

Memory Development

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16.1 INTRODUCTION

The title of this chapter – *Memory Development* – creates the impression that a single entity – *memory* – has a single course of development. Instead, there are several different types of memory, each with its own characteristics and course of development. For example, one type of memory is short-term, lasting only seconds or minutes before fading away, whereas another type is long-term, lasting as long as a lifetime. Some types of memory have a limited capacity, whereas others are, for all practical purposes, limitless. Memory sometimes is context-specific and other times highly flexible. In fact, it sometimes seems that the only thing all memories have in common

is that they are about the past. Yet even this characterization is not universally true, in that remembering to do something *in the future* also qualifies as ‘memory’ of the prospective type.

One primary goal of this chapter is to characterize the major forms of memory. This step is necessary in order to accomplish the second goal, which is to describe the course of development of different types of memory over the first years of life. As will become apparent, different types of memory have different courses of development. Differences in the timing and course of development shed light on some of the mechanisms of age-related change, consideration of which is the third major goal of the chapter.

16.2 DIFFERENT FORMS OF MEMORY

The suggestion that memory is not a unitary construct is an old one. [Maine de Biran \(1804/1929\)](#) is credited as the first to suggest that there might be different forms of memory ([Schacter et al., 2000](#)). The notion was furthered at the beginning of the twentieth century with studies of wounded veterans from World War I. [Kleist \(1934\)](#), a German physician, examined veterans who had received head wounds from gun shots or shrapnel and the behavioral patterns that seemed to result from them. He observed that there were systematic relations between the site of the wound (and resulting brain lesion) and the type of mental impairment experienced by the veteran. The notion that different parts of the brain subserve different cognitive functions, including different types of memory, received especially strong impetus from the famous case of H. M. who, at the age of 27, underwent experimental surgery to treat intractable seizures. To treat the seizures, his surgeon removed large portions of the temporal lobes on both sides of the brain ([Scoville and Milner, 1957](#)). Subsequent to the surgery, H. M. suffered impairment of some forms of memory, yet not all of his memory capacities were disrupted. His case in particular led to the notion that there are different types or forms of memory. Whereas some distinctions within the domain are readily accepted, others are sources of debate.

16.2.1 Short- and Long-Term Memory

Characterizing memory along a temporal dimension is relatively uncontroversial. Whereas some memories are short-term, lasting only seconds, others last much longer, on the order of days, months, and even years. Short-term memory generally is recognized as capacity-limited. It is commonly thought to hold 7 ‘units’ of information – such as digits in a phone number – plus or minus 2 ([Miller, 1956](#)), though estimates of capacity vary. In contrast, long-term memory is virtually limitless in its capacity. There seemingly is no upper limit on the number of items, pieces of information, or personal experiences that one can maintain in long-term memory stores (more on the temporal dimension and capacity limitations of memory below).

16.2.2 Declarative and Nondeclarative Memory

Within long-term memory, many recognize a division based on the contents of memory, its function, its rules of operation, and the neural substrates that support it. Although the precise distinctions captured by the different labels given to the divisions are not identical, there is substantial overlap in contemporary conceptualizations of declarative or explicit memory versus nondeclarative, procedural, or implicit memory. Each is discussed in turn.

16.2.3 Declarative or Explicit Memory

Declarative or explicit memory is devoted to processing of names, dates, places, facts, events, and so forth. These are entities that are thought of as being encoded symbolically and that thus can be described with language. In terms of function, declarative memory is specialized for fast processing and learning. New information can be entered into the declarative memory system on the basis of a single trial or experience. In terms of rules of operation, declarative is fallible: one forgets names, dates, places, and so forth. Although there are compelling demonstrations of long-term remembering of lessons learned in high school and college (e.g., foreign language vocabulary: [Bahrick, 2000](#)), a great deal of forgetting from declarative memory occurs literally minutes, hours, and days after an experience. Declarative memory also has a specific neural substrate. Current conceptualizations suggest that the formation, maintenance, and subsequent retrieval of declarative or explicit memories depend on a multicomponent network involving cortical structures (including posterior–parietal, anterior–prefrontal, and limbic–temporal association areas) as well as medial temporal structures (including the hippocampus and entorhinal, perirhinal, and parahippocampal cortices: e.g., [Eichenbaum and Cohen, 2001](#); [Murray and Mishkin, 1998](#); [Zola and Squire, 2000](#)). The medial temporal structures may be considered ‘primary’ in the sense that without them, whether measured by recall or recognition, declarative memory is impaired ([Moscovitch, 2000](#)).

Declarative memory is itself subdivided into the categories of semantic and episodic memory (e.g., [Schacter and Tulving, 1994](#)), with a finer distinction between episodic and autobiographical memory. Semantic memory supports general knowledge about the world ([Tulving, 1972, 1983](#)). People are consulting semantic memory when they retrieve the facts that the capital of the United States is Washington, DC, that the United States has 50 states, and that with over 660 000 square miles, Alaska is the largest state in terms of land mass. For practical purposes, both the capacity of semantic memory and the longevity of the information stored in it seem infinite. Semantic memory also is not tied to a particular time or place. That is, people know facts and figures, names and dates, yet in most cases, they do not know when and where they learned this information. People might be able to reconstruct how old they were or what grade they were in when they learned some tidbits of information, but unless there was something unique about the experience surrounding the acquisition of this information, they carry it around without address or reference to a specific episode.

In contrast to semantic memory, episodic memory supports retention of information about unique events ([Tulving, 1972, 1983](#)), such as a specific visit to

Washington, DC, or the fact that Alaska was one of the states on a list of state names studied in a memory experiment. Some episodic memories, such as whether a specific state was included in a word list, may not stay with one for very long and are not especially personally relevant or significant. Yet other episodic memories are personally significant and even self-defining. These so-called *autobiographical* memories are episodic memories that are infused with a sense of personal involvement or ownership (Bauer, 2007). They are the episodes on which people reflect when they consider who they are and how their previous experiences have shaped them.

16.2.4 Nondeclarative, Procedural, or Implicit Memory

Nondeclarative, procedural, or implicit memory is devoted to perceptual and motor skills and procedures. Skilled motor behavior, such as dancing or swinging a tennis racket, is not a name, date, place, fact, or event but a collection of finely tuned motor patterns, behaviors, and perceptual skills that one cannot verbally describe. Most types of nondeclarative memory function to support gradual, incremental learning. That is, behavior is modified through practice, experience, or multiple trials. Perhaps as a result of its slow function, a rule of the operation of nondeclarative memory is that the learning is relatively infallible (see [next paragraph](#)). A typical example is riding a bicycle – one may not have ridden a bicycle in many years but when he or she rides one again, he or she ‘just knows how.’ Indeed, breaking an old nondeclarative pattern can be quite difficult, as exemplified by the tendency to, in a moment of panic, slam the pedals backward (as one does on his or her old 1-speed bike) instead of squeezing the hand brakes (as one should on his or her adult, multi-speed bike). As might be expected, given the diversity of behaviors supported by nondeclarative memory, different types of nondeclarative memory depend on different neural structures. For example, motor skill learning and many types of conditioning seemingly are dependent on cerebellum and subcortical structures such as the basal ganglia and priming seems dependent on extrastriate cortex.

Just as declarative memory is subdivided, so too is nondeclarative memory. The most common categories of nondeclarative memory are (1) motor skill learning and (2) priming, and (3) classical conditioning. The range of motor skills that people acquire is limitless. What they have in common is that although there might be a declarative component to them (to stop the bike, put on the brakes), their fluid execution is not accomplished via learning and frequent repetition of the declarative ‘rules,’ but motor practice. Hours and hours and hours of practice lie behind the fluid swish of a tennis

champion’s racket or the dance steps of Ginger Rogers and Fred Astaire. A tennis or dance instructor can tell one how to hold the racket or how to position one’s foot to produce certain steps, but it is not this knowledge on which accomplished athletes depend. Closer to home, people all know that to stop cars that they are driving, they put their feet on the brakes. Yet few if any people know how many pounds of pressure they must put on the brake pedal to stop quickly versus more gradually. The information is encoded in their muscles and joints; it is not accessible to conscious access or description.

Another form of nondeclarative memory is priming, which is facilitated processing of a stimulus following prior exposure to the stimulus. Perceptual priming occurs when subsequent processing of a stimulus is facilitated by prior perceptual exposure to it. Conceptual priming occurs when there is overlap between related concepts in memory. A person who had recently studied a list that included the word ‘Alaska’ would be more likely to include it in a list of states than an individual who had not studied the item. With regard to the distinction between conscious (declarative) and unconscious (nondeclarative) memory, an important point to remember about priming is that it can occur without conscious awareness that the item had been studied earlier, or that subsequent processing was facilitated by earlier processing. That is, facilitated processing occurs even in the absence of recognition or recall of the originally studied item (see [Lloyd and Newcombe, 2009](#) and [Roediger and McDermott, 1993](#), for discussions).

Finally, classical conditioning occurs when two stimuli that naturally do not co-occur become associated with one another through repeated pairing. Typically, one of the stimuli – the unconditioned stimulus – evokes a high-probability or even reflexive response termed the unconditioned response. For example, a puff of air to the eye (unconditioned stimulus) produces a blink (unconditioned response). The other stimulus – the conditioned stimulus – is behaviorally neutral, such as a tone. Classical conditioning occurs when, over time and repeated pairing of the two stimuli, the conditioned stimulus (the tone) takes on the same significance as the unconditioned stimulus, such that it alone is sufficient to produce the response: anticipatory eye closure at the sound of the tone (see [Woodruff-Pak and Disterhoft, 2008](#), for a review). This simple form of learning occurs across phyla (e.g., rodents, nonhuman primates, and humans), making it one of the clearest examples of learning and memory without awareness.

16.2.5 Relations Between Different Forms of Memory

An important point to keep in mind with regard to the distinction between declarative and nondeclarative forms of memory is that, in most cases, one derives both

declarative and nondeclarative memories from the same experience. Learning to drive a car is a good example. In driver's education class, students learn that to go, they step on the accelerator and to stop, they step on the brake. Tests to obtain a license to drive probe the student's memory of appropriate following and stopping distance and the steps involved in parallel parking, for example. But one would never become an expert driver based on this type of memory alone. To become a good driver, one must practice executing the motor movements. Although one may be consciously aware that vehicle stopping distance is 15 feet per second, it is not this knowledge that permits him or her to bring the vehicle to a gentle stop at a stop sign. That skill is acquired through practice, practice, and more practice at driving and braking.

Another important point is that, in most cases, declarative and nondeclarative memories not only are acquired in parallel but also continue to coexist, even after execution of the behavior no longer seems to require conscious awareness. Many skills, such as driving, start out very demanding of attentional resources yet eventually can be performed almost 'automatically,' that is, without conscious attention paid to them. Such changes tempt the conclusion that once these skills no longer require conscious attention to execute, they no longer are declarative. Yet such a conclusion is not valid: If declarative memories were to become nondeclarative, that would mean that they were no longer accessible to consciousness or declaration. The fact that one can tell that vehicle stopping distance is 15 feet per second proves that memory of the procedure is accessible to consciousness, even though one does not have to think about feet per second in order to brake. In other words, one still has the declarative memory, even though it is not that memory on which he or she depends to execute the behavior. In the intact organism, declarative and nondeclarative memory coexist. Many behaviors are executed based on nondeclarative memory alone, but that does not mean that one type of memory has 'turned into' another. Rather, at the time of learning, both types of memory were acquired; skilled performance of the motor behavior may be supported by one (nondeclarative), yet the other (declarative) continues to exist.

The observations that different forms of memory are acquired in parallel and coexist, possibly throughout the life of the memory, beg the question of why organisms would have multiple types of memory. It is likely that either these different forms of memory evolved in order to deal with competing demands for different kinds of information storage or nature took fair advantage of structures that had evolved for other reasons, in order to deal with the demands. Either way, one memory system seems specialized for rapid encoding of information that is subject to equally rapid forgetting

whereas the other seems specialized for acquisition of information at a slower rate yet seemingly permits more robust retention. Why could not a single system accomplish both tasks? Although this question cannot be answered definitively, computer simulations have revealed that a system that can change rapidly to accept new inputs has difficulty maintaining old inputs. Conversely, a system that is good at maintaining old inputs has difficulty 'learning' new things (e.g., [McClelland et al., 1995](#)). This analysis suggests that complementary memory systems work in concert in order to avoid interference with existing knowledge yet still maintain flexibility.

16.3 DEVELOPMENTAL CHANGES IN NONDECLARATIVE AND DECLARATIVE MEMORY

Discussion of developmental changes in all of the different forms of memory is well beyond the scope of this chapter. Instead, exemplars of each major type of memory are discussed as follows: priming, as an exemplar of nondeclarative memory, and episodic and autobiographical memory, as exemplars of declarative memory.

16.3.1 Priming

In the modern cognitive science and neuroscience literatures, priming is perhaps the most thoroughly studied form of nondeclarative memory. As defined above, priming involves facilitated processing of a stimulus as a result of prior exposure to it. Perceptual priming occurs when facilitated processing is based on the surface features of the stimulus; conceptual priming occurs when the facilitation is based on the meaning of the stimuli. In both cases, the facilitation is observed independent of explicit recognition of the stimuli as having been seen before (thus leading to characterization of the effect as nondeclarative).

Perceptual priming is apparent from an early age and is thought to show only small developmental changes. In a typical paradigm, subjects encounter pictures of common objects early in an experimental session. Later in the session they are shown degraded pictures that are slowly made sharper and clearer. Some of the pictures are of the objects studied earlier whereas others are of new objects. Children as young as 3 are faster to name the pictures (i.e., they name them at lower levels of clarity) when they have seen them previously than when they have not. Age-related differences in performance on these types of tasks are not pronounced (e.g., [Hayes and Hennessey, 1996](#); [Parkin and Streete, 1988](#)), even when children are compared with adults

(e.g., [Drumme and Newcombe, 1995](#)). For this reason, perceptual priming is thought to be relatively developmentally invariant (see [Lloyd and Newcombe, 2009](#), and [Parkin, 1998](#) for reviews).

Age-related differences are apparent in conceptual priming paradigms. In a representative conceptual priming paradigm, subjects are presented with words early in a session. Later they are challenged to list members of target categories. For example, in response to the instruction to list as many states as they can, subjects are more likely to nominate 'Alaska' if they saw the word earlier in the session than if they did not. Effects of this nature – effects that seemingly depend on activation of related concepts in memory – are more robust in older relative to younger children (e.g., [Perez et al., 1998](#)). Data such as these have been used to argue that conceptual priming shows salient improvements with age. [Lloyd and Newcombe \(2009\)](#) sounded a cautionary note in their review of this literature, however. They noted the distinct possibility that rather than differences in priming, these paradigms may reflect age-related improvements in conceptual knowledge. That is, the mechanism of priming may be age-invariant, and what accounts for improvements with age is category knowledge. Testing of this possibility is an area for future research.

16.3.2 Episodic and Autobiographical Memory

Episodic and autobiographical memory have a protracted course of development, beginning in the first year of life and extending into early adulthood. As discussed above, episodic memory supports retention of information about unique events that can be located in a particular place and time ([Tulving, 1972, 1983](#)). Autobiographical memories are episodic memories that are especially personally relevant. They are what is thought to make up the life story or personal past.

16.3.3 Questioning the Existence of Episodic Memory in Young Children

Until the middle 1980s, it was widely believed that infants and young children were incapable of remembering specific episodes and thus of forming autobiographical memories. As discussed in [Bauer \(2006b, 2007\)](#), the pessimism as to children's mnemonic abilities stemmed from a number of sources. One salient source of the perspective was the literature on *infantile or childhood amnesia*. Most adults remember few if any memories from the first 3–4 years of life, and from the ages of 3.5–7, they have a smaller number of memories than would be expected based on forgetting alone. As reviewed in [Bauer \(2007, 2008\)](#), the phenomenon is strikingly robust and consistent across time, population, and method (e.g., free recall,

response to cue words, and questionnaire). Although a variety of explanations for the amnesia have been advanced (see [Bauer, 2007, 2008](#), for reviews), one of the most common was also the simplest: adults lacked memories from early in life because children failed to create them.

The suggestion that children younger than age 3 years did not form episodic memories was consistent with the dominant theoretical perspective at the time. A central tenant of Jean Piaget's *genetic epistemology* (see [Flavell, 1963](#), for an introduction to the perspective) was that for the first 18–24 months of life, infants lacked symbolic capacity and, thus, the ability to mentally represent objects and events (e.g., [Piaget, 1952](#)). Instead, they were thought to live in a 'here and now' world that included physically present entities, yet the entities had no past and no future. In other words, infants were described as living an 'out of sight, out of mind' existence. Piaget hypothesized that by 18–24 months of age, children had constructed the capacity for mental representation. However, even then, they were thought to be without the cognitive structures that would permit them to organize events along coherent dimensions that would make the events memorable. Consistent with this suggestion, in retelling fairy tales, children as old as 7 years made errors in temporal sequencing ([Piaget, 1926, 1969](#)). Piaget attributed their poor performance to the lack of reversible thought. Without it, children could not organize information temporally and thus could not tell a story from beginning, to middle, to end. Without this ability, they could not be expected to retain coherent episodic memories.

16.3.4 A New Perspective on Young Children's Memory Abilities

The perspective on infants' and young children's mnemonic abilities began to change in the middle 1980s as a result of recognition of the importance to memory of meaningful and familiar stimuli and development of a means of assessing event memory in pre- and early-verbal children. In an influential series of studies, Mandler and her colleagues (e.g., [Mandler and DeForest, 1979](#); [Mandler and Johnson, 1977](#)) demonstrated that even young children are sensitive to the structure inherent in story materials. When the stories were well-organized, children had high levels of recall. They also tended to 'correct' poorly organized stories, to conform to the hierarchical structure (see [Mandler, 1984](#), for a review). At roughly the same time, Nelson and her colleagues (e.g., [Nelson, 1986](#)) demonstrated that when children were asked to recall 'what happens' in the context of everyday events and routines, such as going to McDonald's, their performance was qualitatively similar to that of older children and even adults. Moreover, it

became apparent that children did not require multiple experiences of events in order to remember them. For example, [Fivush \(1984\)](#) interviewed kindergarten children after only a single day of school. Although the children had experienced the school-day routine just once, they nevertheless provided well-organized reports of the experience.

The change in perspective on memory ability extended to infants as well, with the development of nonverbal means of assessing memories for specific episodes, namely, elicited and deferred imitation. Elicited and deferred imitation entail use of objects to demonstrate an action or sequence of actions that, either immediately (elicited imitation), after some delay (deferred imitation), or both, infants are invited to imitate. [Piaget \(1952\)](#) himself had identified deferred imitation as one of the hallmarks of the development of symbolic thought. [Meltzoff \(1985\)](#) and [Bauer and her colleagues \(Bauer and Mandler, 1989 and Bauer and Shore, 1987\)](#) brought the technique under experimental control. [Meltzoff \(1988\)](#) demonstrated that infants as young as 9 months of age were able to defer imitation of an action for 24 hours. [Bauer and Shore \(1987\)](#) published findings that over a 6-week delay, infants 17–23 months of age remembered not only individual actions but temporally ordered sequences of action. That is, even after 6 weeks, they were able to reproduce in the correct temporal order the steps of putting a ball into a cup, covering it with another cup, and shaking the cups to make a rattle.

Whereas originally, the argument that imitation-based paradigms provide a means of testing declarative memory was based in [Piaget's \(1952\)](#) observations, there are a number of characteristics that support the claim. Because the argument has been developed in detail elsewhere (e.g., [Bauer, 2006b, 2007](#) and [Carver and Bauer, 2001](#)), only two components of it are presented. First, once children acquire the requisite language, they talk about events that they experienced as preverbal infants, in the context of imitation tasks (e.g., [Bauer et al., 2002b; Cheatham and Bauer, 2005](#)). This is strong evidence that the format in which the memories are encoded is declarative, as opposed to nondeclarative or implicit (formats inaccessible to language). Second, the paradigm passes the 'amnesia test.' Whereas intact adults accurately imitate sequences after a delay, patients with amnesia due to hippocampal lesions perform no better than naïve controls ([McDonough et al., 1995](#)). Adolescents and young adults who sustained hippocampal damage early in life also exhibit deficits in performance on the task ([Adlam et al., 2005](#)). This suggests that the paradigm taps the type of memory that gives rise to verbal report. For these reasons, the task has come to be widely accepted as a nonverbal analogue to verbal report (e.g., [Bauer, 2002; Mandler, 1990; Meltzoff, 1990; Nelson and Fivush, 2000; Rovee-Collier and Hayne, 2000; Schneider and](#)

[Bjorklund, 1998; Squire et al., 1993](#)) and is widely used to examine developments in memory for specific episodes in the first two years of life.

16.3.5 Memory for Specific Episodes in the First Two Years of Life

Over the first two years of life, there are developmental changes in memory for specific episodes along a number of dimensions. Perhaps the most salient change is in the length of time over which memory is apparent. Importantly, because like any complex behavior, the length of time an episode is remembered is multiply-determined, there is no 'growth chart' function that specifies that children of X age should remember for Y long. Nonetheless, across numerous studies, there has emerged evidence that with increasing age, infants tolerate lengthier retention intervals. For example, at 6 months of age, infants remember an average of one action of a three-step sequence for 24 hours ([Barr et al., 1996](#); see also [Collie and Hayne, 1999](#)). Nine-month-olds remember individual actions over delays from 24 hours ([Meltzoff, 1988](#)) to 5 weeks ([Carver and Bauer, 1999, 2001](#)). By 10–11 months of age, infants remember over delays as long as 3 months ([Carver and Bauer, 2001](#) and [Mandler and McDonough, 1995](#)). Thirteen- to fourteen-month-olds remember actions over delays of 4–6 months ([Bauer et al., 2000](#) and [Meltzoff, 1995](#)). By 20 months of age, children remember the actions of event sequences over as many as 12 months ([Bauer et al., 2000](#)).

Infants also recall the temporal order of actions in multistep sequences, though retaining order information presents a cognitive challenge to young infants, in particular, as evidenced by low levels of ordered recall and substantial within-age-group variability in the first year. Although 67% of [Barr et al.'s \(1996\)](#) 6-month-olds remembered individual actions over 24 hours, only 25% of them remembered actions in the correct temporal order. Among 9-month-olds, approximately 50% of infants exhibit ordered reproduction of sequences after a 5-week delay ([Bauer et al., 2001, 2003; Carver and Bauer, 1999](#)). By 13 months of age, the substantial individual variability in ordered recall has resolved: 78% of 13-month-olds exhibit ordered recall after 1 month. Nevertheless, throughout the second year of life, there are age-related differences in children's recall of the order in which actions of multistep sequences unfolded. The differences are especially apparent under conditions of greater cognitive demand, such as when less support for recall is provided, and after longer delays ([Bauer et al., 2000](#)).

The first two years of life also are marked by changes in the robustness of memory for specific episodes. For instance, there are changes in the number of experiences

that seem to be required in order for infants to remember. In Barr et al. (1996), at 6 months, infants required six exposures to events in order to remember them 24 hours later. If instead they saw the actions demonstrated only three times, they showed no memory after 24 hours (i.e., performance of infants who had experienced the puppet sequence did not differ from that of naïve control infants). By 9 months of age, the number of times actions need to be demonstrated to support recall after 24 hours has reduced to three (e.g., Meltzoff, 1988). Indeed, 9-month-olds who see sequences modeled as few as two times within a single session recall individual actions of them 1 week later (Bauer et al., 2001). However, over the same delay, ordered recall was observed only among infants who had seen the sequences modeled a total of six times, distributed over three exposure sessions. Three exposure sessions also support ordered recall over the longer delay of 1 month. By the time infants are 14 months of age, a single exposure session is all that is necessary to support recall of multiple different single actions over 4 months (Meltzoff, 1995). Ordered recall of multistep sequences is apparent after as many as 6 months for infants who received a single exposure to the events at the age of 20 months (Bauer and Leventon, in press).

Another index of the robustness of memory is the extent to which it is disrupted by interference. One form of interference that has been studied in infancy is changes in context between encoding and retrieval. Reports on infants' sensitivity to contextual changes are mixed. There are some suggestions that recall is disrupted if between exposure and test, the appearance of the test materials is changed (e.g., Hayne et al., 1997, 2000; and Herbert and Hayne, 2000). However, there also are reports of robust generalization from encoding to test by infants across a wide age range. Infants have been shown to generalize imitative responses across changes in (1) the size, shape, color, and/or material composition of the objects used in demonstration versus test (e.g., Bauer and Dow, 1994; Bauer and Fivush, 1992; Bauer and Lukowski, 2010; and Lechuga et al., 2001), (2) the appearance of the room at the time of the demonstration of modeled actions and at the time of the memory test (e.g., Barnat et al., 1996 and Klein and Meltzoff, 1999), (3) the setting for the demonstration of the modeled actions and the test of memory for them (e.g., Hanna and Meltzoff, 1993; Klein and Meltzoff, 1999), and (4) the individual who demonstrated the actions and the individual who tested for memory of the actions (e.g., Hanna and Meltzoff, 1993). Evidence of flexible memory extends to infants as young as 9–11 months of age (e.g., Baldwin et al., 1993; Lukowski et al., 2009; McDonough and Mandler, 1998). In summary, whereas there is evidence that with age, infants' memories as tested in imitation-based paradigms become more generalizable

(e.g., Herbert and Hayne, 2000), there is substantial evidence that from an early age, infants' memories survive changes in context and stimuli.

16.3.6 Developments in the Preschool Years and Beyond

Beginning in the third year of life, verbal assessments become a viable means for testing episodic memory. This opens up new possibilities: children can be tested not only for memory for controlled laboratory events but for events from their lives outside the laboratory as well. This combination of approaches has yielded a wealth of data about children's memories for the routine events that make up their everyday lives, and about their memories for unique events. Some of the events are highly personally significant and contribute to an emerging autobiography or personal past. Major findings from each of these categories are reviewed.

Early studies of young children's memories for the events of their own lives focused on everyday, routine events. The children's reports included actions common to the activities, and almost invariably, the actions were mentioned in the temporal order in which they typically occurred. Representative of the findings was the answer provided by a 3-year-old child to the question, "What happens when you have a birthday party?": "You cook a cake and eat it" (K. Nelson and Gruendel, 1986, p. 27). This early research revealed 'minimalist,' yet nevertheless accurate, reports by children as young as 3 years of age (see also K. Nelson, 1986, 1997). Subsequent studies revealed that with development, children's reports included more information. For example, in addition to mention of cooking a cake and then eating it, 6- and 8-year-old children told of putting up balloons, receiving and then opening presents from party guests, eating birthday cake, and playing games. Second, relative to younger children, older children more frequently mentioned alternative actions: "...and then you have lunch or whatever you have." Third, with age, children include in their reports more optional activities, such as "Sometimes then they have three games. ...then sometimes they open up the other presents. ..." Finally, with increasing age, children mentioned more conditional activities, such as "If you're like at Foote Park or something, then it's time to go home. ..." (Nelson and Gruendel, 1986, p. 27). Whereas some of the differences in younger and older children's reports might be due to the greater number of experiences of events such as birthday parties that older children have, relative to younger children, experience alone does not account for the developmental differences. In laboratory research in which children of different ages are given the same amount of experience with a novel event, older children produce more elaborate reports relative to younger children (e.g., Fivush et al., 1992; Price and Goodman, 1990).

Young children also form memories of unique events. In an early study, [Fivush et al. \(1987\)](#) found that all of the children in a sample of 2.5–3-year-olds recalled at least one event that had happened 6 or more months in the past. The children reported the same amount of information about events that had taken place more than 3 months ago as they did about events that had taken place within 3 months. In [Hamond and Fivush \(1991\)](#), 3- and 4-year-old children recalled a trip to Disney World they had taken either 6 months previously or 18 months previously. The amount they remembered did not differ as a function of the delay. Moreover, the older and younger children did not differ in the amount of information they reported about the event. Yet the age groups did differ in how elaborate their reports were. Whereas the younger children tended to provide the minimum required response to a question, the older children tended to provide more elaborate responses.

With development, there are changes in what children include in their reports about events. For example, young children seemingly focus on what is common or routine across experiences whereas older children and adults focus on what is unique or distinctive. This trend is illustrated in [Fivush and Hamond \(1990\)](#). In response to an interviewer's invitation to talk about going camping, after providing the interviewer with the distinctive information that the family had slept in a tent, a 2.5-year-old child went on to report on the more typical features of the camping experience. In total, 48% of the information that the children reported was judged to be distinctive, implying that 52% of it was not. By 4 years of age, children report about three times more distinctive information than typical information ([Fivush and Hamond, 1990](#)). One consequence of focus on what is common across experience is that a unique event such as camping gets 'fused' into the daily routine of eating and sleeping. In the process, the features that distinguish events from one another may fade into the background and be lost. The result would be fewer memories of episodes that are truly unique. Conversely, with increasing focus on the more distinctive features of events, there is a resulting increase in the number of memories that are truly unique.

With age, children not only include different types of information in their narratives but also include more information. For example, in research by [Fivush and Haden \(1997\)](#), from 3.5 to 6 years of age, the number of propositions children included in the average narrative increased more than twofold, from 10 to 23. Young children's narratives include basic information about what actions occurred in the event; they feature intensifiers, qualifiers, and internal evaluations, and the actions in the narrative are joined by simple temporal and causal connections (e.g., *then*, *before*, and *after*, and *because*, *so*, *in order to*, respectively). What accounts for the increase in

narrative length over this age period is that with age, children provide (1) more information about who was involved and when and where the event occurred, (2) more information about optional or variable actions (e.g., "*When it turned red light, we stopped*"; [Fivush and Haden, 1997](#), p. 186), and (3) more elaborations ([Fivush and Haden, 1997](#)). As a result, relative to younger children's, older children's stories are more complete, easier to follow, and engaging.

The dramatic increases with age in the amount of information that children *report* tempt the conclusion that there also are age-related increases in the amount of information that children *remember* about events. This is not a 'safe' conclusion, however, in light of evidence that perhaps especially for younger children, verbal reports underestimate the richness of memories (e.g., [Fivush et al., 2004](#); see [Bauer, 1993, in press](#) and [Mandler, 1990](#), for discussions). Indeed, because of the inevitable confounding between increases in age and increases in narrative skills, whereas it is clear that children report more with age, it is not clear whether they also remember more.

16.3.7 Autobiographical Memory

Over the course of the preschool years, autobiographical or personal memory becomes increasingly apparent. Autobiographical memories are the memories of events and experiences that make up one's life story or personal past. They are the stories that people tell about themselves that reveal who they are and how their experiences have shaped their characters. As implied by this description, autobiographical memories differ from 'run-of-the-mill' episodic memories in that autobiographical memories are infused with a sense of personal involvement or ownership in the event. They are memories of events that happened to one's self, in which one participated, and about which one had emotions, thoughts, reactions, and reflections. It is this feature that puts the 'auto' in 'autobiographical.'

Throughout the preschool years, children's memories take on more and more autobiographical features (see [Bauer, 2007](#), for discussion). From a very young age, children include references to themselves in their narratives: "*I fell down.*" With age, they increasingly pepper their narratives with the subjective perspective that indicates the significance of the event for the child ([Fivush, 2001](#)). For example, they go beyond comment on the objective reality of 'falling down' to convey how they felt about the fall: "*I fell down and was so embarrassed because everybody was watching!*" It is this subjective perspective that provides the explanation for why events are funny, or sad, for instance, and thus of significance to one's self.

There also are changes in the marking of events as having taken place at a specific place and time.

For instance, children increasingly include specific references to time, such as “on my birthday,” “at Christmas,” or “last summer” (Nelson and Fivush, 2004). Markings such as these not only establish that an event happened at a time different from the present but also begin to establish a time line along which an organized historical record of when events occurred can be constructed. Children also include in their narratives more orienting information, including where events took place and who participated in them (e.g., Fivush and Haden, 1997). These changes serve to distinguish events from one another, thereby making them more distinctive. Children also include more descriptive detail in their reports, suggestive of a sense of reliving the experience. For example, they include more intensifiers (“Cause she was *very* naughty”), qualifiers (“I *didn’t* like her video tape”), elements of suspense (“And *you know what?*”; examples from Fivush and Haden, 1997), and even repetition of the dialogue spoken in the event (“...I said, ‘I hope my Nintendo my Super Nintendo is still here’.”, from Ackil et al., 2003). The result is a much more elaborate narrative that brings both the storyteller and the listener to the brink of reliving the experience. It is tempting to conclude that these changes account for the finding among adults of a steadily increasing number of memories of events that took place from the ages of 3–7 years (Bauer, 2007).

Relative to those in the preschool years, developments in autobiographical or personal memory in later childhood and adolescence have been relatively neglected. Yet age-related changes in autobiographical reports continue throughout the elementary school years and beyond. An illustration of the types of changes that occur during this period is the breadth or completeness of children’s narratives. Like a good newspaper story, a ‘good’ autobiographical narrative includes a number of elements, including information about the *who*, *what*, *where*, *when*, *why*, and *how* of the experience. The average 7-year-old includes only half the number of these narrative elements than the average 11-year-old (see Bauer et al., 2007).

16.4 MECHANISMS OF DEVELOPMENTAL CHANGE

Given that memory is not a single entity or unity construct, it is not surprising that there is not a single answer to the question of ‘what develops’ in the development of memory. Rather, like all complex behaviors, memory is multiply-determined. An adequate explanation of why it develops as it does will entail multiple levels of analysis, ranging from the cellular and molecular events that allow for the storage of information to the cultural influences that shape the expression of memory (see Bauer,

2007, for discussion). Because the focus of this volume is on basic neural and cognitive processes, the author focuses on these two categories of explanation. The reader is referred to other sources (e.g., Bauer, 2007, *in press* and Nelson and Fivush, 2004) for elaboration of the roles of other aspects of development, including conceptual change and social influences on remembering.

16.4.1 Neural Structures and Processes

A thorough review of the neural substrates that support the different types of memory, and the courses of development of each, is well beyond the scope of this chapter (see Bauer, 2007, 2009 and Nelson et al., 2006 for reviews of subsets of this large literature). Yet a brief review is essential to the goal of identifying possible mechanisms of developmental change. Studies of patients with specific types of lesions and disease and animal models thereof, as well as neuroimaging studies, have made clear that registration of experience and formation of memory traces to represent it involve multi-stage processes that depend on networks of neural structures. For example, encoding, storage, and later retrieval of declarative memories depend on a multicomponent network involving temporal (hippocampus, and entorhinal, parahippocampal, and perirhinal cortices) and cortical (including prefrontal and other association areas) structures (e.g., Eichenbaum and Cohen, 2001; Markowitsch, 2000; Zola and Squire, 2000). In the review to follow, the author focuses primarily on this network in large part because its course of development is better worked out, relative to the networks supporting nondeclarative memory.

16.4.2 The Neural Substrate of Declarative Memory

Formation of a declarative memory begins as the elements that constitute an experience register across primary sensory areas (e.g., visual and auditory). Inputs from primary cortices are projected to unimodal association areas where they are integrated into whole percepts of what objects look, feel, and sound like. Unimodal association areas in turn project to polymodal prefrontal, posterior, and limbic association cortices where inputs from the different sense modalities are integrated and maintained over brief delays (see, e.g., Petrides, 1995). Prefrontal structures not only are involved in the initial processing or *encoding* of experiences into long-term traces but also are implicated in the temporary maintenance of material in short-term and working memory. As well, the neocortical regions involved in the initial perception and registration of experience are thought to be responsible for both perceptual and

conceptual priming (e.g., [Gabrieli, 1998](#); see [Toth, 2000](#) for a review).

For maintenance of traces of experience over delays of longer than a few seconds or minutes, the inputs to the association areas must be stabilized or *consolidated*, a task attributed to medial-temporal structures, in concert with cortical areas ([McGaugh, 2000](#)). Specifically, information from association areas converges on perirhinal and parahippocampal structures from which it is projected to the entorhinal cortex and in turn to the hippocampus. Within the hippocampus, conjunctions and relations among the elements of experience are linked into a single event. Association areas share the burden of consolidation by relating new memories to episodes already in storage: information processed in the hippocampus is projected back through the temporal cortices which in turn project to the association areas that gave rise to their inputs. Eventually, traces are stabilized such that the hippocampus is no longer required to maintain them; consolidated traces are *stored* in neocortex (although, whether memories are ever wholly independent of the hippocampus is debated: see, e.g., [Moscovitch and Nadel, 1998](#) and [Reed and Squire, 1998](#), for opposing views).

Finally, behavioral and neuroimaging data implicate prefrontal cortex in the *retrieval* of memories from long-term storage (e.g., [Cabeza et al., 1997, 2004](#); [Maguire, 2001](#); [Markowitsch, 1995](#)). For example, damage to prefrontal cortex disrupts retrieval of facts and episodes. Deficits are especially apparent (1) in free recall versus recognition, (2) for temporal information versus items, (3) for specific event features, and (4) for source of information. Imaging studies have revealed high levels of activation in prefrontal cortex during retrieval of episodic memories from long-term stores (reviewed in [Gilboa, 2004](#)). Activations in medial prefrontal cortex are observed during retrieval of internally generated information, such as the thoughts and feelings that put the *auto* in autobiographical memories ([Cabeza et al., 2004](#)). Lateral posterior parietal and precuneus also are implicated in retrieval of autobiographical memories. The activations are greater when subjects report retrieving more details about the memory (reviewed in [Gilboa, 2004](#)).

16.4.3 Development of the Neural-Substrate-Supporting Declarative Memory

Developments in the neural-substrate-supporting declarative memory are summarized in a number of sources (e.g., [Bauer, 2007, 2009, in press](#); [Nelson, 2000](#); [Nelson et al., 2006](#); [Richman and Nelson, 2008](#)). In terms of brain development in general, there are changes in both gray and white matter from infancy well into

adolescence (e.g., [Caviness et al., 1996](#); [Giedd et al., 1999](#); [Gogtay et al., 2004](#); and [Sowell et al., 2004](#)). Reflecting changes in vasculature, glia, neurons, and neuronal processes, gray matter increases until puberty. Beyond puberty, as a result of pruning and other regressive events (i.e., loss of neurons and axonal branches), the thickness of the cortical mantle actually declines (e.g., [Giedd et al., 1999](#); [Gogtay et al., 2004](#); [Sowell et al., 2001](#); [Van Petten, 2004](#)). In contrast to curvilinear change in gray matter volume, white matter volume increases linearly with age ([Giedd et al., 1999](#)). Increases in white matter are associated with greater connectivity between brain regions and with myelination processes that continue into young adulthood (e.g., [Johnson, 1997](#); [Klingberg, 2008](#); [Schneider et al., 2004](#)).

In terms of the temporal-cortical episodic-memory network, there are a number of indicators that in the human, many components of the medial temporal lobe develop early. For instance, as reviewed by [Seress and Abraham \(2008\)](#), the cells that make up most of the hippocampus are formed in the first half of gestation and virtually all are in their adult locations by the end of the prenatal period. The neurons in most of the hippocampus also begin to connect early in development: synapses are present as early as 15 weeks gestational age. The number and density of synapses both increase rapidly after birth and reach adult levels by approximately 6 postnatal months. Perhaps as a consequence, glucose utilization in the temporal cortex reaches adult levels at the same time (i.e., by about 6 months: [Chugani, 1994](#); [Chugani and Phelps, 1986](#)). Thus, there are numerous indices of early maturity of major portions of the medial temporal components of the network.

In contrast to early maturation of most of the hippocampus, development of the dentate gyrus of the hippocampus is protracted ([Seress and Abraham, 2008](#)). At birth, the dentate gyrus includes only about 70% of the adult number of cells. Thus, roughly 30% of the cells are produced postnatally. Indeed, neurogenesis in the dentate gyrus of the hippocampus continues throughout childhood and adulthood ([Tanapat et al., 2001](#)). It is not until 12–15 postnatal months that the morphology of the structure appears adultlike. Maximum density of synaptic connections in the dentate gyrus also is delayed, relative to that in the other regions of the hippocampus. In humans, synaptic density increases dramatically (to well above adult levels) beginning at 8–12 postnatal months and reaches its peak at 16–20 months. After a period of relative stability, excess synapses are pruned until adult levels are reached at about 4–5 years of age ([Eckenhoff and Rakic, 1991](#)).

Although the functional significance of later development of the dentate gyrus is not clear, there is reason to speculate that it impacts behavior. As already noted, upon experience of an event, information from

distributed regions of cortex converges on the entorhinal cortex. From there, it makes its way into the hippocampus in one of two ways: via a 'long route' or a 'short route.' The long route involves projections from entorhinal cortex into the hippocampus, by way of the dentate gyrus; the short route bypasses the dentate gyrus. Whereas the short route may support some forms of memory (Nelson, 1995, 1997a,b), based on data from rodents, it seems that adultlike memory behavior depends on passage of information through the dentate gyrus (Czurkó et al., 1997; Nadel and Willner, 1989). This implies that maturation of the dentate gyrus of the hippocampus may be a rate-limiting variable in the development of episodic memory early in life (e.g., Bauer, 2007, 2009; Nelson, 1995, 1997a,b, 2000). Finally, hippocampal volume continues to increase gradually throughout childhood and into adolescence (e.g., Gogtay et al., 2004; Pfluger et al., 1999; Utsunomiya et al., 1999). Myelination in the hippocampal region continues throughout adolescence (Arnold and Trojanowski, 1996; Benes et al., 1994; Schneider et al., 2004).

The association areas also undergo a protracted course of development (Bachevalier, 2001). For example, it is not until the seventh prenatal month that all six cortical layers are apparent. The density of synapses in the prefrontal cortex increases dramatically at 8 postnatal months and peaks between 15 and 24 months. Pruning to adult levels does not begin until late childhood; adult levels are not reached until late adolescence or early adulthood (Huttenlocher, 1979; Huttenlocher and Dabholkar, 1997; see Bourgeois, 2001, for discussion). In the years between, in some cortical layers, there are changes in the size of cells and the lengths and branching of dendrites (Benes, 2001). Although the maximum density of synapses may be reached as early as 15 postnatal months, it is not until 24 months that synapses develop adult morphology (Huttenlocher, 1979). There also are changes in glucose utilization and blood flow over the second half of the first year and into the second year: blood flow and glucose utilization increase above adult levels by 8–12 and 13–14 months of age, respectively (Chugani et al., 1987). Other maturational changes in prefrontal cortex, such as myelination, continue into adolescence, and adult levels of some neurotransmitters are not seen until the second and third decades of life (Benes, 2001). It is not until adolescence that neurotransmitters such as acetylcholine reach adult levels (discussed in Benes, 2001).

Although much of the attention to developmental changes has focused on the medial-temporal and prefrontal regions, there also are age-related changes in the lateral temporal and parietal cortices. Cortical gray-matter changes occur earlier in the frontal and occipital poles, relative to the rest of the cortex, which matures in a parietal-to-frontal direction. The superior

temporal cortex is last to mature (though the temporal poles mature early; Gogtay et al., 2004). The late development of this portion of the cortex is potentially significant for memory as it is one of the polymodal association areas that plays a role in integration of information across sense modalities.

16.4.4 Functional Consequences of Development of the Temporal–Cortical Network

What are the consequences for behavior of the slow course of development of the neural network that supports declarative memory? At a general level, one may expect concomitant behavioral development: As the neural substrate develops, so does behavior (and vice versa, of course). But precisely how do changes in the medial temporal and cortical structures, and their interconnections, produce changes in behavior? In other words, how do they affect memory representations? To address this question, one must consider the basic processes involved in memory-trace formation, storage, and retrieval and how the 'recipe' for a memory might be affected by changes in the underlying neural substrate. In other words, one must consider how developmental changes in the substrate for memory relate to changes in the efficacy and efficiency with which information is maintained over the short-term, encoded and stabilized for long-term storage, in the reliability and ease with which it is retrieved.

16.4.5 Basic Cognitive and Mnemonic Processes

With developmental changes in the temporal–cortical network, one may expect changes in basic cognitive processes and in behavior. The basic processes involved in memory are encoding, consolidation, and retrieval of memory traces. Although the processes are difficult to cleanly separate from one another (e.g., when the encoding ends and the consolidation begins is a challenging question to address), they do build on one another and thus are described in the nominal order in which they occur: short-term maintenance and encoding, consolidation and storage, and retrieval.

16.4.6 Encoding

Association cortices are involved in the initial registration and temporary maintenance of experience. Because prefrontal cortex in particular undergoes considerable postnatal development, it is reasonable to expect that neurodevelopmental changes in it relate to age-related changes in the speed and efficiency with which information is encoded into long-term storage. Consistent with this suggestion, in a longitudinal study,

Bauer and her colleagues (Bauer et al., 2006) found differences in the amplitudes of event-related potential (ERP) responses to familiar stimuli between 9 and 10 months of age that correlated with age-related improvements in recall after a 1-month delay. Behavioral data also indicate developments in encoding throughout the second year of life. For example, relative to 15-month-olds, 12-month-olds require more trials to learn multistep events to a criterion (learning to a criterion indicates that the material was fully encoded). In turn, 15-month-olds are slower to achieve criterion, relative to 18-month-olds (Howe and Courage, 1997). Indeed, across development, older children learn more rapidly than younger children (Howe and Brainerd, 1989). Changes in the temporary registration of information are apparent throughout the preschool years and school years (e.g., Cowan and Alloway, 2009). The net result of these changes is that children become increasingly adept not only at maintaining information in temporary registration but also in initiating the type of organizational processing that promotes consolidation of it.

16.4.7 Consolidation and Storage

As reviewed earlier, medial temporal structures are implicated in the processes by which new memories become 'fixed' for long-term storage; cortical association areas are the presumed repositories for long-term memories. In a fully mature, intact adult, the changes in synaptic connectivity associated with memory-trace consolidation continue for hours, weeks, and even months, after an event. Memory traces are vulnerable throughout this time, as evidenced by the fact that lesions inflicted during the period of consolidation result in deficits in memory whereas lesions inflicted after a trace has been consolidated do not (e.g., Kim and Fanselow, 1992; Takehara et al., 2003). For the developing organism, the period of consolidation may be one of greater vulnerability for a memory trace, relative to the adult. Not only are some of the implicated neural structures relatively undeveloped (i.e., the dentate gyrus and prefrontal cortex) but also the connections between them are still being sculpted and thus are less than fully effective and efficient. As a consequence, even once children have successfully encoded an event, they remain vulnerable to forgetting. Younger children may be more vulnerable to forgetting, relative to older children (Bauer, 2004, 2006a).

To examine the role of consolidation and storage processes in long-term memory in 9-month-old infants, Bauer et al. (2003) combined ERP measures of immediate recognition (as an index of encoding), ERP measures of 1-week delayed recognition (as an index of consolidation and storage), and deferred imitation measures of recall

after 1 month. After the delay, 46% of the infants evidenced ordered recall of the sequences, and 54% did not. At the immediate ERP test, regardless of whether they subsequently recalled the events, the infants evidenced recognition: Their ERP responses were different to the old and new stimuli. This strongly implies that the infants had encoded the events. Nevertheless, 1 week later, at the delayed-recognition test, the infants who would go on to recall the events recognized the props, whereas infants who would not evidence ordered recall did not. Thus, in spite of having encoded the events, a subset of 9-month-olds failed to recognize them after 1 week and subsequently failed to recall them after 1 month. Moreover, the size of the difference in delayed-recognition response predicted recall performance 1 month later. Thus, infants who had stronger memory representations after a 1-week delay exhibited higher levels of recall 1 month later (see also Carver et al., 2000). These data strongly imply that at 9 months of age, consolidation and/or storage processes are a source of individual differences in mnemonic performance.

In the second year of life, there are behavioral suggestions of between-age group differences in consolidation and/or storage processes as well as a replication of the finding among 9-month-olds that intermediate-term consolidation and/or storage failure relates to recall over the long-term. In Bauer et al. (2002a), 16- and 20-month-olds were exposed to multistep events and tested for recall immediately (as a measure of encoding) and after 24 hours. Over the delay, the younger children forgot a substantial amount of the information they had encoded: they produced only 65% of the target actions and only 57% of the ordered pairs of actions that they had learned just 24 hours earlier. For the older children, the amount of forgetting over the delay was not statistically reliable. It is not until 48 hours that children 20 months of age exhibit significant forgetting (Bauer et al., 1999). These observations suggest age-related differences in the vulnerability of memory traces during the initial period of consolidation.

The vulnerability of memory traces during the initial period of consolidation is related to the robustness of recall after 1 month. This is apparent from another of the experiments in Bauer et al. (2002a), this one involving 20-month-olds only. The children were exposed to multistep events and then tested for memory for some of the events immediately, some of the events after 48 hours (a delay after which, based on Bauer et al., 1999, some forgetting was expected), and some of the events after 1 month. Although the children exhibited high levels of initial encoding (as measured by immediate recall), they nevertheless exhibited significant forgetting after both 48 hours and 1 month. The robustness of memory after 48 hours predicted 25% of the variance in recall

1 month later; variability in level of encoding did not predict significant variance. This effect is a conceptual replication of that observed with 9-month-olds in [Bauer et al. \(2003\)](#) (see [Bauer, 2005](#) and [Howe and Courage, 1997](#), for additional evidence of a role for post-encoding processes in long-term recall). The findings that infants who are 'good consolidators' have high levels of long-term recall are reminiscent of [Bosshardt et al. \(2005\)](#) with adults: fMRI activations 1 day after learning were predictive of forgetting 1 month later.

Changes in the processes by which memory representations are consolidated and stored can be expected to continue throughout the preschool years. However, although neuroimaging techniques such as ERPs could be brought to bear on the question, as they are in the infancy period, such studies have not been conducted with preschool-age children. Neither is there a plethora of behavioral studies to address the question. A major reason is that few studies include the requisite type or number of tests. Frequently, studies of long-term memory fail to include a measure of initial encoding (e.g., [Liston and Kagan, 2002](#)), thus making it impossible to determine the variance associated with encoding processes. They also tend to measure recall only once, at the end of the retention interval, thus making it impossible to determine the variance associated with post-encoding processes during the period of consolidation. An exception to this approach is described in the next section.

16.4.8 Retrieval

Prefrontal cortex is implicated in retrieval of memories from long-term storage sites. Prefrontal cortex undergoes a long period of postnatal development, making it a likely candidate source of age-related differences in long-term recall. Surprisingly, although retrieval processes are a compelling candidate source of developmental differences in long-term recall, there are few data with which to evaluate their contribution. A major reason is that most studies do not allow for assignment of relative roles of the processes that take place before retrieval, namely, encoding and consolidation. As discussed in the section on encoding, older children learn more rapidly than younger children. Yet age-related differences in encoding effectiveness rarely are taken into account. In fact, as just noted, in many studies, no measures of encoding or initial learning are obtained. In addition, with standard testing procedures, it is difficult to know whether a memory representation has lost its integrity and become unavailable (consolidation or storage failure) or whether the memory trace remains intact but has become inaccessible with the cues provided (retrieval failure). Implication of retrieval processes as a source of developmental change requires that encoding

be controlled and that memory be tested under conditions of high support for retrieval.

In the infancy period, one of the studies that permits assessment of the contributions of consolidation and/or storage relative to retrieval processes is [Bauer et al. \(2000\)](#) (see also [Bauer et al., 2003](#), described earlier). The study provided data on children of multiple ages (13, 16, and 20 months) tested over delays of 1–12 months. Immediate recall of half of the events was tested, thus providing a measure of encoding. Because the children were given what amounted to multiple test trials, without intervening study trials, there were multiple opportunities for retrieval. As discussed by Howe and his colleagues (e.g., [Howe and Brainerd, 1989](#); [Howe and O'Sullivan, 1997](#)), for intact memory traces, retrieval attempts strengthen the trace and route to retrieval of it, thereby increasing accessibility on each test trial. Conversely, lack of improvement across test trials implies that the trace was no longer available (although see [Howe and O'Sullivan, 1997](#), for multiple nuances of this argument). Third, immediately after the recall tests, relearning was tested. That is, after the second test trial, the experimenter demonstrated each event once and allowed the children to imitate. Since [Ebbinghaus \(1885\)](#), relearning has been used to distinguish between an intact but inaccessible memory trace and a trace that has disintegrated. Specifically, if the number of trials required to relearn a stimulus was smaller than the number required to learn it initially, savings in relearning were said to have occurred. Savings presumably accrue because the products of relearning are integrated with an existing (though not necessarily accessible) memory trace. Conversely, the absence of savings is attributed to storage failure: there is no residual trace upon which to build. In developmental studies, age-related differences in relearning would suggest that the residual memory traces available to children of different ages are differentially intact.

To eliminate encoding processes as a potential source of developmental differences in long-term recall, in a reanalysis of the data from [Bauer et al. \(2000\)](#), subsets of 13- and 16-month-olds and subsets of 16- and 20-month-olds were matched for levels of encoding (as measured by immediate recall; [Bauer, 2005](#)). The amount of information the children forgot over the delays then was examined. For both comparisons, even though they were matched for levels of encoding, younger children exhibited more forgetting relative to older children. The age effect was apparent on both test trials. Moreover, in both cases, for older children, levels of performance after the single relearning trial were as high as those at initial learning. In contrast, for younger children, performance after the relearning trial was lower than at initial learning. Together, the findings of age-related differential loss of information over time and of age effects in

relearning strongly implicate storage processes, as opposed to retrieval processes, as the major source of age-related differences in long-term recall.

The conclusions from the infancy literature are consistent with the results of research with older children conducted within the trace-integrity framework (Brainerd et al., 1990) and conceptually related fuzzy-trace theory (Brainerd and Reyna, 1990). In this tradition, to eliminate encoding differences as a source of age-related effects, participants are brought to a criterion level of learning prior to imposition of a delay. To permit evaluation of the contributions of storage processes versus retrieval processes, participants are provided multiple test trials, without intervening study trials. In one such study, 4- and 6-year-old children learned and then recalled eight-item picture lists (Howe, 1995). In this study, as in virtually every other study conducted within this tradition (reviewed in Howe and O'Sullivan, 1997), the largest proportion of age-related variance in children's recall was accounted for by memory failure at the level of consolidation and/or storage, as opposed to retrieval. Whereas consolidation and/or storage failure rates decline throughout childhood, retrieval failure rates remain at relatively constant levels (Howe and O'Sullivan, 1997). The apparent lack of change in retrieval failure rates throughout childhood undermines the suggestion that retrieval processes are a major source of developmental change during this period.

If not by affecting retrieval, by what means do developmental changes in prefrontal cortex influence memory development in infancy and childhood? As discussed in Bauer (2006a, 2007), rather than on retrieval processes, a major effect of developments in prefrontal structures may be on consolidation and/or storage processes. Consolidation is an interactive process between medial temporal and cortical structures. As such, changes in cortical structures may be as important to developments in consolidation processes as are changes in medial temporal structures. Moreover, the ultimate storage sites for long-term memories are the association cortices. Thus, developmental changes in prefrontal cortex may play their primary role in supporting more efficient consolidation and more effective storage.

16.5 CONCLUSION

The title of this chapter – *Memory Development* – gives the impression that its subject will be singular: a singular system with a singular course of development. On the contrary, there are many different forms of memory, each with its own characteristics and developmental course. Although some broad generalizations apply, most of what one can be said to know about memory is relevant within a limited frame and for a subset of

the types of memory. Continued progress in understanding memory and its development requires that appropriate distinctions be maintained.

Historically, most types of memory were thought to be relatively late to develop. This expectation was perhaps nowhere more apparent than in reference to episodic and autobiographical memory. Research in the last decades of the twentieth century made clear that the assumption was unwarranted. When they are tested with structured stimuli and personally relevant events and materials, even young children show evidence of mnemonic competence. Thus, in sharp contrast to expectations of developmental discontinuities in event memory, there is ample evidence that the capacity to remember past events develops early. The research also made clear, however, that development is a protracted event, beginning in infancy and continuing into late adolescence. A full accounting of the development of 'memory' thus requires a long-term perspective.

Finally, it is a truism to say that complex behaviors are multiply determined. In the field of the development of memory, this dictum must be embraced wholeheartedly. Within the same space of time as the mnemonic capabilities of even young children were chronicled, progress in explaining the timing and course of development was made at a variety of different levels. Although much remains to be discovered, understanding of the cellular and molecular events that permit the storage and later retrieval of information is now within reach. Similarly, people are on the verge of understanding how basic memory processes determine the life course of a memory at different points in developmental time. People may look forward to the day when multiple levels of explanation come together into a comprehensive account of the processes and determinants of the capacities called *memory*.

SEE ALSO

Cognitive Development: Structural Brain Development: Birth Through Adolescence; Developing Attention and Self Regulation in Infancy and Childhood; A Neuroscience perspective on empathy and its development; Executive Function: Development, Individual Differences and Clinical Insights.

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