indicator of brain pathology (e.g., Bäckman & Small, 2007). It is reasonable to assume that aging samples mix preclinical and subclinical cases with individuals who have no brain pathology (Sliwinski, Hofer, & Hall, 2003), although some would claim that such partitions are not based on qualitative differences of normal versus pathological, but rather, quantitative differences of amount of age-related pathology, and perhaps age of onset of noticeable symptomatology.

An ongoing issue in clinical memory assessment is whether a category of mild cognitive impairment (MCI) can be differentiated from dementia, on the one

hand, and normal aging, on the other. Kral (1958) argued for a category of benign senescent forgetting as distinct from dementia, and that idea continues to have some currency in classifying persons as having MCI (Peterson, 2003). A substantial proportion of persons diagnosed as having MCI (Smith, Peterson, Parisi, & Ivnik, 1996) on the basis of low norm-referenced memory test performance transition to dementia a few years later, which has led some to question the utility of MCI as a separate diagnostic entity.

Individual differences in timing of onset of dementia diagnosis may be due, in part, to cognitive reserve (Stern, 2002). Some individuals begin adulthood with better functional memory, and have more to lose before brain changes can lead to performance impairments (Tucker-Drob, Johnson, & Jones, 2009).

■ FUTURE ISSUES IN THE STUDY OF LIFE-SPAN MEMORY DEVELOPMENT

Researchers working either in the field of child development or aging have initiated fruitful lines of research to better understand how memory develops and changes within confined age periods. However, little effort has been invested in directly examining and integrating the mechanisms underlying memory changes across the life span. As reviewed earlier, research within separate life periods has addressed whether age-related differences in memory functioning can be accounted for by information-processing constraints or processing resources. In addition to general resource account, there are memory-specific mechanisms that drive memory changes across different age periods. By taking a life-span lens in approaching developmental issues, findings and paradigms in the adult literature could inform new directions in child research, and vice versa. For example, the prominent theory of fuzzy-trace theory has been applied to address changes in false memory in child development (Brainerd & Reyna, 2004) and aging (Dehon, 2006), respectively.

More directly, the inclusion of a life-span sample within the same study helps to elucidate the particular characteristics of episodic memory in children, and vice versa. For example, in the life span study of Brehmer et al. (2007), children and older adults possessed similar levels of baseline performance. However, children gained more from extensive strategy training than older adults, demonstrating life-span differences in developmental plasticity. In the Shing et al. (2008) study, children showed lower hit rates in associative recognition than all other age groups before strategy instruction, but this age pattern was eliminated after instruction and practice. Older adults, on the other hand, showed persistently higher false-alarm rates on rear-ranged pairs (mostly accompanied with high ratings of confidence, see Shing et al., 2009). Whereas both age groups of the extreme ends of life span show lower memory functioning than younger adults, children and older adults exhibit different patterns of memory problems. By including children and older adults in the same study, one attains a better understanding of what is general and special about the memory performance of each of the two groups. Additional attention to connecting and contrasting development across the full range of the life span could be highly beneficial (e.g., Craik & Bialystok, 2006; Shing et al., 2008).

There are many other questions about memory development that beg for further attention. We highlight a few of them. First, there is a need for better understanding of the development of encoding/retrieval interactions, going beyond focus

on either encoding or retrieval as a locus of developmental changes in memory. One important developmental influence may be the role of prior knowledge on effective encoding and subsequent guided retrieval search for the same information. Relative to children, older adults have acquired extensive semantic and rich autobiographical knowledge in the course of their lives. Therefore, it is conceivable that older adults are more likely to process new information and guide remembering in connection to existing representations. On the other hand, children's encoding of new information may rely heavily on the creation of representations that carry a strong novelty value and may be less readily blended with retrieved past experiences. It is possible that older adults' greater susceptibility to interference is in part a consequence of more elaborated and integrated semantic knowledge structures that guide encoding with substantial benefit, but also create more opportunities for retrieval interference (Buchler & Reder, 2007). Whether such effects are less likely during child development, or, alternatively, can be observed under specific encoding conditions (e.g., learning in the classroom) is an interesting and open question.

Second, research on metacognition and metacognitive control has expanded rapidly in the last decade. However, we still do not understand how and whether individuals at different points in the life span spontaneously engage in the kind of top-down self-regulation envisioned by metacognitive theory (effective use of monitoring to achieve self-regulation) as opposed to a more reactive, stimulus driven type of cognitive control. New task paradigms that can explicitly separate reactive versus proactive cognitive control (Braver et al., 2009) are needed in this area.

Finally, an important theme in the cognitive aging literature is the issue of relationships between lifestyle factors and individual variation in aging-related decline. For example, the degree to which an individual is engaged in mentally and physically stimulating activities regularly may be correlated with steepness of cognitive decline. Several rigorous microlongitudinal studies have demonstrated that improvements in cardiovascular fitness impart positive effects on human cognitive abilities, with the largest benefits occurring for executive-control processes (see review by Colcombe & Kramer, 2003). From a life-span perspective, early development is characterized by selection and optimization processes that shape individual differentiation at later stages of life in a cumulative fashion. Neural and behavioral evidence strongly suggests that early interventions targeted toward disadvantaged children are more effective and have higher returns than later remedial interventions (Heckman, 2006; Knudsen, Heckman, Cameron, & Shonkoff, 2006). An important issue for future investigation is to understand the ways in which lifestyle factors such as physical and intellectual activities at early stages of life, including childhood (e.g., Deary, Whalley, & Starr, 2009), can help maintain cognitive competence during adulthood and old age.

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