

Development of Episodic and Autobiographical Memory:

A Cognitive Neuroscience Perspective

Nora S. Newcombe¹, Marianne E. Lloyd² and Kristin R. Ratliff¹

1 - Temple University

2- Seton Hall University

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You've made it through 365 days of sleep deprivation and diaper changes! But it's all been worth it. It's Baby's First Birthday!!

While your baby may appreciate it someday, know that 1-year-olds will have no memory of the big celebration - so be sure to have a camera on hand for the classic photo or video footage of your frosting-covered 1-year-old.

A short, sweet celebration is recommended to accommodate baby's nap time.
<http://www.chiff.com/entertain/first-birthday.htm>

This excerpt from a web guide to planning birthday parties takes for granted that children will not remember events in their infancy—even the most festive or emotional. That first taste of fudge icing, the exciting feeling of wearing a party hat and being the center of attention, the bouncy notes of *Happy Birthday* sung by adoring relatives--all these experiences will be lost if not recorded on film. Why should this be true? And how can we square this lack of memory with the impressive array of data suggesting that babies are learning a great deal about their environment and that their early experiences affect their development? How could babies acquire their first words without being able to form memories, or how could they form attachment relationships to particular adults without remembering faces and voices? Clearly, there is a mystery here.

The inaccessibility of early event memories in later life is sometimes called *infantile amnesia* and sometimes called *childhood amnesia*. Interest in the phenomenon began with Freud (1905/1953) but was sporadic through most of the twentieth century, although there were occasional essays (e.g., Schactel, 1947) and empirical investigations (e.g., Waldfogel, 1948; Rubin, 1982) devoted to it. However, Pillemer and White's (1989) thoughtful review chapter jump started modern research on the topic, and investigations have since accumulated at an accelerating rate. Several books have been devoted in whole or in part to early autobiographical memory and the problem of infantile or childhood amnesia (e.g., Bauer, 2006b; Howe, 2000;

Pillemer, 1998). We are learning a great deal about key aspects of early event memory.

Nevertheless, several problems have not yet been addressed adequately.

The first key issue is the description of what is meant by infantile and childhood amnesia. Infantile amnesia and childhood amnesia are often considered synonymous terms, so that investigators envision a unitary phenomenon. Consequently, there is much discussion of questions such as when “it” is offset, or if “it” is real, and so forth. Actually, however, we argue that the situation is more complex. There seem to be two separable phenomena, an early two-year period of dense amnesia from which people remember close to nothing, and a subsequent period lasting about three to five years during which amnesia is lifting, but from which people retain some spotty and uneven memories.

A second issue arises from the fact that our current understanding of memory development emphasizes early competence and the existence of explicit memory even in infancy (for review, see Bauer, 2006b; chapters 7-10 in Oakes & Bauer, in press). Thus, a reading of the contemporary memory literature might persuade one that observations of infantile amnesia are somehow simply erroneous. Perhaps, properly understood, we remember as much from the first two years as can be expected, given the long delays involved, or the likelihood that what was encoded initially does not match later conceptual frameworks used at retrieval. A slightly different but related viewpoint is the claim that any deficiencies in early memories arise from continuously-developing processes, with no qualitative differences in memory as children develop (e.g., Bauer, 2006b; Courage & Howe, 2004).

This chapter takes a different tack on this matter. Working within the paradigm of contemporary cognitive neuroscience, we argue that, although implicit memory and explicit semantic memory are present early on, there is no good evidence of early episodic (and autobiographical) memory in infancy. Indeed, this state of affairs may have functional significance, because building semantic knowledge about a new world is a primary task for infants and toddlers, and doing so efficiently may be easier when episodic aspects of acquisition

events are *not* retained. For example, it is more important for babies to learn the word “banana” than to remember where or from whom they learned it. In this fashion, we propose a solution to the apparent paradox of excellent infant memory coupled with poor adult memory for early events—we are talking about different kinds of memory. In doing so, we also suggest an important discontinuity in memory development

A third issue revolves around the causes of early amnesia (among writers who accept its existence). Many investigators argue that the primary cause of increasing autobiographical memory is change in children’s language, cognition and social interactions (for review, see Nelson & Fivush, 2004). We argue that such changes provide some part of an explanation of early memory development, but not a complete one. Consideration of these factors should be augmented by an examination of changes within the mnemonic system itself, at both the behavioral and the neural levels.

Let us preview our hypotheses even more specifically. We argue for early functioning of implicit memory (in its various forms) as well as of semantic memory during the initial period of *infantile amnesia*, but with extremely limited episodic memory based on the immaturity of areas of the medial temporal lobe. Thus, we propose an analogy between infants and toddlers on the one hand and people suffering from hippocampal damage on the other, and further suggest that hippocampal maturation may account for the developmental transition occurring at around 2 years. (See Bachevalier, 1990; Nadel & Zola-Morgan, 1984 and Schacter & Moscovitch, 1984 for similar claims but with different dating of transitions.) In making this argument, we present data from development in several spatial tasks known to depend on hippocampus, exploiting the idea that the human hippocampus may subserve functions related to both the spatial domain and episodic memory, perhaps because both functions require the binding together of various cues in the environment (Rolls, Stringer, & Trappenberg; 2002; O’Keefe & Nadel, 1978). We then argue that the period of *childhood amnesia* may be analogous to source amnesia, and that changes across this period may be linked to maturation of function in prefrontal cortex, as previously

suggested by Schacter, Kagan and Leichtman (1995). We also consider the possibility that, alternatively or in addition, hippocampal areas may continue to develop across this time period.

The plan of the chapter is as follows. We begin by considering delineation of the phenomenon, and the case for two distinct periods. We then proceed to discuss two important literatures that form essential background for conceptualizing the development of memory: first, the question of how to define the human memory system and its components, including how we define autobiographical and episodic memory, and second, what is known about the brain bases of episodic and autobiographical memory. In the main body of the chapter, we discuss the development of episodic and autobiographical memory, beginning with whether there is evidence for episodic as well as semantic memory in the first two years of life. Following this discussion, we consider whether early memories can be retained in implicit form, even in the complete absence of explicit memories, as occurs with dense amnesics; whether biological factors contribute to the end of infantile amnesia; and, whether biological factors contribute to the gradual lifting of childhood amnesia. We end by relating this discussion to two claims concerning autobiographical memory development: that it is primarily the product of developments in non-mnemonic domains, such as sense of self, ideas of narrative structure, recognition of the social importance of remembering, and linguistic development, and that it is quantitative in nature rather than showing qualitative transitions.

I. Differentiating Infantile and Childhood Amnesia

Infantile or childhood amnesia is often treated as a unitary phenomenon, but mounting evidence suggests that it is probably complex and multiply determined (Neisser, 2004). One key distinction that may contribute to understanding our lack of early event memories is that there seem actually to be two phenomena that constitute two distinctive periods of early amnesia. The first period encompasses the first two years, a period from which very few if any events are consciously recalled. For this period, there may be a productive analogy to what researchers examining individuals with brain damage call *dense amnesia*. The second period encompasses the

next three to five years, a period during which events are recalled at lower rates than might be expected from a normal forgetting function, may be remembered in an unusually fragmentary form, and may seem globally familiar rather than specifically recallable. For this period, there may be a productive analogy to what researchers examining individuals with brain damage call *source amnesia*. To keep matters straight, we refer to the first period as *infantile amnesia*, and the second as *childhood amnesia*.

One line of evidence favoring the delineation of these two separate periods comes from the distribution of autobiographical memories through the first decade of life, acquired from studies that ask people for large numbers of such memories using various probe techniques. For example, people may be asked to recall past events that relate to specific cue words, such as “sand,” and then asked to date the memories. Several studies have been conducted that chart frequency of events recalled from childhood as a function of the age of the child when they occurred (Crovitz & Quina-Holland, 1976; Crovitz & Schiffman, 1974; Waldfogel, 1948; Wetzler & Sweeney, 1986). Rubin (2000) constructed an overall distribution relating age to frequency of memories, based on an assembly of about 11,000 childhood memories gathered in various studies using the probe technique and other methods. The resulting curve, shown in Figure 1, shows very few autobiographical memories predating the age of 2 years, with a rising but still small number of memories evident in the interval between turning 2 and turning 3. The number of memories increases steeply thereafter, but levels off beginning at about the age of 5 years, with mature levels clearly evident by around 7 years, so that adults remember events from later elementary school at about the levels predictable from the time elapsed since the events. Thus, it appears that autobiographical memory over the first decade of life can be characterized as showing three different periods: in the first, there are almost no autobiographical memories, in the second, autobiographical recall is increasing rapidly, and in the third, autobiographical memory is at mature levels.

Other lines of evidence favor the kind of curve delineated by Rubin and the notion of two separable periods of early amnesia followed by mature functioning. First, looking at the proposed demarcation between infantile and childhood amnesia at around 2 years, data from studies in which people have been asked about single specific events likely to be memorable, such as birth of a younger sibling or a hospitalization, reveal verified recall of some aspects of such events beginning at around the age of 2 years but extremely rare, and close to non-existent, before (Crawley & Eacott, 1999, 2006; Eacott & Crawley, 1998, 1999; Sheingold & Tenney, 1982; Usher & Neisser, 1993; Winograd & Killinger, 1983). An alternative demarcation point might be suggested at 3 years, based on studies asking people to recall and date their earliest memory. Such dates cluster around 3 years, although they vary somewhat depending on age, gender and culture (Fiske & Pillemer, 2006; Kihlstrom & Harackiewicz, 1982; MacDonald, Uesiliana & Hayne, 2000; Matsumoto & Stanny, 2006; Mullen, 1994; Peterson, Grant & Boland, 2005; Wang, 2001). It is reasonable, however, to suppose that questioning regarding the “earliest memory” is a relatively insensitive assessment of the offset of infantile amnesia, because people do not know a priori what their earliest memory is. Given the scarcity of memories from the ages of 2 and 3 years, they are quite likely to hit on a memory from when they were 3 as their earliest if they simply conduct a random search of those memories, and perhaps especially if they first retrieve the most vivid. Asking for recall of known (and verifiable) events seems to be the stronger methodology because this is a more targeted way to investigate what if any memories from earlier time periods are available.

Second, demarcating childhood amnesia and ordinary forgetting at around 5 to 7 years can also be supported by other kinds of findings, besides the data summarized by Rubin. For one thing, studies asking about memory for specific events such as hospitalizations show steep increases across the age range from 2 to 6 years, similar to the increases seen in Figure 1. Unfortunately, they rarely include data on events experienced at later ages, such as 10 or 12 years, to establish whether there is a leveling at adult levels during the elementary school years. One

exception is work examining memory for the German invasion of Denmark in 1940 and the end of the German occupation in 1945 (Berntsen & Rubin, in press). This study found that memories for these events increased linearly up to as late an age as 8 years, and remained level thereafter. However, this study is not definitive, because by 8 years memories were at ceiling levels (so development might continue even later) and in addition because, these events, though dramatic, may have been difficult for children younger than 8 years to understand, and adults may have sheltered them from discussion of at least the first event (so mature memory might be seen earlier had children really known about the events when they happened). Clearly, more research along these lines, using different events, would be welcome.

Another line of evidence relative to the age when mature memory for events appears is obtained when people are asked to judge whether events in their early childhood were simply known from others' reports or actually remembered. The median age of remembered events is around 6 years (and the median age of events simply known about from family stories is around 3 years) (Bruce, Dolan & Phillips-Grant, 2000; Bruce, Wilcox-O'Hearn, Robinson, Phillips-Grant, Francis & Smith, 2005; Multhaup, Johnson & Tetirick, 2005).¹ Overall, autobiographical memory appears to reach mature levels in the early school years, between the ages of 5 and 7.

II. Architecture of the Human Memory System

The psychology of memory has a long history, dating back to Ebbinghaus' heroic work with his own memory for consonant-vowel-consonant trigrams in the nineteenth century. A notable feature of that approach was that investigators assumed that there was a single entity called "memory", whose laws they were aiming to discover. The advent of information processing theory led to functional distinctions, as between sensory stores, short-term memory and long-term memory (Atkinson & Shiffrin, 1969), or between memory tasks such as recognition and recall (e.g., Mandler, Pearlstone & Koopmans, 1969; Warrington & Weiskrantz, 1970), or, in a path-breaking effort, between episodic and semantic memory (Tulving, 1972).

However, toward the end of the 20th century, the study of memory and its development was transformed by a new way of thinking about long-term memory. Understanding this approach, and how to define autobiographical memory within it, is key to analysis of the development of autobiographical memory.

A. A Modern Typology of Long-Term Memory

The modern framework was inspired by findings that individuals with brain damage could show evidence of forming new memories, as long as one considered that explicit, conscious, verbal access was not the essential attribute of memory. So, for example, amnesic patients can learn and retain a new motor skill (e.g., Milner, 1962), such as playing an acceptable game of golf even while forgetting what shots were made on a previous hole (Schacter, 1983). Similarly, prosopagnosic patients who do not recognize even very familiar faces can show facilitated perceptual processing of faces seen before (de Haan, Bauer & Greve, 1992), and implicit and explicit memory are dissociated in posthypnotic amnesia (Barnier, 2002). Even normal adults showed evidence of this kind of phenomenon (Jacoby & Dallas, 1981). Findings of this sort gave rise to a distinction between declarative and procedural memory (e.g., Squire, 1986; Squire & Zola-Morgan, 1988) or alternatively, between explicit and implicit memory (e.g., Schacter, 1987). Explicit or declarative memory refers to the ability to consciously retrieve memories based on previous experience and knowledge whereas implicit or procedural memory refers to evidence that past experience influences perceptual processing or other kinds of responses without conscious awareness²

There has been some criticism of this kind of distinction from proponents of a unitary memory store, who suggest that the difference might amount to little more than one between stronger and weaker memory traces, (e.g., McBride & Doshier, 1997; Ratcliff & McKoon, 1996; Shiffrin & Steyvers, 1997), or might confound other relevant distinctions (Roediger & Blaxton, 1987). However, data regarding the neural bases of memory has tended to support the idea of a fundamental dichotomy, which is now widely if not universally accepted.

The dichotomy is not, however, the end of classification. There are also important distinctions within the realms of explicit (or declarative) and implicit (or nondeclarative or procedural) memory. Figure 2 displays a modern typology. With regard to the first realm, the fundamental contrast is that between semantic and episodic memory proposed originally by Tulving (1972) although subsequently refined (Tulving, 1983; 1986; 2002; also see Schacter, 1987; Schacter & Tulving, 1994). With regard to the second realm, there seem to be several different kinds of memory that are not explicit, but that are also quite different from each other. Implicit memory is divided into procedural skill (the kind of motor memory we mentioned above, such as memory for a golf swing), associative memory (including various kinds of classical conditioning and perhaps with further sub-divisions), non-associative learning (such as habituation), and priming (which includes changes in perceptual skill such as increased rapidity of identification or identification under degraded conditions).

B. What is Autobiographical Memory?

How does autobiographical memory fit into this scheme? A good deal of discussion has addressed the question of defining autobiographical memory (e.g., Brewer, 1986). One simple way to think about the matter is to suggest that semantic and episodic memory can each concern the self (or not). That is, we can define a 2 by 2 table such as the one shown as Table 1, with autobiographical memory occupying the bottom cell on the right (i.e., episodic memory of a self-related kind). Autobiographical memory is thus distinct from autobiographical knowledge (I know that I was born in Toronto, and this is a self-related piece of semantic knowledge, but I have no memory of the event). Self-related episodic memory is also distinct from impersonal episodic memories such as those studied in many traditional memory experiments (the memory of being in a free recall experiment and seeing “tree” on a word list is only trivially part of my autobiography). One advantage of this categorization is that it suggests that much of what we know about the development of episodic memory from research on classic episodic memory tasks that are not self-related (e.g., free recall) may also apply to autobiographical memory. Because

there is a large volume of such research (e.g., see review by Schneider & Bjorklund, 1998), considering its relevance for autobiographical memory development is worthwhile. For example, perhaps some of the phenomena of the period of childhood amnesia can be explained by young children having strategy deficits of various kinds. That is, older children who are asked about their third grade classroom might first start by thinking of their teacher or friends. Younger children are less likely to guide their memory searches in such a way, and thus may appear not to remember when in reality, they are not performing in a way to promote remembering. In addition, they may be more prone to actually forgetting, due to the lack of memory review.

An elaboration on this typology suggests that episodic memory is actually composed of inter-dependent facts that could individually be considered to be semantic memories. Thus, for example, I know that I own a green flowered skirt, I know that I went to a certain concert, and I know that my friend Lily went to the same concert. Individually, these could be considered semantic memories, two of which are self-related. But when they are put together, so that I know that I wore the skirt when I went to the concert with Lily (and especially when joined with other facts such as what we ate first, how we got to the concert, where it was, what the music sounded like and so forth), we have an episodic memory of the autobiographical kind. The recent literature has termed this process of putting together aspects of a situation *feature binding* (e.g., Mather, Mitchell, Raye, Novak, Greene & Johnson, 2006).

However, two important unsettled issues are associated with this way of defining autobiographical memory. First, Tulving (1993; Wheeler, Stuss & Tulving, 1997) has described episodic memory as *mental time travel*, using the term *autonoetic recall* to refer to the capacity to be aware of past, present and future experience. In doing so, he emphasizes the vividness and particularity of episodic memory in general and autobiographical memory in particular. Many people agree that these qualities are distinctive characteristics of what they mean subjectively by autobiographical memory. In contrast, a great deal of evidence dating back to Bartlett indicates that memory is reconstructive, and many researchers have emphasized that autobiographical

memory is no exception. In a position close to the opposite of Tulving's, Conway and Pleydell-Pearce (2000) have argued that what we call autobiographical memory is constructed in working memory given the current state of the self. The construction uses autobiographical knowledge in long-term memory and is somewhat grounded by it, but that knowledge is also in turn influenced by the construction generated. An intermediate position is taken by Johnson and her collaborators, whose *source monitoring framework* for thinking about autobiographical memory also attributes importance to inference processes and yet retains the construct of self-related episodic memory as a real entity rather than one undergoing potentially infinite constructive modification (Johnson, Hashtroudi & Lindsay, 1993).

A second issue concerns the role of emotion and the self. An autobiographical memory seems to many writers to be more than simply an episodic memory in which one is a participant. My memory of going to the concert with Lily also includes components that are unique to the fact that I was a participant, such as what I thought and what I felt, and the memories are spatially and temporally constrained by my sensorimotor experience; that is, by real-world facts about where I went at what time. Factors such as self-reflection and personal temporality seem to be essential aspects of autobiographical memory (Klein, German, Cosmides & Gabriel, 2004).

In summary, autobiographical memory can usefully be considered as episodic memory that relates to the self and that, as such, is likely to be more emotional and more personally meaningful than episodic memories that lack such relevance. As with all memories, inference is used in constructing and evaluating recall and recognition attempts, and hence memory is far from veridical. Nevertheless, autobiographical memory may have a phenomenological quality of "mental time travel" to the extent that it includes a great deal of inter-linked information. Autobiographical memory is a uniquely important kind of episodic memory because of its relevance to human cognitive and emotional life: people treasure their personal memories and work to retain them by making scrapbooks, taking photos, sharing them at family gatherings and so on.

III. Brain Bases of Human Memory

One of the reasons for adopting the typology of long-term memory shown in Figure 2 is that researchers have documented the varying areas of the brain that have specific roles in each of the postulated types of memory. Specifying such brain bases gives us a purchase for thinking about the memory system and its development that is lacking in purely behavioral approaches.

A. Role of the Hippocampus in Episodic and Semantic Memory

One manner of distinguishing brain areas that is controversial, in a way that is important for this chapter, is the idea of a common base for episodic and semantic memory. This conceptualization has been widely endorsed, with the view being that, for any kind of explicit memory, the hippocampus is important early in memory encoding and during a consolidation process during which it acts as a pointer to information stored neocortically, with ultimate dependence only on neocortex (e.g., Alvarez & Squire, 1994; McClelland, McNaughton & O'Reilly, 1995). An alternative is that semantic memory depends on temporal lobe cortex surrounding the hippocampus while episodic memory depends either on hippocampus proper (Mishkin, Suzuki, Gadian & Vargha-Khadem, 1997) or on the hippocampus plus certain other parts of the hippocampal complex (Hayes, Ryan, Schnyer & Nadel, 2004), and, furthermore, that the hippocampus is always involved in retrieval of episodic memories not just during a period of consolidation (Nadel, Ryan, Hayes, Gilboa & Moscovitch, 2003). The evidence for thinking that episodic and semantic memory are supported by somewhat different brain systems and that hippocampus is important to episodic memory on a continuing basis comes from three sources: recent re-investigations of classic cases of adults with hippocampal lesions such as H.M., studies of developmental amnesics (i.e., children who suffered hippocampal damage early in life), and imaging studies of normal adults.

1. Reconsidering amnesia. With respect to dense amnesia of the kind caused by large bilateral hippocampal lesions and that afflicts well-known patients such as H.M., the prevailing wisdom had been that there was an inability to form new explicit memories, either semantic or

episodic, along with well-preserved semantic and episodic memory for material learned before the operation or accident. However, two subsequent findings cast doubt on this generalization. First, amnesics including H.M. can apparently acquire at least some new semantic information. For example, in the context of his hobby of solving cross-word puzzles, H.M. is helped by semantic clues referring to post-operative facts and names (Skotko, Kensinger, Locascio, Einstein, Rubin, Tupler, Krendl & Corkin, 2004). H.M. also appears to have acquired post-operative semantic information about the names and accomplishments of individuals who became famous after his operation occurred in 1953, such as John Glenn (O’Kane, Kensinger & Corkin, 2004). Second, pre-operative autobiographical memory is more impaired than previously imagined, for H.M. and for two other patients, W.R. and K. C (Rosenbaum, Kohler, Schacter, Moscovitch, Westmacott, Black, Gao & Tulving, 2005; Steinvorth, Levine & Corkin, 2005). (Pre-operative semantic knowledge is in fact well preserved, as has always been believed.) The difficulties with pre-operative episodic memories and the ability to acquire post-operative semantic memories suggest a continuing and central role for hippocampus in episodic and autobiographical memory, and a less important role for hippocampus in semantic memory.

2. *Developmental amnesia.* Cases of developmental amnesia support the hypothesis that hippocampus is not central to semantic memory encoding and retention. Children exposed to hypoxia sometimes develop bilateral hippocampal abnormality, with reductions in hippocampal volume ranging from 43 to 71% (de Haan, Wyatt, Roth, Vargha-Khadem, Gadian & Mishkin, 2006). Their temporal lobe regions are usually well within normal range, suggesting that damage is restricted to the hippocampus. When studied in later childhood and adulthood, they show severe episodic memory impairments but apparently well-preserved ability to form semantic memories. Delayed recall tests prove extremely difficult, while scores on tests of immediate memory and recognition are within the normal range compared to healthy controls (Baddeley, Vargha-Khadem, & Mishkin, 2001; Gadian, Aicardi, Watkins, Porter, Mishkin, & Vargha-Khadem, 2000; Vargha-Khadem, Gadian, & Mishkin 2001; Vargha-Khadem, Gadian, Watkins,

Connelly, Van Paesschen, & Mishkin, 1997). Additionally, these children have significantly impaired spatial memory (King, Trinkler, Hartley, Vargha-Khadem, & Burgess, 2004) and are not well oriented in the temporal elements of events, such as the date and time.

Two out of three reported developmental amnesia cases (Vargha-Khadem et al., 1997) accumulated semantic memory of factual knowledge *after* hippocampal damage (sustained at birth). This supports the account that for episodic functioning the hippocampus is primarily associated with recall and binding contextual information of events, while the surrounding parahippocampal structures may provide more support for semantic memory based on recognition and familiarity. As pointed out by de Haan et al. (2006), a very interesting aspect of these cases is that, even when damage is sustained in infancy, impairments do not become evident until the children reach school age. One possible reason for this pattern is that semantic memory normally develops first, and hence the difficulties of the children exposed to hypoxia are not noted by observers until the age at which normal children begin to exhibit strong episodic memory skills. Interestingly, the timing of 6 years or so for the age at which deficits are first apparent fits well with the offset age for childhood amnesia that we described previously.

3. Imaging of normal adults. Imaging studies conducted with normally-functioning adults also support an important role for the hippocampus in autobiographical recall. Researchers have found hippocampal activation when people recall information about contextualized and inter-linked objects, people, locations and times, such as who gave you an object when and where (Burgess, Maguire, Spiers & O'Keefe, 2001; Hayes et al., 2004). Hippocampal activation appears independent of the age of the autobiographical memory, thus casting further doubt on the notion of a consolidation process after which the hippocampus is not involved in recall (Addis, Moscovitch, Crawley & McAndrews, 2004; Gilboa, Winocur, Grady, Hevenor & Moscovitch, 2004; Maguire & Frith, 2003a, b; Rekkas & Constable, 2005; Ryan, Nadel, Keil, Putnam, Schnyer, Trouard, & Moscovitch, 2001). Notably, qualities of the recollection such as detail and emotionality are correlated with variations in hippocampal activation (Addis et al., 2004). Some

aspects of these findings have yet to be worked out: hippocampal activation that is independent of the age of the memory may be restricted to the left hippocampus (Maguire & Frith, 2003b), or remote and recent memories may activate different parts of the hippocampus (Gilboa et al., 2004). But the continued involvement of the hippocampus in autobiographical recall seems clear.

B. Role of the Frontal Lobes in Episodic and Semantic Memory

People with damage to frontal cortex have memory problems, although they are not nearly so marked as the afflictions of people with damage to medial-temporal areas. However, frontal patients do show large and significant decrements in recall, as well as small but still significant decrements in recognition (for a review, see Wheeler, Stuss & Tulving, 1995). One particularly interesting phenomenon shown by frontal patients has been termed *source amnesia*. People with source amnesia can learn new information, but they have great difficulty later in knowing when, where and from whom they learned it (Schacter, Harbluk & McLachlan, 1984). Such problems suggest not only forgetting of sources, narrowly construed, but also difficulty with episodic memory, which requires the inter-linking of who-when-where information with semantic facts.

Studies using fMRI or other techniques to image brain functioning of normal adults suggest that left prefrontal cortex may be particularly important for detailed episodic remembering, for autobiographical memory, and for source judgments (e.g., Conway, Pleydell-Pearce, Whitecross & Sharpe, 2003; Ranganath, Johnson & D'Esposito, 2000; Raye, Johnson, Mitchell, Nolde & D'Esposito, 2000; but see Thaiss & Petrides, 2003), although localization to the left is not a universal finding (Greenberg, Rice, Cooper, Cabeza, Rubin & LaBar, 2005; Hayes et al., 2004; Vandekerckhove, Markowitsch, Mertens & Woermann, 2005). The nature of the role of prefrontal cortex in episodic and source memory is not yet clear. Consistent with the role of prefrontal cortex in executive function more generally, strategic retrieval and evaluation processes may be the domain of this brain area, coupled with co-activation of memories in areas concerned more specifically with memory such as the hippocampus (Cabeza, Prince, Daselaar,

Greenberg, Budde, Dolcos, LaBar & Rubin (2004); Greenberg et al., 2005; Vandekerckhove et al., 2005). Additionally, prefrontal cortex may be involved during autobiographical memory retrieval due to the relevance of some areas in prefrontal cortex for self-referential processing (Cabeza, et al., 2004; Keenan, Wheeler, Gallup & Pascual-Leone, 2000). An important aspect of recalling life events is differentiating what really happened from what was imagined or heard from a third party. Imagined or recounted events appear to be differentiated from experienced ones by more perceptually-relevant areas being active during remembering of the latter (Cabeza et al., 2004; Conway et al., 2003; Slotnick & Schacter, 2004). Thus, PFC may be involved in reality monitoring through a role in appraisals of these activation patterns.

C. Brain Bases of Binding in Episodic Memory

We have mentioned that the ability to link together different aspects of experience is central to the formation of an event memory. Such *binding* processes have sometimes been studied in situations in which people are asked to remember intra-item associations, such as the color as well as the shape of an object (e.g., Wheeler & Treisman, 2002), as well as in situations in which people are asked to remember inter-item associations such as the location of objects (e.g., objects are shown against backgrounds, and people are probed on their memory for the unique relation of the object and the background) or word relationships (e.g., Naveh-Benjamin, 2000). Inter-item associations may be especially relevant to event memory, because they serve to create the what-where-when structure of autobiographical narrative, although the study of intra-item associations is also interesting.

Studies of contextual binding suggest the importance of the hippocampus for the binding process and for the decrements in binding observed in the elderly (Chee, Goh, Venkatraman, Tan, Gutchess, Sutton, Hebrank, Leshikar & Park, 2006; Goh, Siong, Park, Gutchess, Hebrank & Chee, 2004; Mitchell, Johnson, Raye & D'Esposito, 2000). Thus, we should consider whether hippocampal change, extending through 5 years of age or even later, might be linked to a growing

ability to form inter-item associations that eventually leads to an end of the period of childhood amnesia.

D. What Is Known About Development of Brain Areas Relevant to Episodic Memory?

We have identified numerous brain areas important to episodic memory, including most notably the hippocampus and prefrontal cortex. Thus, it is natural to ask what is known about development of these areas. Could immaturity in one or both of them contribute to infantile or childhood amnesia? Unfortunately, the current literature does not provide a great deal of guidance. For prefrontal cortex, the problem is that development is known to extend across a very long developmental span, with initial synaptic proliferation followed by a pruning process and other associated changes that extend into late adolescence (Giedd, Blumenthal, Jeffries, Rajapaske, Vaituzis, Liu, Beny, Tobin, Nelson, & Castellanos, 1999; Huttenlocher & Dabholkar, 1997; Sowell, Delis, Stiles, & Jenigan ., 2001). Thus, almost any developmental change could be plausibly linked to changes in prefrontal cortex, given that we do not know in a detailed way the level of maturation in different areas needed to support specific functions. For hippocampus, the problem is that we have very little direct information. Many researchers have read the sparse literature as suggesting that maturation of this area occurs very early in life (e.g., Nelson, 1995), although other sources describe changes that extend over the first 5 years or even beyond (Alvarado & Bachevalier, 2000; Gogtay, Nugent, Herman, Ordonez, Greenstein, Hayashi, Clasen, Toga, Giedd, Rapoport & Thompson, 2006; Seress, 2001; Utsunomiya, Takano, Okazaki & Mitsudome, 1999).

Given this situation, we present data gathered inferentially from behavioral techniques. That is, if a particular task is known to recruit a certain brain area, such as hippocampus, based on data from non-human animals, imaging of normal adults, or work with patients with brain damage, then the development of success on the task may provide an indirect assessment of maturation of the brain area. This strategy entails many assumptions. When data from non-human animals are used, we assume that parallels across species. This matter is debated sometimes but

there is solid evidence for evolutionary continuity in function, at least for hippocampus (Kesner & Hopkins, 2006). When tasks that are non-mnemonic in nature are used, we assume that brain areas that support more than one function can be assessed using either one. In particular, hippocampus seems particularly central both to spatial and to episodic memory, a linkage that may be far from accidental (as suggested originally by O'Keefe & Nadel, 1978, and discussed since by many authors, e.g., Rolls, et al., 2002; Whishaw & Wallace, 2003). Spatial memory and navigation requires the contextual linkage of a variety of relevant cues to location, so that a structure evolved to allow for successful spatial behavior might be particularly well suited to also encode contextualized events.

E. Summary

Episodic memory in general, and autobiographical memory in particular, depend on both prefrontal cortex (which may be especially involved in effortful retrieval and strategic memory decisions) and on hippocampus (which may be especially involved in storage of memory traces themselves and the binding of various traces to form an inter-linked context-specific memory). In addition, various other brain areas may be involved, most notably when emotion is retrieved or when specific sensory detail is accessed. Relatively little of a specific nature is known about the development of the hippocampus and prefrontal cortex, although frontal development is a lengthy process and hippocampal development probably extends through at least 5 years. Notably, brain areas involved in semantic memory may be different than those involved in episodic memory, so that the two forms of explicit memory may be more distinct than is often recognized.

IV. Memory in the First Two Years

Scientists still debate the presence of explicit memory in the first 6 months of life. During this early period, the available techniques for assessing memory are visual paired comparison, which measures how much infants look at novel as opposed to familiar stimuli, and the conjugate reinforcement paradigm, which examines infants' rates of kicking when they see mobiles that have formerly been controllable in that way. Both of these paradigms are sometimes argued to

reflect implicit rather than explicit memory (Snyder, in press, on the VPC; Bauer, DeBoer & Lukowski, in press, on conjugate reinforcement), although some vigorously advocate the view that they tap explicit memory (Rose et al., in press, on the visual-paired comparison paradigm, and Rovee-Collier, 1997 on conjugate reinforcement). However, there is consensus that explicit memory is clearly evident by 6 months of age from experiments using deferred imitation of action sequences, a technique that passes the “amnesia test”; that is, impaired performance in both adults with hippocampal damage (McDonough, Mandler, McKee & Squire, 1995) and cases of developmental amnesia (Adlam, Vargha-Khadem, Mishkin & de Haan, 2005). Deferred imitation of a series of experimenter-modeled actions can first be demonstrated at 6 months, albeit in simple forms involving short sequences, brief delays or repeated retrievals (Barr, Dowden & Hayne, 1996; Barr, Rovee-Collier & Campanella, 2005). Memory as assessed by deferred imitation strengthens in various ways through the first 2 years, becoming capable of more complex encodings that last over longer retention intervals and that require less specific cues for retrieval (Hayne, Boniface & Barr, 2000; Hayne, MacDonald & Barr, 1997). These findings bring us to a conundrum. By at least the second year of life, action sequences are well retained over periods of several months (e.g., Bauer, Hertsgaard & Dow, 1994; Bauer, Hertsgaard & Wewerka, 1995), and everyone seems now to agree that such memory is explicit in nature. Given that fact, how is it possible that later on, autobiographical memories will be close to non-existent?

This question might have several answers. One possibility is that explicit memory, even in the second year of life, is still insufficiently robust to allow for the formation of memories that will survive retention periods of decades. However, the data on retention over lengthy periods of time reduce the plausibility of this argument. Another possibility is that early explicit memory may be semantic in nature rather than episodic. Remembering the sequences shown in deferred imitation experiments, such as three actions required to make a rattle, may yield a memory regarding how to make a rattle that is not linked to where one learned it, from whom, with what materials and so on. Indeed, data on deferred imitation and retention of action sequences show

that children often do generalize over such dimensions (Bauer & Dow, 1994; Lechuga, Marcos-Ruiz & Bauer, 2001). Although they may perform better with the original materials than with analogous ones, it is not clear that an advantage for the original materials indicates specific episodic recall. It could also derive from the original objects being better retrieval cues, as when *bread* is a better cue for *butter* than *milk* is. Clearly, generalization of what is learned would be adaptive: it is far more important for children to learn facts and skills than to know the circumstances in which they were acquired.

Unfortunately, there is no direct evidence on the episodic versus semantic nature of memory in the first two years of life. The lack of linguistic skills in this period always poses a challenge to delineating such matters. However, researchers have addressed the issue using nonverbal means, and there have been claims of startling episodic skills in non-human animals who seem to remember specific details about past experiences (with scrub jays, Clayton & Dickinson, 1998, 1999; Clayton, Yu, & Dickinson, 2001, 2003; with pigeons, Zentall, Clement, Bhatt, & Allen, 2001; with rats, Babb & Crystal, 2006; Kart-Teke, Silva, Huston & Dere, 2006). For example, taking advantage of the natural caching behavior of scrub jays, Clayton and Dickinson (1998) observed that the birds would return to search for previously stored perishable items only after short delays, switching to non-perishable food after a long delay, indicating an episodic-like memory for where and when certain foods were stored and where to locate them following a variable delay. Although these results from non-human animals are susceptible to a semantic memory interpretation (repeated reinforced trials may produce rule learning rather than reliance on memory of specific events), that possibility too could perhaps be excluded in further research. The first step is to adapt such techniques for use with young children, as pioneered by Hayne (in press) with preschool children.

The hypothesis that early explicit memory is semantic but not episodic is strikingly supported by the studies of children suffering from developmental amnesia, who can acquire a normal store of semantic knowledge and who certainly learn to speak, but who have very

deficient episodic memory abilities. There are, however, no definitive demonstrations in normal children either of the hypothesis that early memory is not episodic or of the alternative that it is. Nevertheless, the supposition does solve the issue of how one could have early explicit memory and yet little if any autobiographical recall. Mandler (2004, pp. 239-240) summarized the situation in a similar way:

None of the experimental data [on infant memory] provides any evidence for spatiotemporal dating of these memories. Indeed, it seems somewhat unlikely that when an observed event comes to mind at a later time the infant is also aware of when or where it happened. Spatiotemporal dating is not required for recall...By age 2, verbal recall protocols suggest some awareness of when and where events being recalled took place.....but this issue has not been systematically studied....We also do not know whether these early recall memories are autobiographical.

If we adopt the supposition that early explicit memory is semantic but not episodic as a working hypothesis, what then are the remaining puzzles about early autobiographical memory? We see four key questions: (1) Can memories be retained in implicit form, even in the complete absence of explicit memories, as occurs with dense amnesics such as H.M.? (2) Is there a role for hippocampal development, and perhaps prefrontal development, in the end of infantile amnesia? (3) What are the roles of later hippocampal development and/or frontal development in the gradual lifting of childhood amnesia and the development of source memory? (4) How does this discussion relate to other conceptualizations of early autobiographical memory, such as the claim that memory development is quantitative rather than showing qualitative transitions, or claims that development of autobiographical memory is primarily the product of developments in other domains, such as sense of self, ideas of narrative structure, recognition of the social importance of remembering, and linguistic development?

V. Implicit Memory in the Absence of Explicit Memory?

Fairly soon after studies of implicit memory in normal adults began appearing, there were demonstrations that preschool children showed good implicit memory also. The research mainly involved perceptual priming, in both visual and auditory modalities, and the conclusion emerged that these abilities did not develop but were present in mature form early on (Carroll, Byrne, & Kirsner, 1985; Church & Fisher, 1998; Greenbaum & Graf, 1989; Mitchell, 1993; Naito, 1990). Some findings challenge this generalization. Priming that depends on conceptual relations sometimes shows age-related change (e.g., Mecklenbrauker, Hupbach, & Wippich, 2003; Murphey, Mckone, & Slee, 2003; Perruchet, Frazier, & Lautrey, 1995), but this seems unsurprising in light of the fact that concepts are changing and knowledge is accumulating (Lloyd & Newcombe, in press). More broadly, in terms of the overall picture in implicit memory, findings that implicit sequence learning shows age-related change (Thomas & Nelson, 2001; Thomas, Hunt, Vizueta, Sommer, Durston, Yang, & Worden, 2004) suggest that different forms of implicit memory may have different developmental functions. Priming may be present early, but other forms of implicit memory appear to develop.

As we have seen, patients suffering from amnesia, or other cognitive difficulties such as prosopagnosia, often show evidence of implicit memory even when explicit memory is impaired. Is the same phenomenon observable developmentally? That is, do children show at least some forms of implicit memory, most especially perceptual priming, in cases where explicit memory is lacking? Several studies have addressed this issue in the context of a naturalistic situation, namely memory shown by elementary school children for faces of preschool classmates they had not seen since preschool (Newcombe & Fox, 1994; Lie & Newcombe, 1999). Other work has examined the question in the context of a more controlled experiment, assessing memory for novel pictures that were shown to children for durations and at times that were experimenter-determined (Drumme & Newcombe, 1995). In all studies, we studied explicit memory by asking for recognition judgments, but methods for assessing implicit memory varied. The first study of memory for faces of preschool classmates used galvanic skin response to assess implicit memory

(Newcombe & Fox, 1994), whereas the other used a behavioral measure involving judgments of whether faces viewed from different perspectives were the same or different (Lie & Newcombe, 1999). The technique was based on previous work with normal adults and adults suffering from prosopagnosia, adapted for use with children by Newcombe and Lie (1995). Implicit memory for novel pictures was examined using a technique commonly used in the developmental and adult priming literature, namely perceptual identification of blurry pictures gradually brought into focus, where previously-seen pictures are typically recognized at higher degrees of fuzziness (Drummey & Newcombe, 1995).

All three studies revealed evidence that implicit memory can be evident in children even when explicit memory is lacking. Newcombe and Fox (1994) identified one group of children who had fairly good recognition memory for their classmates and another group who showed no evidence of recognition. The striking finding regarding implicit memory was that galvanic skin responses (GSR) were not only reliably above chance overall, but equivalent for the two groups. That is, the group of children who could not recognize pictures of their former classmates did show implicit responsivity to their pictures at levels equal to those who did recognize them (see Figure 3). Lie and Newcombe (1999) found higher levels of recognition than Newcombe and Fox did, and hence were not able to identify a group of children who showed no evidence of explicit memory. They did, however, compare performance on the implicit task for pictures of classmates who were and were not correctly recognized, and found equivalent levels of accuracy on the implicit task for classmates in the two categories. Drummey and Newcombe (1995) studied children three months after the initial showing of a picture book, as well as immediately. After three months, 3-year-old children showed no evidence of picture recognition, but they did show reliable perceptual priming. In addition, comparison to older children and adults showed that recognition memory showed marked age-related increases, as would be expected of an explicit memory measure, but perceptual priming was developmentally invariant.³

Taken together, these data suggest that implicit memory can indeed be preserved when explicit memory is lacking. This statement should not be taken to imply, however, that implicit memory does not decay. GSR responses in the Newcombe and Fox (1994) data were better than chance at statistically reliable levels, but accuracy was low relative to what would be expected from prior studies of prosopagnosics. In addition, perceptual priming declined over the 3-month interval in the Drummey and Newcombe (1995) study. Similarly, in Lie and Newcombe (1999), accuracy on the implicit measure declined significantly across that three-year period.

One question that this group of studies cannot answer is whether implicit memory based on experiences occurs in the first 2 years of life, the period of infantile amnesia. Although some children in the preschool classmate studies entered group care as infants, we could not identify any large subset of situations in which two infants were in the same group early on, but were separated subsequently as opposed to continuing to attend the same childcare center. The only research that may address survival of implicit memory comes from follow-up work on children who participated in research on auditory localization at about 6 months of age (Myers, Clifton & Clarkson, 1987; Perris, Myers & Clifton, 1990). Two years later, they were more likely than control children who had not been in the situation before to retain the old action sequences and be able to grasp the object that was making a sound. With rare exceptions, they did not show evidence of explicitly recalling having been in the situation before. However, the status of retention of action sequences as a measure of implicit versus a form of explicit memory is not secure. Action sequences are exactly what deferred imitation tasks assess, and those tasks have been convincingly shown to be explicit in nature. Nevertheless, the follow-up studies on auditory localization also report evidence of differential reactions to the situation itself, such as greater comfort being in the dark, that do seem likely to be implicit in nature.

Clearly, more work on implicit memory in the first two years of life is needed. First, we need to determine definitively if implicit memory exists at all. There is actually very little evidence regarding how early we can see evidence of perceptual priming, with or without

concomitant explicit memory. To our knowledge, there are no studies of priming in children younger than 3 years using techniques analogous to those used with older children and adults. Although priming as defined within the conjugate reinforcement paradigm is evident in very young infants (Rovee-Collier, 1997) and infants and adults show analogous repetition priming as assessed by event-related potentials (Webb & Nelson, 2001), the evidence is too scarce to conclude that perceptual priming is present in infancy. Second, we need to address whether, if priming exists, it survives (or other kinds of implicit memory last) in cases where explicit memory formed by infants fades. The Myers et al. (1987) and Perris et al. (1990) studies are suggestive, but not definitive.

VI. Are There Biological Bases for the Lifting of Infantile Amnesia?

So far, we have proposed that early explicit memory is primarily or entirely semantic in nature—although the existence of early episodic memory needs to be more directly addressed. We have also suggested that implicit memory may be available from the period of infantile and childhood amnesia—although there is not nearly as much direct evidence concerning the period of infantile amnesia as one would like. In this section, we consider the proposition that the apparent lack of episodic memories in the first two years of life reflects the relative immaturity of the hippocampus. The relevant data come from several non-memory tasks: a variant of the visual paired-comparison task (VPC); the delayed non-match to sample (DNMS) task; and, several spatial tasks including place learning.

A. Context and the VPC Task

As we have mentioned, success in VPC is evident very early in life and is widely assumed to show explicit rather than implicit memory (although see Snyder, in press, for doubts). However, in a variant of the procedure, success is not observed until between 12 and 18 months of age (Robinson & Pascalis, 2004). In this situation, a picture of an object is presented to an infant on a solid-colored background. Then, pictures of a novel object and the old object are shown in a paired comparison test, in which background color either remains constant or changes

to another color. When the color context is changed, babies do not show memory for the objects until between 12 and 18 months. This fact is intriguing, given evidence that the same difficulty is shown in monkeys with hippocampal lesions (Pascalis & Bachevalier, 1999) and in an amnesic patient with bilateral hippocampal damage (Pascalis, Hunkin, Holdstock, Issac & Mayes, 2000). The transition between 12 and 18 months is earlier than the offset of infantile amnesia at 2 years, but the finding is broadly consistent with the idea of later developments in hippocampally-based memory functions than are often postulated (e.g., Nelson, 1995). However, further studies are needed to understand the bases of lack of novelty preference with changing backgrounds. Later in development, relating objects to their backgrounds will prove challenging (Sluzenski, Newcombe & Kovacs, 2006), but at this earlier age, it seems as if the objects and their backgrounds are too tightly bound together, so that change in the color of a background creates a new stimulus.

B. Delayed Non-Match to Sample

In the DNMS task, a novel object is presented, removed, and then presented again, together with a new novel object. The correct response is to select the object that differs from the one previously presented. Success on DNMS is known to depend on medial-temporal lobe structures (e.g., Malkova, Bachevalier, Webster & Mishkin, 2001). One would imagine that success on this task would appear early in life, because the required response is almost identical to the response required in the VPC—the baby simply has to reach for a novel object rather than look at a picture of a novel object. Nonetheless, success on the classic version of DNMS is not seen until 21 months of age (Diamond, 1990; Overman, Bachevalier, Turner & Peuster, 1992). Success is, however, seen earlier when the reward for a correct choice is directly attached to the selected object using Velcro on the base, rather than located in a well revealed by moving the selected object (Diamond, Churchland, Cruess & Kirkham, 1999). Further work has shown that the key element crucial for early success is the physical connectedness of the object and the reward—spatial and temporal proximity are not essential (Diamond, Lee & Hayden, 2003). From these data, the argument has been made that the hippocampus matures early, supporting memory

for objects, and that what infants and toddlers need to acquire is the ability to make the connection between the response and the reward when they are not physically connected, which may depend on another brain area: the periarculate region of prefrontal cortex (Diamond, 2006).

Unfortunately, we do not know as much as we would like about the brain bases of performance on the modified DNMS task. The classic DNMS task may require the hippocampus not so much for the memory demands of the task, which are quite slight, but to establish the relation of the object to the reward when they are not physically connected. In contrast, the modified version of the task does not require the child to make the connection between the object and the reward because they are physically connected. Thus, the modified DNMS task might require less involvement of the hippocampus than the original task. Some evidence for this idea comes from the fact that animals with hippocampal damage are known to approach discrimination learning problems in a fundamentally abnormal way (O'Keefe & Nadel, 1978). Instead of initially learning the association between a particular reward and a specific location or item, these animals associate rewards with a particular response. Thus, patients with hippocampal damage or monkeys with hippocampal ablations might succeed at the modified DNMS task, but this hypothesis has not so far been tested. It may be that the late age at transition to success on the classic DNMS task (21 months) remains diagnostic of hippocampal maturity.

C. Place Learning

Place learning is the ability to locate a position using information about its distance and direction from distal landmarks. Research on the development of place learning has been conducted both in rats and in human children. Beginning with the research on rats, studies have delineated a detailed description of the timing and sequence of acquisition, in studies mostly using the Morris water maze (Morris, 1984). In this task, a rat is placed in a circular pool of murky water and must swim to a platform hidden just under the surface of the water to escape the water, which functions as an aversive stimulus. Because nothing in the pool itself can guide their search, the rats only find the platform if they use landmarks outside of the pool, thus

demonstrating place learning. Pre-weanling rats are able to solve the water maze at 20 to 26 days (Rudy & Paylor, 1988; Rudy, Sadler-Morris & Albert, 1987; Schenk, 1985), or at a slightly younger age when pools are smaller (Carman & Mactutus, 2001) or when body temperatures are kept close to normal so that the physical act of swimming is less physiologically challenging (Brown & Whishaw, 2000). After 26 days, rats continue to improve in their ability to place learn (Brown & Kraemer, 1997; Schenk, 1985).

Maturation of the hippocampus is likely to be one of the principal mechanisms underlying development of the place learning system. We have long known that the hippocampal formation is required for success in the water maze when there are no coincident landmarks (Morris, 1983). The hippocampus of infant rats shows extensive development in the first week after birth and continues to develop for at least a few weeks after that. The cell density in the dentate gyrus of the hippocampus reaches adult levels at about 25 days and the hippocampus shows metabolic activity from around 30 days (Schenk, 1985). The developmental milestones seen with the behavioral place learning tasks correspond roughly to the developmental course of the hippocampus, providing suggestive evidence that the development of the hippocampus is involved with the development of place learning (Nadel & Zola-Morgan, 1984; Schenk & Morris, 1985).

A similar situation may obtain for humans. Human place learning is also supported by the hippocampus, based on studies involving both brain-injured and normal human adults (Bohbot et al., 1998; Holdstock et al., 2000; Iaria, Petrides, Dagher, Pike & Bohbot, 2003; Maguire et al., 1998; Maguire, Frackowiak, & Frith, 1996; Maguire, Frackowiak, & Frith, 1997), including a study using single-cell recording techniques, which allow for more precision in understanding the nature of the neural structures supporting task performance (Ekstrom, Kahana, Caplan, Fields, Isham, Newman & Fried, 2003). In children, place learning is first seen around 21 months of age (Newcombe, Huttenlocher, Drummey & Wiley, 1998). Newcombe et al. examined the development of the use of distal landmarks located at the edges of a room that contained a

centrally-located sandbox. Children ages 16-36 months observed a toy being hidden in the rectangular sandbox, moved to the opposite side, and then searched for the toy. Half the children performed this search with visible landmarks in the room and half without visible landmarks (because a circular white curtain surrounded the sandbox). Children 22 months and older performed better when the landmarks were visible, but younger children did not. In other words, children younger than 22 months did not seem to use the distance from surrounding objects to locate objects after movement; that is, they did not exhibit what has been called place learning. These results are consistent with earlier work (Bushnell, McKenzie, Lawrence, & Connell, 1995; DeLoache & Brown, 1983; Mangan, Franklin, Tignor, Bolling & Nadel, 1994).

As with rats, earlier roots of place learning may be evident in simpler situations, albeit in environments that do not require the use of distance and direction from several landmarks considered together (Clearfield, 2004; Lew, Bremner & Lefkovich, 2000; Lew et al., 2004). In addition, place learning is not complete when it is first observed at 21 months. It continues to develop well into the school years, with children showing increasing precision in their use of increasingly more distal landmarks in increasingly complex settings (Laurance, Learmonth, Nadel & Jacobs, 2003; Leplow, Lehnung, Pohl, Herzog, Ferstl & Mehdorn, 2003; Overman, Pate, Moore & Peuster, 1996; see review by Learmonth and Newcombe, in press). Nevertheless, first emergence of recognizable place learning at 21 months is a strong clue that this may be a time of important hippocampal change with implications for mnemonic functioning.

D. Other Spatial Tasks

Changes in performance on several other spatial tasks also support a developmental shift toward increased hippocampal functioning at the end of the second year of life. Prior work on children's memory for spatial location of objects using the sandbox paradigm (Huttenlocher, Newcombe & Sandberg, 1994; Newcombe et al., 1998) had examined memory for only a single object, hidden for less than a minute. To be useful, however, spatial location memory needs to allow for representing multiple locations, to allow for the learning of spatial relations among

objects, and to support recall after a substantial filled delay. Sluzenski, Newcombe and Satlow (2004) tested children from 18 to 42 months on three more complex sandbox search tasks: recall of two locations rather than just one, learning a spatial relation between two objects, and retaining the location of a single object over a filled delay. Results indicated a marked transition in the ability to perform at non-chance levels on all three tasks that occurred between 18 and 24 months, with moderate age-related improvement thereafter. Similar data have been reported by another research group: children between 18 and 24 months show a sharp increase in the ability to remember multiple locations over delays of 20 minutes and 24 hours by finding hidden objects among an array of three hiding spaces (Russell & Thompson, 2003).⁴

Each of these tasks is known to have hippocampal bases. Monkeys with hippocampal resections show impairments in remembering two locations (but not one) even after only a very brief delay, suggesting that the ability to represent multiple objects requires intact hippocampal structures (Angeli, Murray, Mishkin, 1993; Parkinson, Murray, & Mishkin, 1988). Lesions to hippocampal structures impair performance on conditional spatial discrimination tasks similar to Slunzenski et al.'s relational task, both in animals (Kimble, 1963; Marston, Everitt, & Robbins, 1993) and humans (Daum, Shugens, Channon, Polkey, & Gray, 1991; Myers, Hopkins, Kesner, Monti, & Gluck, 2000). Hippocampal lesions lead to impairment in the memory for a single location with delays as brief as 10-20 seconds when egocentric responding cannot be used to solve the task (Bohbot, et al., 1998, Long & Kesner, 1998).

E. Summary

The existing evidence, although still sparse, suggests the possibility of a general transition in hippocampal functioning toward the end of infancy, in which a capability emerges for durable and complex memory that involves contextualized coding. In the VPC work, abstracting the object away from its background may be an essential prerequisite for distinguishing episodic elements that should be encoded separately (for some purposes) and yet bound together (for others). In the DNMS work, relating an action to a separated consequence

could be considered an aspect of contextualized memory, perhaps requiring hippocampus, although an alternative is that such linkage depends on a region of prefrontal cortex. Perhaps the strongest support for an important watershed in behaviors that are hippocampally based comes from the place learning research, with support from three other lines of spatial memory development (recall of two locations, learning a spatial relation, and retaining the location of a single object over a filled delay).

Nevertheless, we must recognize that all of this work is highly inferential and future research is needed along many lines, including work that more finely distinguishes among different areas of the hippocampus and the hippocampal complex (Nemanic, Alvarado & Bachevalier, 2004). In addition, it would be interesting to gather data with infants and young children on other tasks with strongly established hippocampal substrates, such as certain kinds of classical eyeblink conditioning (Green & Woodruff-Pak, 2000).

VII. Are There Biological Bases for the Lifting of Childhood Amnesia?

During the period between 2 and 6 years, children show clear evidence of episodic memory and recall of autobiographical events. For example, they can report on distinctive events such as class field trips several weeks, and even years, after the events occurred (e.g., Hudson & Fivush, 1991), although such reports are typically heavily scaffolded by adults. In addition, as older children and adults, they will have access to memories of some of these events, although these memories will be fewer than one might predict (Rubin, 2000). Thus, this period seems much less mysterious than the first two years of life, when there is little evidence of episodic memory and from which events are rarely if ever recallable in adult life. Nevertheless, there are questions about episodic functioning in this period. In this section, we review evidence for discontinuities in this period, and their possible biological bases, in two areas: source memory and binding. These abilities are centrally important functions that are necessary for achieving episodic recall that interlinks various aspects of an event to create a memory of a specific experience taking place at a certain time and place, and enriched with perceptual and emotional

detail. As might be expected given this description and the facts about offset of childhood amnesia already discussed, they are not robustly present in children until the age of 6 years or so.

A. Source Memory

As already mentioned, patients with frontal lobe lesions appear to suffer from source amnesia (Janowsky Shimamura, & Squire, 1989; Schacter, Harbluk & McLachlan, 1984; Shimamura & Squire, 1987). When taught new facts (which they retain quite well), they are far more likely than controls to make erroneous source attributions. These errors go beyond simply confusing plausible sources such as two experimenters, each of whom taught certain facts. Instead, frontal patients also make extra-experimental errors, in which they claim to have read the facts in *TV Guide*, known them from childhood, or so on. Similar problems with source errors have been found in elderly individuals, who often suffer from subtle difficulties with frontal function (Craik, Morris, Morris & Loewen, 1990; McIntyre & Craik, 1987). These data suggest that extra-experimental errors in source memory paradigms may serve as a marker for frontal functioning. Such errors are directly relevant to the growth of episodic memory, because access to details of who was present at events, as well as where and when events happened and perceptual detail regarding them, are exactly what we mean by episodic and autobiographical memory.

The ability to encode, retain and recall source is not readily apparent at the age of 3 years. The developmental course of the appearance of this ability is charted in various paradigms. Some studies of source memory in children, conducted as part of research on theory of mind, have shown marked improvement between 3 and 4 years (Gopnik & Graf, 1988; Perner & Ruffman, 1995; Taylor, Esbensen & Bennett, 1994; Wimmer, Hogrefe & Perner, 1988). Investigators in the theory of mind tradition have typically asked children how they know something (e.g., How do you know that the child will search for the smarties in the pencil box?), and the jump in performance at 4 years is typical of the age-related changes found in other theory of mind tasks, such as questions about the appearance versus the real nature of objects that look like something different from what they are (e.g., a sponge that looks like a rock). If source memory were truly

mature by 4 years, however, changes in source memory would fit poorly with the slower lifting of childhood amnesia, which takes a good deal longer. These studies may, however, have found relatively early success at source tasks because they offered children a forced choice among plausible alternatives, and thus, did not allow for the possibility of extra-experimental errors. In addition, they used very short delays.

To assess developmental change in extra-experimental errors, Drummey and Newcombe (2002) devised a child-appropriate analogue to the fact-teaching paradigm used by Schacter et al. (1984). Either an experimenter or a puppet taught 4-, 6- and 8-year-old children novel (but true) facts such as that the Nile is the longest river in the world. One week later, when children remembered a fact, they were asked how they knew this information. In these circumstances, 4-year-olds made an astonishing number of extra-experimental errors (59%) whereas 6- and 8-year-olds committed such errors at relatively low levels and did not differ from each other (13% and 19% respectively; see Figure 4). Because extra-experimental errors are signatures of frontal lobe deficits, the results suggest dramatic change between the ages of 4 to 6 years in the ability of that cortical area to support mnemonic functioning.

Additionally, Drummey and Newcombe (2002) looked at correlations between source memory and behavioral measures of frontal functioning (category generation, a modified Wisconsin Card Sort, and a modified Stroop task). Higher scores on the card sort task predicted fewer extra-experimental errors among a group of 4-year-olds not showing ceiling levels of such errors, even after controlling for a measure of general intelligence. However, the other two putative frontal measures did not show such correlations. The correlational approach is simply not a very powerful tool for the examination of biological bases of memory. Modern statistical analyses such as SEM or HLM may provide a better approach for understanding the relationships between test and task performance.

Another way to examine source memory is suggested by the source monitoring framework developed by Johnson et al. (1993). People must often distinguish between whether

they really did something or only imagined doing it, a judgment that has been termed *reality monitoring*. The data on source memory in preschool children are mixed. On the one hand, by 4 years of age, performance in source monitoring tasks is already at above chance levels in some situations (Lindsay, Johnson & Kwon, 1991; Welch-Ross, 1995). On the other hand, with more difficult tasks, such as distinguishing between internally-generated stimuli (thoughts versus actions) or making distinctions after substantial delays, developmental improvement continues into the school years (Parker, 1995; Sussman, 2001).

Sluzenski, Newcombe and Ottinger (2004) noted that much of the previous work on reality monitoring has involved isolated actions or short sequences rather than extended naturalistic events. This fact limits its implications for the development of autobiographical memory, as does the fact that reality monitoring has often been assessed after brief intervals. Accordingly, Sluzenski et al. studied 4-, 6- and 8-year-olds who were engaged in four events, such as making a greeting card or unpacking a picnic basket. Two events were enacted using real objects while the other two events were imagined, guided by a taped description. When reality monitoring judgments were elicited, especially after a week's delay, 4-year-olds had more trouble than older children distinguishing between real and imagined events. This difficulty appeared despite the fact that independent assessment of the characteristics of their memories (i.e., with free recall, cued recall and recognition) showed that they had the inferential bases for a distinction (e.g., they retained more perceptual detail regarding really-experienced events). Younger children's problems with reality monitoring seemed to derive from two sources: first, in some cases, their memories were at levels low enough that they provided unreliable guides for judgment, and second, strategically, they may not realize that differences in the characteristics of their memories allow them to decide whether or not something really happened.

The experiments by Sluzenski et al. (2004) are intriguing for consideration of autobiographical memory, in part because after delays of a week, children often erred in reality monitoring by saying that an experienced effect was imagined rather than vice versa. In studies

with short delays, the opposite error is usually more frequent. Believing that something real was imagined seems, over the really long run of years, to be likely to result in a paucity of autobiographical memories. This pattern of data may represent an instance of attributing memory characteristics poorly. That is, perhaps children failed to appreciate the effect of delay on the quality of their memories. When events happened recently, resulting in relatively strong memory traces, they were assumed to be experienced whereas, once the memory had weakened, children assumed the event must have been imagined. By adulthood, one is better able to account for differences in memory strength (e.g., Hoffman, 1997).

In Sluzenski et al.'s (2004) experiments, the only assessments of linkage to frontal function were again correlational, but that strategy did achieve some positive results. Looking at the data across experiments revealed several noteworthy relations between episodic memory for events and fluency of category generation as a measure of frontal functioning, even after controlling for age and scaled vocabulary scores. The clearest relations were between category fluency and free recall of the events; free recall may be a purer measure of episodic memory than cued recall or recognition, where associative strategies and responses to general familiarity likely come into play.

In summary, there is evidence that 4-year-olds show important deficiencies, relative to school-aged children, in the ability to avoid extra-experimental errors on source tasks and in the ability to distinguish between events they really experienced and those they only imagined. These abilities are relevant to the problem of childhood amnesia from a functional point of view, in that a memory will not seem convincingly autobiographical if its context and, most important, its veridicality, are not retained. The findings also buttress the argument that changes are related to biological changes in prefrontal functioning, most strikingly because extra-experimental errors are a hallmark of adults with damage to that area, but also, more weakly, based on some correlational evidence.

B. Binding

In many ways, the essence of episodic memory is the binding together of relations among co-occurring stimuli (Johnson & Chalfonte, 1994; Schacter, Norman, & Koustaal 1998). It is possible to remember an aspect of a situation (e.g., “I have met Elfrida Oliphant”) without remembering Elfrida’s face, where or when you met her, what she said to you and so on. These different kinds of information need to be inter-related, probably independently; put another way, an event is not a holistic entity but instead the assemblage of a net of pair-wise associations (Trinkler, King, Spiers & Burgess, 2006). In fact, memory for isolated aspects of what were originally experienced as events is essentially what we mean by semantic memory: knowing Elfrida is a fact about oneself rather than an autobiographical memory. Given this analysis, it is surprising that relatively little attention has been paid in developmental research to the development of binding, especially since a good deal of work with the elderly suggests the interdependence of binding deficits with declines in source monitoring and episodic memory (Castel & Craik, 2003; Chalfonte & Johnson, 1996; Chee, et al., 2006; Li, Naveh-Benjamin & Lindenberger, 2005; Mitchell, Johnson, Raye & D’Esposito, 2000; Mitchell, Johnson, Raye, Mather & D’Esposito, 2000).

Sluzenski, Newcombe and Kovacs (2006) aimed to create a task to study the early development of binding that would be motivating for young children, and easy for them to understand. In particular, they sought to develop engaging stimuli, and settled on a task in which pictures of animals were shown against complex backgrounds, as shown in Figure 5. These backgrounds were not the animals’ natural habitats, to avoid confounding age with knowledge of animals and where they usually live. Instructions drew children’s attention to the backgrounds as well as the animal, and assured that they understood the kinds of recognition judgments we asked them to make.

When tested in the same session as that in which acquisition occurred, recognition for animals alone and for backgrounds alone did not differ between 4- and 6-year-olds or between 6-year-olds and adults. Such equivalence is necessary to evaluating the possibility of age

differences in binding, because if either kind of information is not encoded well, clearly binding would not be expected. Against this baseline of age-equivalent memory for component information, it was interesting that 6-year-olds were more likely than 4-year-olds to bind that information together, remembering not just that they saw a lion, or not just that they saw a certain street scene, but that the lion was on that street. By contrast, 6-year-olds and adults did not differ.

In a second experiment designed to assess developmental improvements in binding (Kovacs, Newcombe & Hansell, 2005), the stimuli were simpler, and more similar to those used in prior studies with elderly populations. Participants looked at line drawings of simple objects such as umbrellas done in colored ink. They later decided whether they had seen a black-and-white umbrella (item memory alone), a certain shade of green before (color memory alone), and a green umbrella (assessment of binding). Item and color memory were both accurate but not ceiling levels across age, indicating that all age groups had access to the required featural information. Nevertheless, the same developmental pattern in binding emerged as that seen by Sluzenski et al.: differences between 4- and 6-year-olds but no differences between 6-year-olds and adults. Thus, it appears that between the ages of 4 and 6 years, children's performance in learning relations among different aspects of a stimulus improves significantly.

C. Summary

In this section, we have reviewed evidence of marked changes between the ages of 4 and 6 years in the ability to retain bound information that supports episodic recall and that allows for the accurate reporting or reconstruction of source information, regarding both who said something and also whether or not an event really happened. These changes are interdependent, as was most clearly seen in the Sluzenski et al. (2004) study, where the ability to judge whether something really happened depended in part on levels of memory for the component aspects of the episode from which a judgment could be made, but that younger children also lacked the ability to use the characteristics of their memory to make judgments. The overall thrust of this work so far is simply to support the proposition that age changes in episodic and autobiographical

memory during the preschool years are intertwined with these more basic memory processes in terms of overlapping developmental curves and (sometimes) correlational relations (although those are methodologically more difficult to assess). In addition, evidence tentatively links these behavioral changes to development in functioning of prefrontal cortex, most strikingly in the extra-experimental error data of Drummey and Newcombe (1995). However, hippocampal functioning may also be relevant to development of episodic memory in preschool children, especially in the case of feature binding, because binding is known to depend on hippocampus.

VIII. Alternative Conceptualizations of the Development of Episodic Memory

In this chapter, we have advanced the case for distinctive periods in the development of autobiographical recall and for distinctive biological reasons for the phenomena of infantile and childhood amnesia. The research basis for these assertions in the work of developmental psychologists is relatively sparse, but the hypotheses gain in weight from consideration of related work in adult memory, memory and aging, comparative cognition, and the biological substrates of memory processes. Nevertheless, although the ideas are plausible, we recognize that this conceptualization differs from many other contemporary views of memory development, which tend to emphasize early competence, developmental continuity, and social reasons for change (e.g., Bauer, 2006a,b; Howe & Courage, 1993, 1997; Nelson & Fivush, 2004). In this section, we concentrate on ways in which our framework differs from other approaches to early memory development. Our overall message is that many (although not all) of the differences among approaches are more apparent than real, and that the various traditions of inquiry are actually providing complementary information.

A. What is the Role of Other Lines of Development in the Development of Episodic Memory?

Young children's recall of events is related to their understanding of how to structure a narrative, to their developing understanding of social situations and acquisition of scripts for events, and to the cultural demands placed on them for telling stories about their experience (see Nelson & Fivush, 2004, for review). This general style of theorizing encompasses many specific

lines of inquiry including, for example, studies showing that parental interaction shapes children's memories through focusing attention on the past and scaffolding accounts of past events (e.g., Mullen, 1994; Haden, Ornstein, Eckerman, Didow, 2001; Reese, Haden & Fivush, 1993), and that discussion about past events is related to event memory (e.g., McGuigan & Salmon, 2004) and further related to the development of self concept ("an autobiographical self", e.g., Bird & Reese, 2006). Other studies show fascinating cultural variation in the development of autobiographical memory (e.g., Wang, 2006; Wang, Hutt, Kulkofsky, McDermott & Wei, 2006). For example, Chinese children remember less about past events than their Euro-American peers, a difference that turns out to be mediated by their lower levels of knowledge about emotional situations.

In addition to the substantial amount of attention that has been devoted to social interaction and cultural variation in autobiographical memory development, other research has focused on contributions of cognitive and language development to personal event memory. In terms of cognitive development, Howe and Courage (1993, 1997) have linked the end of infantile amnesia at around 2 years to the acquisition of a concept of self. In addition, research has shown that children are unlikely to retain memories for events that they poorly understood at the time they occurred, such as a fire alarm evacuation at a preschool (Pillemer, Picariello & Pruett, 1994). In terms of language development, research has shown that autobiographical memories are more easily retrieved when queried in the language used at the time of acquisition (e.g., Marian & Neisser, 2000), which have supported a correlated idea that perhaps language is simply too poorly developed in early childhood to allow the encoding and rehearsal necessary for accurate explicit memory. In addition, children apparently cannot easily "translate" their memories from a preverbal format to a linguistic format as language development proceeds (Simcock & Hayne, 2002). These explanations of failures to retain autobiographical memories all center on the idea that improvements in socioemotional understanding, cognitive abilities or language will lead to improvements in memory performance.

All of these factors are likely important in the mix of changes resulting in the emergence of mature levels of autobiographical recall. The question is whether any one change, or even the entire set of proposed changes, can alone account for the phenomena. We think social, cognitive and language changes external to the memory system itself have difficulty accounting for some aspects of memory development. For example, consider what we know about face recognition. As we have seen, recognition memory for faces of children known during preschool survives only at fragile levels in later childhood (Newcombe & Fox, 1994; Lie & Newcombe, 1999). However, language development seems quite unsuited to accounting for this phenomenon, because faces are not linguistically encoded (Hancock, Bruce & Burton, 2000). Nor can it be said that young children are not interested in faces or fail to understand their significance, because we know that faces are vitally important even to newborns (Morton & Johnson, 1991). It is likely that infants' and preschoolers' attention to faces and motivation to remember them are at ceiling levels. Thus, without considering the development of memory systems themselves, it is hard to explain why we have such difficulty remembering the faces of people with whom we interacted extensively in the first five years of life.

Furthermore, all of the factors described here are likely to contribute individually and in interaction with other factors. One example of this phenomenon comes from another study of source monitoring done in our lab (Kovacs & Newcombe, 2006). Adults' source judgments are more accurate when they focus on speakers' emotions rather than focusing on their own emotions (Johnson, Nolde, & DeLeonardis, 1996), perhaps because thinking about the speaker encourages processing of the perceptual characteristics of that person, as well as binding of that perceptual information to the content of what is being said. But a great deal of developmental work suggests that younger children are less likely to spontaneously adopt the perspective of another person than older children, so we wondered to what extent the age-related differences in source memory that we had observed in Sluzenski et al. (2004) were due to changes in encoding focus. In three experiments, we found that, when 4- and 5-year-olds heard an audiotape (or saw a videotape) of

two similar (or dissimilar) speakers, 5-year-olds were more likely to show better source memory when asked to adopt another person's focus, although 4-year-olds did show a benefit under supportive conditions in which the sources were made very distinctive, the task instructions were thoroughly explained, and the information was presented in several formats. Overall, the data suggest that the benefit for source memory of focusing on another person develops over the preschool years with easy tasks showing sensitivity before more difficult source judgments. Of course, in life outside the laboratory, we are not prompted to think about the emotions and thoughts of others. Examination of the development of spontaneous focus on others might well show substantial contributions of parental interaction and culture to this kind of thought, which in turn supports source encoding, which in turn supports autobiographical recall.

Multi-directional webs of causation should not exclude the analysis of the brain substrates of memory functions. Experience is often vital in stimulating brain development (Greenough, Black & Wallace, 1987; Shonkoff & Phillips, 2000). Thus, hippocampal and prefrontal "maturation" is likely a misnomer if maturation is taken to imply a passive, autonomous process that goes on at a standard developmental pace irrespective of what children are doing and being asked to do. Instead, demands to remember events and support in evoking recall may well lead to accelerated development of the frontal-hippocampal circuitry that enables this function. Thus, social factors such as the push from some adults for children to be able to recount events in their day may act on memory by driving brain development, rather than simply working at a functional level.

B. Qualitative Versus Quantitative Change in the Development of Episodic Memory

Debates about whether developmental change is qualitative or quantitative in nature are long standing, typically highlighted in introductory textbooks as one of three or four key questions about human development. However, this dichotomy is more apparent than real. Smith and Thelen (1993) talk about how the "view from above" makes qualitative differences seem

salient, while the “view from below” emphasizes ongoing, fine-grained, quantitative change. Elman, Bates, Johnson, Karmiloff-Smith, Parisi and Plunkett (1996) discuss in detail how quantitative change at one level of analysis can lead to emergent qualitative change, a familiar example being quantitative changes in temperature that span freezing or boiling points. Thus, claims that early episodic memory is fundamentally similar to mature memory, differing only in quantitative aspects of encoding efficiency or storage duration, seem to miss the discontinuity at another level of analysis, namely in whether events will later be retrievable at all (for infantile amnesia), or at adult levels (for childhood amnesia) (see Courage & Howe, 2004, for recent discussion of this position). That is, if encoding is insufficient to allow for retrieval of an event in later life, a change that is quantitative at one level of analysis has created an effect (inability to remember the first two years of life) that is qualitative at another level of analysis.

A separable issue is whether any hypothesized qualitative change occurs abruptly or has a single cause. Such changes have been claimed in the literature on autobiographical memory development: For example, Howe and Courage’s (1993, 1997) propose that self recognition brings the period of infantile amnesia to a close. The answer to the abruptness question is clearly that change is almost always gradual; in this chapter, even when we have reviewed some transitions that are abrupt within a single study, as in Newcombe et al.’s (1998) data on place learning or Drummey and Newcombe’s (2002) findings on extra-experimental source errors, we see also that, with suitable task changes, there are earlier precursors of transition and later refinements to a competence, often taking years. This fact makes analysis of congruencies in developmental curves challenging, although not impossible. The answer to the second question has been previewed previously in our discussion of multiple causation (see also Howe, Courage & Edison, 2003). Various factors come together in complex ways to create change and analysis of causation is challenging given the likelihood of feedback loops. To return to the hypothesis about self recognition emerging episodic memory may well support cognitive recognition of the self, as well as the opposite. In addition, both may depend on common biological substrates in prefrontal

cortex (Keenan et al., 2000), and (lest we think we have reached bedrock by invoking biology), environmental press may in part create change in the nervous system.

IX. Conclusion

People are often fascinated by memories for their earliest years, believing that they may hold the key to personal insights and opportunities for emotional growth. Nevertheless, the available evidence indicates that such memories are virtually non-existent in the first two years of life, and, although increasing over the next four or so years, are very often patchy and fog-covered until the beginnings of elementary school. This evidence sits oddly with recent data on the strength of memory in infancy and early childhood, leading to much excitement about a focused search for explanations of the mysteries involved in the contrast. The accumulating data suggest that explanations will be multi-factorial rather than unitary. In this chapter, we have endeavored to make the case that an important aspect of the explanation involves research that makes full use of current distinctions regarding the architecture of the human memory system and its brain bases, and that uses an array of techniques including not only developmental work but research with brain-damaged patients, non-human animals, and human adults studied both behaviorally and with imaging techniques. We have also argued that there are urgent unanswered questions, concerning topics such as whether memory in the first two years is primarily semantic. Given the pace of current progress, we are optimistic that answers to these questions, and perhaps even resolution to the mystery of early amnesia, are within our grasp.

Footnotes

¹ Bruce et al. (2000) suggested that the mean of the two ages, which was 4.64 years in their study, provides an estimate of the end of childhood amnesia because at that age the amount of recallable memories exceeds the amount of events that are known from others. In fact, based on estimated ages to which memory fragments (as opposed to more extended events) are dated, Bruce et al. (2005) argue for 3 years as the age of offset of childhood amnesia. We believe, however, that these estimates fail to distinguish infantile amnesia from childhood amnesia. The earliest age at which anything can be verifiably remembered is different from the age at which memory begins to obey the laws of normal forgetting.

² However, see Mandler (2004) for arguments that the implicit-explicit distinction is not exactly the same as the procedural-declarative distinction.

³ Adult priming was at surprisingly low levels, a finding for which we have no real explanation.

⁴ Although Moore and Meltzoff (2004) found accurate performance by 14-month-olds after a 24-hour delay, their hiding situation involved very distinctive locations and a very highly marked hiding procedure, and they did not examine age-related change.

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Table 1

What Is the Relation of Episodic Memory to Autobiographical Memory?

	Semantic	Episodic
Impersonal		
Self-Related	Paris is the capital of France.	“Tree” was on the free recall list.
	That’s a picture of Al Gore.	A picture of that face was in this experiment.
	I was born in Toronto.	My picnic was last Sunday.
	That’s a picture of my mother.	That’s a picture of the guy I met at Joe’s party.

Figure 1: The distribution of memories as a function of age, which demonstrates the rapid increase in autobiographical memories during very early childhood and reaching maturation around 7 years of age (adapted from Rubin, 2000).

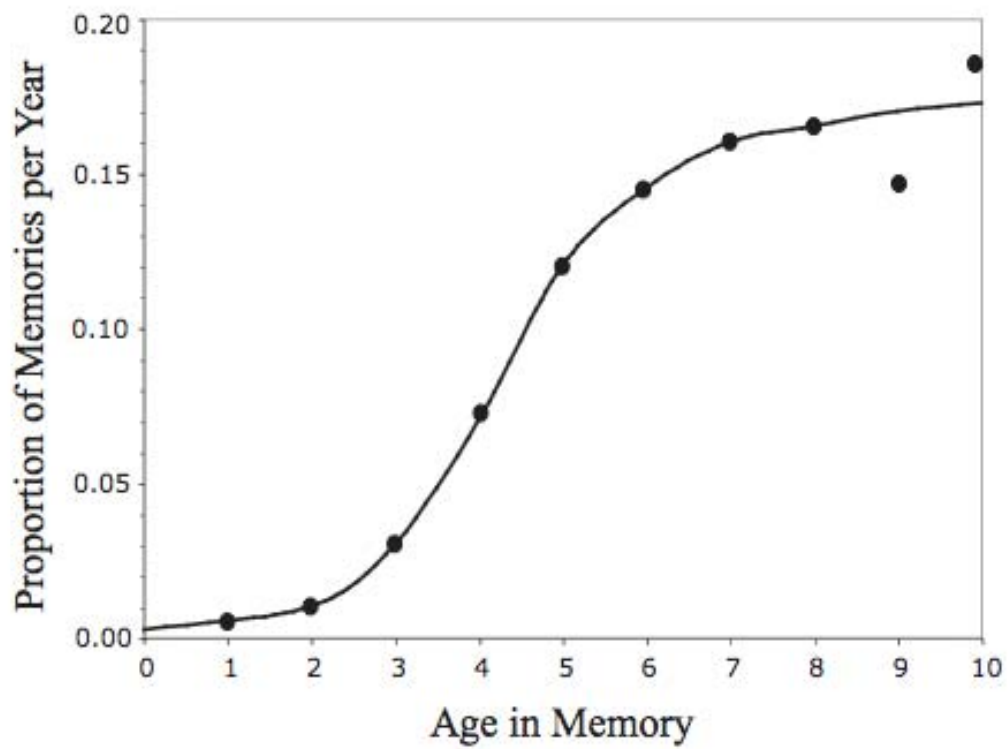


Figure 2: A contemporary depiction of human memory illustrating the distinctions within declarative and nondeclarative systems

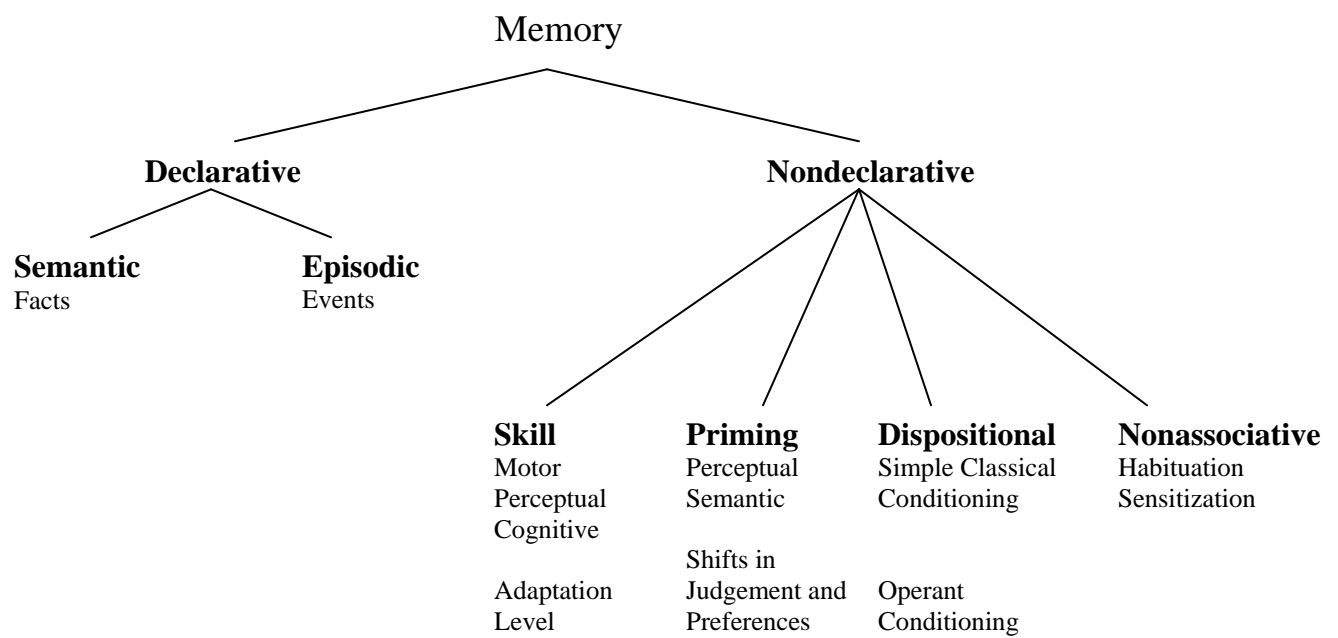


Figure 3: Equivalent implicit memory performance (measured by galvanic skin responses) despite differences in explicit (recognition memory) performance. From Drummey & Newcombe (1995).

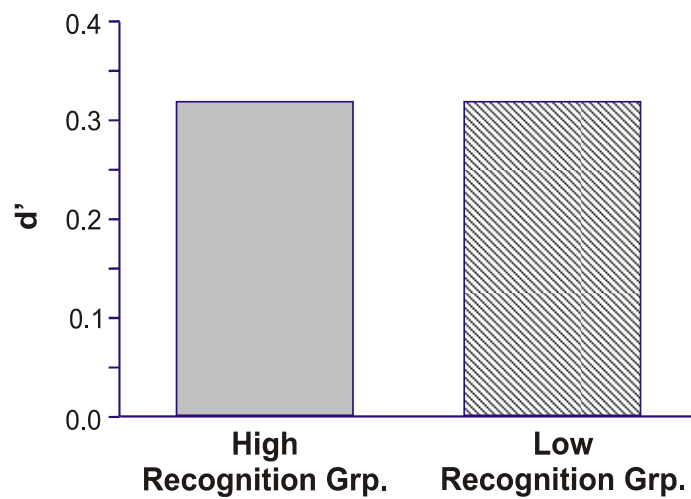


Figure 4: Source attributions (correct, extra-experimental, and intra-experimental) after a one week delay for new facts learned by 4-, 6-, and 8-year-old children. From Sluzenski et al. (2004).



Figure 5: Example of the complex stimuli used to test memory binding in young children. From Sluzenski et al. (2006).

