
Building Blocks of Recollection

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WHAT IS RECOLLECTION?

In adults, the term *recollection* refers to the cognitive process that allows individuals to retrieve information about distinct features associated with an event (Yonelinas, 2002). It is through recollection that individuals are able to recover “qualitative” information, such as the temporal or spatial context surrounding an event or the novel associations between different components of an event. In everyday memory tasks, recollection is apparent when individuals are able to recall not only that a specific person looks familiar, but also their name, the place they first met them, and the last time they had an encounter with them (e.g., “That’s Simona. I met her in 2005 at UC Davis. I saw her at a conference in Berkeley, California last summer.”). In laboratory examinations of memory, recollection is apparent when participants judge that they specifically “remember” items from a study list versus that they simply “know” the items were on the list (e.g., “I remember the word *pizza* was on the list because the word before it was *eggplant*. I was hungry and thought an eggplant-pizza would be a very interesting meal.”)

In adults, recollection has been examined from experimental, computational modeling, neuropsychological, neuroimaging, and individual difference perspectives. Evidence from these studies has specified the nature of recollection, its role in the retrieval of specific contextual information, and its neural substrates (Yonelinas, 2002, Chapter 1 this volume). Taken together, these findings provide ample support for the notion that memory in adults is subserved by multiple separable processes, one of which is recollection.

WHY IS THE DEVELOPMENT OF RECOLLECTION IMPORTANT?

One relatively unexplored aspect of recollection is its development. Examination of how recollection is assembled and the factors that influence this process is both

necessary and beneficial. First, knowledge regarding the development of recollection will contribute to a more complete understanding of the structure, function, and organization of recollection in adults. Similar to understanding any complex structure, such as a skyscraper, one gains a better understanding of the final formation by observing how it is constructed over time (e.g., Elman et al., 1996). Such complete understanding of psychological phenomena is viewed as a fundamental endeavor in science.

Second, knowledge regarding the development of recollection may also improve our current understanding of "failures" or "disorders" in memory, including information on how and when they arise, why they exist, and possible avenues for intervention or enhancement. For example, increased understanding of memory development in general has helped explain why children perform as well as adults on some memory tasks and why they fall short on others (e.g., Chi, 1978; Schneider, 1993). This information is not only descriptive but also practical as it can be applied in clinical, educational, and classroom settings to improve memory performance.

Finally, from a phenomenological perspective, recollection provides richness and detail to our memories for the past. These details become especially significant when one considers how they contribute to our autobiographies or memories for personally relevant events in our own lives (e.g., graduations, weddings, vacations). Perhaps because of this importance at a personal level, for almost a century (Freud, 1905/1953), researchers have been struck by the lack of detail included in our memories from early childhood. Empirical research has shown that this phenomenon is not simply due to forgetting because of the passage of time, but is rather a ubiquitous form of amnesia referred to as *infantile* or *childhood amnesia* (for recent reviews see Bauer, 2007b, 2008). Even in light of this persistent interest, a variety of questions remain, including: Why do adults show so few, if any, memories from infancy and early childhood? Because recollection underlies our ability to retrieve information about events and their distinct features, examining its development may begin to shed light on phenomena such as infantile or childhood amnesia.

One logical place to begin examining the development of recollection is by asking *when* recollection, or the "building blocks" of recollection, can be detected during ontogeny. The goal of this chapter is to address this question, by reviewing findings from a variety of paradigms in school-aged children, preschoolers, toddlers, and infants. By starting with research in older children and working backward in developmental time, it is hoped that a greater connection can be made between what is currently known about recollection in adults and the roots of this ability. Paradigms used to examine recollection (and memory in general) change drastically over the lifespan. This is mostly due to the large differences in verbal, motor, and attentional capabilities of participants at various ages. By progressively examining younger age groups, it is hoped that the rationale and justification for modifications to traditional adult recollection paradigms will become more readily apparent. Finally, such sequential description may also contribute to increased understanding of what changes in recollection from infancy to adulthood.

Overall, the data reviewed in this chapter suggest that the roots of recollection can be identified in all age groups. However, these abilities are rudimentary and fragile, especially during the first year of life and undergo substantial developmental change as children transition from infancy, through childhood, and into adulthood. Part of the challenge for future investigations will be to identify the mechanisms underlying this change and the factors that influence this process. Comments on this challenge and particular approaches that may prove especially useful in this endeavor are highlighted throughout.

EVIDENCE FOR RECOLLECTION IN SCHOOL-AGED CHILDREN

Over the last decade, several studies have examined recollection in school-aged children. Typically, these investigations have borrowed paradigms from the adult literature (e.g., the remember/know and signal detection procedures) to isolate the process subserving retrieval of "qualitative" information (i.e., temporal or spatial context surrounding an event or the novel associations between different components of an event). In general, these memory tasks include the administration of a study list followed by a test phase in which children are required to: (a) make a memory judgment and (b) verbally reflect on that response and/or provide subjective ratings of confidence regarding their response (Anooshian, 1999; Billingsley, Smith, & McAndrew, 2002; Brainerd, Reyna, & Howe, 2009; Ghetti & Angelini, 2008; Holliday, 2003; Piolino et al., 2007). In one of the earliest studies, Billingsley and colleagues (2002) used the "remember/know paradigm" (Tulving, 1985) to examine recollection in a group of 8- to 19-year-old participants. Similar to studies in adults, children were first required to remember a series of pictures and words. At test, they were asked to recall if specific stimuli had been on the previous study lists. For each item that children identified as being from the study list, they were also asked to indicate whether they *remembered* the item (i.e., had a specific memory of it, such as memory for the other words with which it was paired, how it appeared on the screen, or another specific detail about the encounter with the item) or *knew* the item was on the study list (i.e., knew they had encountered it without having a specific or detailed memory of the experience). Results indicated all participants were able to complete the task and make distinctions between remembering and knowing. Although know responses were equivalent between age groups, remember responses increased with age (for both the picture and word tasks). These findings suggested that although recollection can be detected in school-aged children, the development of this process continues at least through the adolescent years.

One limitation of this investigation was that no direct evidence was provided indicating that 8-year-olds used the remember/know options in the same manner as 12-year-olds and adults. To address this issue, Ghetti and Angelini (2008) recently employed the dual-process signal detection model commonly used in adult research (Yonelinas, 1994) and examined recollection in 6-, 8-, 10-, 14-, and 18-year-old participants. In their study, children were asked to remember colored line drawings and indicate at test whether or not they had seen the drawing during

study and provide a confidence rating for each judgment (i.e., very sure, kind of sure, not sure). Receiver operating curves were obtained by combining the memory and confidence responses (i.e., plotting hits in relation to false alarms as confidence changed). Similar to the study by Billingsley and colleagues (2002), results revealed evidence of recollection in all age groups. Recollection also showed continued development from childhood (6 to 8 years) into early adolescence (10 years and up), whereas familiarity showed no development over this time (once processing time was equated; Ghetti & Angelini, 2008).

Overall, studies in school-aged children strongly suggest that recollective processes can be detected using adult paradigms, although continued development occurs at least until the adolescent years. What remains unclear is whether this development is due to changes in recollection per se or in other cognitive abilities required by these paradigms (e.g., the ability to successfully monitor one's memory performance). In an attempt to address this question, Brainerd and colleagues (2009) recently sought to examine whether evidence for recollection could be obtained in school-aged children using data from paradigms that were cognitively less demanding (i.e., ones that did not require subjective judgments regarding memory or confidence). If changes in recollection are observed under these conditions, it can more confidently be concluded that recollective processes are developing, as opposed to cognitive abilities associated with demand characteristics. Toward this end, Brainerd and colleagues (2009) used data from list recall paradigms (e.g., paired-associates, recall, free recall, or cued recall conditions) that present similar types of stimuli as the adult memory paradigms (e.g., words or pictures that must be remembered) but do not require performance monitoring (e.g., confidence ratings for each memory judgment). They applied a computational modeling approach to a large sample of data from children (7 to 8 years) and young adolescents (11 to 12 years) in order to examine whether recollection-type processes (i.e., those that directly access memory traces and provide vivid restoration of realistic details that are sensitive and labile) could be identified. Indeed, their results showed evidence that recollection, familiarity, and reconstruction were all detectable in childhood, even under conditions with a low cognitive burden in terms of performance monitoring, and that substantial developmental change occurred between childhood and young adulthood, again suggesting the prolonged development of recollection (see Brainerd et al., 2009, for elaboration).

Neural Bases of Recollection in School-aged Children

The neural bases of recollection have been identified in adults using both functional magnetic resonance imaging (fMRI) and event-related potentials (ERPs). Functional MRI provides information about what spatial regions in the brain may be contributing to these processes, whereas ERPs provide information regarding the timing of these processes. Because the brain undergoes considerable developmental change throughout childhood and adolescence (e.g., Giedd et al., 1999; Giedd et al., 1996), it is unclear whether the same circuitry that is engaged when

adults complete tasks requiring recollective processing also underlies recollection in school-aged children. A few studies have begun to examine this issue (see Thomas & Jorgenson, Chapter 9 this volume).

FMRI

Functional MRI examines changes in regional blood flow that occur in response to a stimulus or set of stimuli. fMRI studies in adults have revealed changes in blood flow in regions of the medial temporal lobe (MTL) and prefrontal cortex (PFC) during tasks that require recollection (Diana & Ranganath, Chapter 7 this volume; Eichenbaum, Yonelinas, & Ranganath, 2007; Ranganath et al., 2004; Yonelinas, 2002; Yonelinas et al., 2002; cf. Squire, Wixted, & Clark, 2007). In particular, recollection has been shown to involve the hippocampus, a structure located deep in the MTL that is characterized by a protracted developmental course (see "Potential mechanisms of change" section for elaboration), whereas other memory processes (e.g., familiarity) do not (Ranganath et al., 2004). These findings, coupled with data from patients with brain damage to these regions, have been taken to suggest that a relatively specific MTL-PFC circuit underlies the encoding and retrieval of distinct features associated with the context of the event (i.e., recollection).

In one of the first developmental studies, Ofen and colleagues (2007) investigated which brain regions were involved in the formation of memories in a sample of 49 children and adults (ages 8 to 24). Individuals viewed pictures of scenes during fMRI scanning and made judgments as to whether they were indoor or outdoor scenes. Upon completion of scanning, a remember/know paradigm was used to evaluate recognition memory. Results revealed that both MTL and PFC were active during the encoding phase of the memory task (see also Ghetti, DeMaster, Yonelinas, & Bunge, 2010; Menon, Boyett-Anderson, & Reiss, 2005; Thomas & Jorgenson, Chapter 9 this volume). Consistent with reports in adults, activation in these regions was greater for scenes that were subsequently remembered than for scenes that were forgotten. Moreover, the extent to which these regions were recruited was associated with recollection (i.e., remember) responses as opposed to familiarity (i.e., know) responses. These findings suggest that, in school-aged children, the circuitry engaged during encoding memory tasks involving recollective processes may be similar to that in adults (Thomas & Jorgenson, Chapter 9 this volume).

Age-related changes in the extent of activation of these regions were also reported. For instance, Ofen and colleagues (2007) reported increases with age in specific PFC, but not MTL, regions during encoding and that these changes were correlated with developmental gains in recollection. In contrast, Ghetti and colleagues (Ghetti, DeMaster, et al., 2010) recently reported age-related changes in activation profiles of MTL structures (both hippocampus and posterior parahippocampal gyrus), suggesting that these regions become more selective for recollection processes during development, regardless of behavioral performance. Finally, Menon, Boyett-Anderson, and Reiss (2005) reported both changes (i.e., decreases) in MTL activation with age (regardless of performance) as well as

increases in effective connectivity between MTL and left, dorsolateral PFC. Thus, although a similar circuit may be involved during recollection in school-aged children, considerable development continues within and between these regions throughout the adolescent years (Thomas & Jorgenson, Chapter 9 this volume).

ERPs

ERPs represent the activity of large populations of neurons that have been synchronously activated in response to a discrete stimulus. When responses elicited by a certain class of stimuli are averaged together (e.g., all responses to novel items versus responses to previously learned items), differences in the spatiotemporal properties of the resulting waveforms allow for the inference of differences in neural processing related to cognition. To date, adult ERP studies have used a wide variety of tasks to examine recollection, ranging from the remember/know paradigm to paradigms that explicitly ask participants to recollect specific details of the study context (e.g., the original color of the stimulus, or when it occurred within a study session). Regardless of the paradigm used, results from these investigations suggest that recollection is associated with a distinct spatiotemporal topography characterized by distributed, positive-going activity that occurs late in the waveform and is maximal over left parietal regions (Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Friedman & Johnson, 2000; Diana & Ranganath, Chapter 7 this volume; Rugg & Yonelinas, 2003). Thus far, ERP investigations in school-aged children have largely used the latter type of paradigm, that examines how retrieval of specific details relates to the study context (Cycowicz, Friedman, & Duff, 2003; Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; Friedman, Chapter 10 this volume; Friedman, de Chastelaine, Nessler, & Malcolm, 2010).

For example, Cycowicz and colleagues used ERPs to examine memory for items and their context in 10- and 12-year-old children and adults (Cycowicz et al., 2003). During the task, participants viewed line drawings in either red or green ink. ERPs were collected during memory retrieval when individuals made recognition memory judgments about individual drawings (drawn in black ink) and the original color in which they were presented. Results indicated that all age groups showed similar ERP responses. However, ERPs generated when subjects retrieved information about the contextual details (i.e., presumably reflecting recollection) showed age-related changes associated with improvements in memory performance. These results suggest that although school-aged children are able to recollect contextual details, and this process generates an ERP response similar to that observed in adults, this ability and its ERP correlate shows prolonged development during late childhood/adolescence. These authors suggest that this continued development is primarily due to changes in PFC, which they argue contribute to the successful postretrieval monitoring of source information (Cycowicz et al., 2003).

Czernochowski and colleagues (2005) also used ERPs to examine memory for items and their context (spoken words vs. photos, red vs. blue background color, and first vs. second study block) and included a slightly younger group of children

(6- to 8-year-olds, 10- to 12-year-olds, and adults). They used an exclusion paradigm that required children to make old/new memory judgments and indicate whether the item had been shown in a given target context before or not. Consistent with findings from Cycowicz et al. (2003), ERP components related to retrieval of contextual details were present in all age groups and these components showed functional characteristics similar to those in adults. However, in the youngest age group (6 to 8 years), these ERP components were only found in the subgroup of 6- to 8-year-olds whose performance levels were sufficiently high, suggesting there may be a lower age limit for which the exclusion paradigm can be used effectively.

In sum, current empirical evidence suggests that recollection can be identified in school-aged children (and dissociated from other mnemonic processes, such as familiarity), yet it shows continued development during this time period (see also Brainerd, Reyna, & Holliday, Chapter 5 this volume; Ghetti, Lyons, & DeMaster, Chapter 6 this volume; Newcombe, Llyod, & Balcomb, Chapter 4 this volume). This developmental change may be related to brain development occurring during this period that is tractable via fMRI or ERP methodologies (Diana & Ranganath, Chapter 7 this volume; Thomas & Jorgenson, Chapter 9 this volume); however the exact nature of the developmental course and the mechanisms contributing to such change remain largely unknown.

EVIDENCE FOR RECOLLECTION IN PRESCHOOL CHILDREN

Studies of recollection in preschool children are exceedingly rare due to the fact that the demands of most adult paradigms are too cognitively complicated (i.e., they require reliable subjective judgments regarding memory or confidence). One exception is the process dissociation procedure (Jacoby, 1991), which was used by Anooshian (1999) to examine recollection in preschoolers (mean age: 4 years, 6 months, range: 3 years, 11 months to 5 years, 3 months) in comparison to college students. In their task, participants viewed two sets of pictures. One set was seen in the context of hearing a story and the second set (that was perceptually similar) was not associated with the story (participants were told that a filmmaker was saving the second set of pictures for a different film). Following a brief delay, participants were asked to identify pictures under two separate instructional conditions. In the first condition (exclusion condition), participants were asked to identify only pictures they saw in the context of the story (thus excluding any pictures that they had seen but were not associated with the story as well as any new pictures). In the second condition (inclusion condition), participants were asked to identify any picture they had seen previously, regardless of whether it was associated with the story or not. The comparison of hit and false alarm rates in the inclusion and exclusion conditions allows for estimates of recollection and familiarity. Their results showed that children and adults performed above chance, suggesting that both recollection and familiarity were contributing to the recognition memory judgments. As in studies of school-aged participants, adults obtained higher estimates for recollection than did preschool children despite comparable estimates of familiarity between the two groups.

Although this study was successfully conducted with preschoolers and suggests the existence of recollective processes in this age range, 25% of preschoolers were excluded from analysis because they could not understand and/or follow task instructions (i.e., they selected more story pictures with the exclusion vs. the inclusion instructions). In addition, the authors also reported that extensive pilot testing was necessary to develop the task scenario and that great effort was made to ensure the procedure made sense to young children. Clearly there is a lower bound to which paradigms of this nature can be used with young children.

A possible alternative paradigm can be found in the source memory literature. Source memory paradigms differ from the process dissociation procedure in that evidence for recollection is derived directly from the correct recall of a contextual detail on a given trial, thus eliminating the cognitive demands required by two separate instructional conditions. In source memory paradigms, individuals are presented with items in two (or more) contexts (e.g., line drawings presented in either green or red ink) and, at test, are required to make judgments regarding the original context for items they encountered previously (e.g., did they originally see a particular drawing in red or green ink). A correct judgment regarding the contextual details of an item (such as the color it was originally presented in) is, by definition, recollection (i.e., "qualitative" information regarding contextual details). Therefore, one can begin to examine recollection (albeit indirectly or objectively as opposed to subjectively) using these source memory paradigms (e.g., Schacter, Harbluk, & McLachlan, 1984). The primary advantage is that these paradigms are less cognitively demanding than the process dissociation procedure, as they involve fewer instructional conditions and, presumably, can be used reliably with preschool-aged children. Thus, these paradigms may be especially useful in shedding light on the early development of recollection.

Evidence supporting the feasibility of administering source memory paradigms in preschool children comes from a study by Drummey and Newcombe (2002). In this study, children (aged 4, 6, or 8 years) learned novel facts (e.g., "a giraffe cannot make any sounds") from one of two different sources (i.e., a puppet or an experimenter). After a 1-week delay, children were asked to recall (a) the novel fact (e.g., "What animal cannot make any sounds?") and (b) the source from who the fact was learned ("Who did you learn that from?" see Rybash & Colilla, 1994; Schacter et al., 1984, for a similar paradigm). Results indicated that all three age groups showed evidence for recollection in that they could recall the source from whom the facts were learned. Consistent with the findings reported in the preceding discussion, performance on this measure increased as a function of age. However, given that all 4-year-old children understood the task and were able to complete it even after a delay of 1 week suggests that this paradigm may be especially effective for younger children (see also Lindsay, Johnson, & Kwon, 1991).

Evidence from Other Verbal Paradigms

The evidence just reviewed suggests that even 4-year-old children show memory for contextual details associated with events, but what about younger preschool

children (e.g., 3-year-olds)? As previously mentioned, most empirical paradigms designed to examine recollection directly have not included children this young due to their high cognitive demands. Moreover, new or alternative paradigms have not been developed because, to date, dual-process models of memory have largely been ignored in developmental literature (Brainerd et al., 2009; Newcombe & Crawley, 2007). In general, most research that has been conducted on the development of memory in younger preschool-aged children has focused on the distinction between procedural and declarative memory. Data from these investigations may provide evidence of recollection (or the roots of recollection) in younger children. Using the definition provided by Yonelinas (2002), findings from empirical research are presented showing young children's ability to recall details related to (a) spatial or (b) temporal context surrounding events or (c) memory for arbitrary associations between components of events.

Research on children's autobiographical memory provides one area in which there is rich data to explore, as these tasks require children to verbally describe unique events in their lives. Until the 1980s, it was largely believed that young children could not form memories about life events, or, if formed, that these memories were fragile, unorganized, and short-lived. However, pioneering work by several developmental psychologists has indicated that young children can remember and verbally report on such events (e.g., Nelson & Gruendel, 1986; Todd & Perlmutter, 1980). Perhaps one of the most well-known studies examined 3- and 4-year-old children's memory for a trip to Disney World (Hamond & Fivush, 1991). In this study, children who visited Disney World at either 3 or 4 years of age were asked to recall their experience. Half of the children were interviewed 6 months after their trip and half were interviewed after 18 months. All children recounted a great deal of accurate information about their Disney World experience, including specific and rich information regarding contextual details of the event. For example, children's memory narratives contained information about activities (e.g., "I went to the Tea Cup ride"), descriptions of the environment surrounding these events ("The tunnel was dark"), as well as information on affect ("I was scared"), animatrons ("The witch on the Snow White ride laughed loudly"), and explanations for events ("My Mom said it was too crowded"). Given the specificity of the contextual details provided, these narratives provide evidence for recollection as defined by Yonelinas (2002). This is not to say there were no differences between the age groups; older children's reports were more detailed and spontaneous than those from younger children. However, age (and retention interval) did not influence the amount of information recalled. Thus, even children as young as 3 years of age were able to recollect their experience after delays as long as 18 months!

Peterson and Rideout (1998) used a similar paradigm to examine children's recall for events that occurred even earlier in their lives. In this study, children were interviewed after experiencing injuries that required them to visit the emergency room (e.g., a laceration on the leg requiring stitches). The children fell in three age ranges: 13 to 18 months, 20 to 25 months, or 26 to 34 months at the time of the incident. Children were interviewed about the event within days of its

occurrence (if they were verbal) and after 6, 12, and 18 or 24 months. Most of the children in the oldest group (26 to 34 months) who had narrative skills at time of injury demonstrated good verbal recall 2 years later (e.g., "It was bleeding all down my leg," "Then I went to the hospital," "I got 4 needles in my knee," "I got 14 stitches," "[The] nurse gave me a yellow popsicle;" Peterson & Rideout, 1998). Although their findings suggested that verbal abilities at the time of the event were an important predictor of subsequent verbal memory reports, even children in the intermediate age group (20 to 25 months), who could not narrate about past events at the time of injury, were also able to verbally recall aspects of the target events even after delays of 18 months. Thus, memories reflecting recollective processes likely exist in the minds of children even in the absence of the ability to verbally report on them.

Evidence from Nonverbal Paradigms

Given evidence suggesting that qualitative details surrounding an event are encoded (and subsequently recalled) in preverbal children, examination of children's responses on behavioral memory paradigms may provide a rich source in which to examine the development of recollection. Data from behavioral paradigms have reliably shown that representational competence is present in children as early as the first year of life (Mandler, 1998) and that the capacity to recall certain aspects of events is also in place at this time (Bauer, 2006; Hayne, 2004; Nelson, 1997; Rovee-Collier, 1997).

Returning to the definition of recollection provided by Yonelinas (2002), recollection involves retrieval of "qualitative" information about an event, such the (a) spatial or (b) temporal context or (c) the novel associations between different components of an event. Thus, data from a subset of behavioral paradigms that examine memory for spatial location, memory for temporal order, or memory for novel associations may begin to reveal whether memory for this type of information is reliability present in preverbal children. In these tasks, children are required to recall contextual details in the absence of perceptual support. In order to do this successfully, information regarding the context must be encoded during the presentation of the event and subsequently retrieved from the memory representation, as no perceptual cues exist to support retrieval (see Bauer, DeBoer, & Lukowski, 2007, for elaboration).

Evidence that young children are able to recall "qualitative" details about previously experienced events would, at the very least, suggest that the raw materials of recollection are present early in development. However, because recollection would be inferred by memory for "qualitative" details (as opposed to being assessed directly), there may be no direct evidence—one way or the other—that this retrieval is also accompanied by a recollective experience. However, it is still critically important to examine these abilities because, at minimum, they represent the "building blocks" that will ultimately develop into true recollection over time. Future research will need to adapt the nonverbal paradigms reviewed in the following sections to definitively conclude that there is an accompanying recollective experience.

MEMORY FOR SPATIAL LOCATION

Hayne (2007) has examined memory for location in young children using a unique spatial memory task. In this task, 3- and 4-year-old children were asked to remember where 3 to 5 objects (stuffed animals of characters children knew, e.g., Mickey Mouse, Bert, Ernie) were hidden in different locations in their homes. Following a 5-minute delay, children were required to recall one of the rooms in which objects were hidden (e.g., bedroom), the identity of the object in that room (e.g., Bert), and the specific hiding place in that room (e.g., under the bed). Results indicated that both 3- and 4-year-old children were able to recall information regarding spatial context (i.e., where the items had been hidden) and there was no difference between 3- and 4-year-olds' performance. Furthermore, when asked to do so, children could also recall the order in which the items had been hidden, indicating that they remembered something about the temporal context as well (see Horn & Myers, 1978, for similar paradigm).

MEMORY FOR TEMPORAL ORDER

Memory for temporal order has been examined using the deferred imitation paradigm (Bauer, Wenner, Dropik, & Wewerka, 2000). This technique is borrowed from infant research and capitalizes on young individuals' propensity to imitate others' actions. Memory is inferred when children observe another person's actions and then reproduce those specific actions in the same temporal order after a delay. In the laboratory, these paradigms typically consist of an adult using a set of props to create a series of novel actions. For example, the adult may "make a gong" by placing a bar across a support to form a crosspiece, hang a metal disk from the crosspiece, and use a mallet to hit the disk and make it ring. After a pre-specified delay (ranging from minutes to months), children's memory can be measured in two ways: (a) the number of actions they imitate, and (b) the number of actions they imitate in the correct temporal order.¹ The true advantage of this paradigm is that neither verbal instructions nor verbal report are required.

Bauer has convincingly argued that the imitation paradigm provides a measure of declarative memory, even in preverbal children (Bauer, 2007b; Bauer et al., 2007). Supporting evidence includes the following: the remembered information (a) is accessible to language once children acquire linguistic capacity (Bauer, Kroupina, Schwade, Dropik, & Wewerka, 1998; Cheatham & Bauer, 2005), (b) can be learned in a single trial (Bauer & Hertsgaard, 1993), (c) is subject to forgetting (Bauer, Cheatham, Strand Cary, & Van Abbema, 2002; Bauer, Van Abbema, & de Haan, 1999), (d) is flexible across changes in retrieval context² (Barnat, Klein, & Meltzoff, 1996; Bauer & Dow, 1994; Hanna & Meltzoff, 1993), and (e) is impaired

1. In most investigations, only the first instance of each action is recorded to control for problem solving or success due to trial and error (see Bauer et al., 2000).

2. Flexibility across changes in retrieval context may only be true for infants older than 12 months of age as there are some data to suggest that 6-month-old infants do not generalize if they are exposed to sequences in one context (e.g., their home) and are asked to recall them in another (e.g., the lab; Hayne, Boniface, & Barr, 2000).

in individuals who suffer damage to the hippocampus (Adlam, Vargha-Khadem, Mishkin, & de Haan, 2005; DeBoer, Wewerka, Bauer, Georgieff, & Nelson, 2005; McDonough, Mandler, McKee, & Squire, 1995; Riggins, Miller, Bauer, Georgieff, & Nelson, 2009a). Finally, the content of the information recalled is similar to that recalled in verbal declarative memory tasks (e.g., *what* happened, *where*, *when*, and *why*). For example, when making a gong, children show memory that in order to make a ringing sound with the mallet, first a crosspiece needs to be put in place and then a disk needs to be suspended from it.

Relevant to the issue of recollection, we discuss evidence from imitation paradigms showing that preschool children can recall *when* items occur in events, as this provides evidence that they are able to recall details regarding the temporal context. Recently, Riggins, Miller, Bauer, Georgieff, and Nelson (2009b) used the imitation paradigm to examine temporal order memory in a sample of typically developing 3- and 4-year-old children. Children were asked to remember nine different actions in a specified order. All actions were related to a common theme and used a distinct set of props (e.g., in the "camping" event sequence, children baited a fishing hook, caught a fish, set up a tent, played a guitar, drank hot cocoa etc . . .). Memory for the temporal order of the actions was assessed immediately and after a 1-week delay. Results revealed that both 3- and 4-year-old children were able to recall temporal order information, suggesting memory for "when" items occurred in the event sequence (although performance was better in the older age group).

In addition to the behavioral recall measures at the 1-week delay assessment, this study (Riggins et al., 2009b) also used ERPs to examine the neural representation associated with the memory trace. In this portion of the experiment, children viewed pictures of the props used in the event sequences and pictures of new props they had never seen before. Consistent with previous studies, differences between processing of old and new stimuli was reflected in two ERP components: (a) an early component that has been previously related to attention and memory processes in infants (Carver, Bauer, & Nelson, 2000; Courchesne, Granz, & Norcia, 1981; de Haan & Nelson, 1997; Nelson & Collins, 1991), and (b) a later component that has previously been related to memory or context updating in infants (Nelson, 1994). Recall of individual actions in the event sequences was correlated with peak amplitude of the early component but not the later component. In contrast, recall of temporal order information was correlated with the later component and not the early component. It was suggested that retrieval of contextual information (i.e., temporal order) was related to differences in distributed activity late in the electrophysiological response, which may be reflective of recollection processes. Although speculative, this result is similar to findings in ERP literature in adults and school-aged children (reviewed in the "ERPs" section under "Neural bases of recollection in school-aged children" in this chapter) that report a temporal dissociation between early components that reflect familiarity and later components that reflect recollection (Cycowicz et al., 2003; Czernochowski et al., 2005; Duarte et al., 2004; Friedman et al., 2010; Friedman & Johnson, 2000). Also consistent with this suggestion are results from source analysis in infant ERP studies that have linked late components similar to the one observed in this study

to brain regions in the right temporal cortex (see Reynolds & Richards, 2005, for elaboration).

MEMORY FOR NOVEL ASSOCIATIONS

Previous research provides evidence supporting the notion that imitation paradigms measure an individual's recollection for the original demonstration of the event sequence as opposed to more general semantic knowledge regarding how the objects work (see Bauer, 2007b; Bauer et al., 2000). One example is provided by studies showing children's recall of temporal order information for event sequences that only contain arbitrarily ordered items. Although some event sequences in imitation paradigms contain enabling relations between items (which serve to conceptually constrain the order in which the individual actions should be completed in order to achieve the desired end state; e.g., baiting the hook before catching the fish), other sequences contain completely arbitrary associations between the actions (i.e., achieving the desired end state is not dependent on performing the actions in the correct temporal order; e.g., playing the guitar before or after drinking hot cocoa). If children were simply encoding information about how the objects worked, it would not be necessary to also encode the temporal order of arbitrary events because the desired end state could be achieved regardless of the order; in fact it is a matter of personal preference which should be done first. If, on the other hand, children recall the order of the arbitrary sequences, this suggests more than just a semantic representation was formed. Both types of event sequences were included in the study by Riggins and colleagues (2009b). Results indicate that both 3- and 4-year-olds were able to remember temporal order information (at slightly lower levels) even for sequences that only contained arbitrary relations, suggesting true recollection of the original demonstration was present (Bauer et al., 2007).

Impairments in Imitation Performance in Patients with Hippocampal Damage

If the hippocampus is preferentially involved in recollection, then it follows that individuals with damage to this region should show impairments on tasks requiring recollection. Indeed, this logic has been referred to by some as the "amnesia test" and has been argued to provide some of the strongest support that imitation paradigms rely on hippocampally mediated memory systems. For example, in the earliest of these investigations, McDonough and colleagues (1995) used an age-appropriate version of the deferred imitation paradigm to compare memory performance in seven adult patients with amnesia (approximately half of whom had confirmed damage to the hippocampus), patients with frontal lobe damage, and control participants. After a 24-hr delay, adults in the control group and those with frontal lobe damage showed evidence that they recalled both the individual actions and the temporal order of the actions in the event sequences; however, patients with amnesia did not. Adlam and colleagues (2005) also used a deferred imitation paradigm to examine memory in 12 patients (ages 10 to 26 years) with developmental amnesia, a condition associated with bilateral

hippocampal volume reduction caused by hypoxic-ischemic events during the perinatal period (see section on "Potential mechanisms of change" for elaboration). Like the adult-onset cases of amnesia (McDonough et al., 1995), patients with developmental amnesia recalled fewer actions and less temporal order information than the age-, sex-, and IQ-matched control group after a 24-hr delay. DeBoer and colleagues (2005) used the deferred imitation paradigm to examine memory in a group of 13 infants of diabetic mothers (at 12 months of age) who were at-risk for hippocampal damage due to exposure to multiple neurologic risk factors during the prenatal period (chronic hypoxia, hyperglycemia/reactive hypoglycemia, and iron deficiency), which have been shown to disproportionately alter hippocampal development. Infants of diabetic mothers demonstrated a selective deficit in the ability to recall the temporal order of event sequences after a 10-minute delay, even after statistically controlling for differences in gestational age and global cognitive abilities. Finally, a recent longitudinal follow-up of this sample of infants of diabetic mothers (Riggins et al., 2009a) revealed that these memory deficits continued to persist into the third year of life and also altered the late ERP component described previously that is proposed to reflect hippocampally mediated recollective memory processes. Together, these findings from patient populations in adulthood, childhood, and infancy suggest that successful performance on behavioral imitation paradigms is dependent on the integrity of the hippocampus in infancy, childhood, and adulthood. Given that this brain structure is essential for recollection (Eichenbaum et al., 2007; Ranganath et al., 2004; Yonelinas et al., 2002), these results support the view that imitation paradigms can be used to assess recollection abilities across the lifespan.

EVIDENCE FOR RECOLLECTION IN TODDLERS AND INFANTS

Memory for Spatial Location

Empirical evidence exists that both toddlers and infants show memory for spatial context. For example, DeLoache and Brown (1979) examined young children's memory for spatial location using a motivating game of hide-and-seek. In the task, 18- and 30-month-old children were told that a small stuffed animal (e.g., Big Bird) was going to hide and that they should remember where the stuffed animal was hiding in order to find him later. Children then watched while the toy was concealed in some natural location in their own home (e.g., under a couch cushion, behind a door, inside a cabinet), and after a prespecified delay (ranging from 3 minutes to 24 hr) children were asked to retrieve the toy. Both 18- and 30-month-old children demonstrated robust memory (>72% errorless retrieval) for the location of the hidden toy, regardless of the delay. These findings are impressive in that 18-month-olds remembered the spatial location just as well as the 30-month-olds in this simple search task. Although there is some evidence that older children may use spatial cues more effectively (DeLoache & Brown, 1983), the fact that spatial context could be reliably recalled suggests evidence of recollection for the past hiding experience.

Using naturalistic observational methods (i.e., parental diary studies), Ashmead and Perlmutter (1980) have reported several instances in everyday life in which 7- to 9-month-old infants recalled the location of objects (such as a favorite toy) after long delays. Newcombe, Huttenlocher, and Learmonth (1999) extended these findings to 5-month-old infants using a series of looking-time studies examining the ability to code the location of an object hidden in a sandbox. Results from this investigation revealed that infants looked longer when objects appeared in locations that violated their expected locations, suggesting that they recollected the original spatial location. Finally, a unique study by Myers, Clifton, and Clarkson (1987) suggested that not only can infants recall details regarding spatial context, but that these memories may be quite robust. They examined long-term memory in 5 children who had participated 15 to 19 times between 6 to 40 weeks of age in a laboratory study of the perception of auditory space in both a lighted and darkened room. When children returned to the lab 2 years later, they provided evidence that they retained memory of the unique objects and actions from the experiment in which they had participated during early infancy. Specifically, compared with a control group they played more with objects from the earlier experiment in a lighted room and in a darkened room they were more likely to grasp and hold onto invisible objects (which was the behavior tested in the earlier experiment). Taken together, these findings suggest that even very young infants show memory for spatial location suggesting that these memories may involve recollection of specific contextual details.

Memory for Temporal Order

There is a great deal of evidence that toddlers and infants show memory for temporal context using the elicited and deferred imitation paradigms. This ability has been reported in infants as young as 6 months of age. For example, Barr, Dowden, and Hayne (1996) used the deferred imitation paradigm in a group of 6-month-old infants to examine recall of a three-action event sequence. The infant's task was to pull a mitten off a puppet's hand, shake the mitten, and replace the mitten on the puppet's hand. One quarter of the infants in the study showed evidence for recall of temporal order after a 24-hr delay. Although only present in a small subset of infants, these individuals did show evidence suggesting memory for temporal order. One limitation of this study that may have underestimated infant's abilities was that the actions in the sequence were physically constrained, such that it was necessary to complete the first action before the second or third actions could even be attempted. Thus, not only did infants have to recall the first action (remove the mitten) but had to successfully complete it in order to begin to recall and attempt the second (shaking) and third (replacing) actions.

To address this limitation, Bauer and colleagues have conducted a series of systematic studies examining memory for temporal order using two-step action event sequences with props that do not have this constraint (e.g., making a gong as described previously). These studies have shown that approximately 50% of 9-month-old infants are able to recall temporal order information after a 5-week

delay (Bauer, Wiebe, Carver, Waters, & Nelson, 2003; Bauer, Wiebe, Waters, & Bankston, 2001; Carver & Bauer, 1999). Although only half of the sample shows evidence for recollection, this finding is impressive given the long delay (5 weeks) over which the information is recalled.

These studies show that although memory for temporal order is present in some infants at 9 months of age, there are also data to suggest that there is great improvement in this ability across the next year of life. First, the ability to recall temporal order becomes more reliable across individuals: at 10 months of age, 80% of infants evidence recall of temporal order information after a 1-month delay (Bauer et al., 2006), and by 20 months of age, 100% of children recall order information after a 1-month delay (using age-appropriate sequences with four actions; Bauer et al., 2000). Second, this ability also becomes more robust, as 10-month-old infants are able to recall temporal order information after longer delays (e.g., 3 months as opposed to 1 month, Carver & Bauer, 2001) and 20-month-olds show memory for portions of the events as long as 1 year later (Bauer et al., 2000).

Bauer and colleagues have linked these differences in ordered recall to differences in representation at the neural level using ERPs. Specifically, these studies have shown differences in the processing of old and new stimuli in the two ERP components previously described (i.e., the early component related to attention and memory processes and the later component related to memory updating and perhaps recollection). These differences in ERP responses are evident at both the group and individual levels. In one study, differences in both ERP components were reported, although these differences were only found in the group of 9-month-old infants who showed evidence of memory for temporal order following a 1-month delay (i.e., they were not present in those who did not recall the event sequences; Carver et al., 2000). In subsequent studies, the amount of information recalled has been shown to be correlated with the magnitude of differential processing in both ERP components, such that greater recall is associated with greater differences in processing (Bauer et al., 2006; Bauer et al., 2003). Bauer and colleagues (2006, 2003) have used these ERP findings to suggest that individual differences in both brain development and mnemonic processes (i.e., encoding, consolidation, and storage) contribute to the variability in temporal order memory described previously (see the section on "Potential mechanisms of change" for expansion on the issue of brain development).

In sum, memory for temporal order has been observed in infants as young as 6 months of age. However, this ability is not reliably observed in all infants and, when it is observed, appears fragile as it fades quickly over periods of delay. Thus, although present early in life, memory for temporal order improves dramatically over the first two years of life (Bauer et al., 2000). ERPs have been shown to provide an additional level of analysis that is related to memory performance and may be useful for examining the neural bases of this developmental change (Bauer, 2007a).

Memory for Novel Associations

Most of the imitation studies described herein have used event sequences that are constrained by enabling relations (i.e., relations that serve to conceptually

constrain the order in which the individual actions should be completed in order to achieve the desired end state). For example, when making a rattle out of two nesting cups and a bell, one must (a) put the bell into one of the cups, (b) cover this cup with the second cup, and (c) then shake the cups to make a rattle (e.g., Bauer & Dow, 1994). The steps need to be completed in this order to achieve the desired end state; however, it is indeed possible to complete all steps despite the order (i.e., one could cover the second cup and then shake the cups without the bell inside). One reason these sequences have been used so often in infant memory paradigms is that they bolster performance. As is the case for older children and adults, infants show superior ordered recall for events that contain enabling relations between items, compared with events that contain arbitrary associations between items (for review see Bauer, 1997, 2002). Thus, for research questions regarding the reliability and robustness of memory in early childhood, which has predominated the infant literature, the use of these types of events that support memory performance is critically important.

However, more relevant to the discussion of the emergence of recollection, is whether infants and toddlers are also able to recall events in which relations between events are arbitrary (i.e., when it is not necessary to complete the actions in a specified order to achieve the desired end state), as this is more of a direct test of whether the original demonstration was truly recollected. An example of a sequence with arbitrary relations is making a party hat. In this sequence, one can complete the following steps in any order and still achieve the desired end state: (a) put a pom-pom in the top of a cone-shaped base, (b) attach a sticker to the front of the cone, (c) attach a colored band to the base of the cone (e.g., Bauer & Dow, 1994). Indeed, several investigations have shown that both infants and toddlers are able to recall sequences that only contain arbitrary relations between items (Bauer & Dow, 1994; Bauer & Hertsgaard, 1993; Bauer & Travis, 1993; Mandler & McDonough, 1995). For example, Bauer and Hertsgaard (1993) report that both 13.5- and 16.5-month-olds were able to recall the temporal order of sequences with arbitrary relations immediately (on 81% and 67% of trials, respectively) and after a 1-week delay (on 60% and 65% of trials). Thus, evidence exists that memory for novel associations between components of events is present even in preverbal infants.

EVIDENCE FOR RECOLLECTION IN INFANTS YOUNGER THAN 6 MONTHS?

The data reviewed herein suggests that the building blocks of recollection may be present in infants as young as 6 months of age, but what about infants younger than 6 months? Unfortunately, due to the physical and motor maturity required by behavioral imitation paradigms, these methods have not been used with infants younger than 6 months of age. Paradigms that have typically been used to examine memory in infants less than 6 months primarily include: visual paired comparison tasks, habituation procedures, and the mobile conjugate reinforcement task. All of these paradigms have been instrumental in providing evidence that

infants can and do form memories during this period. However, these methods do not typically provide data relevant to the question as to which mnemonic processes are contributing to the memory representations. For example, in looking-time studies, longer fixation on certain stimuli can indicate recognition; however, whether this recognition is due to recollection or another mnemonic process (e.g., familiarity) is unknown. Moreover, without measures of recall, it becomes increasingly difficult to determine what "qualitative" aspect of the event (i.e., spatial context, temporal context, or novel associations) is remembered.

Unfortunately, at present, there does not seem to be body of literature or comprehensive set of data available to answer the question as to whether recollection (or its building blocks) is present in infants younger than 6 months of age. One fruitful avenue for future research will be to develop paradigms that will begin to address this question. These tasks may use modifications to commonly used behavioral methods and/or use recordings of brain activity (e.g., ERPs, fMRI, or near-infrared spectroscopy, NIRS) to probe neural events associated with behavior observed during these behavioral assessments. However, until these studies are conducted, the issue of whether infants aged 6 months and younger show evidence for recollection remains largely unaddressed.

DEVELOPMENT

Although there is evidence that the building blocks of recollection are present as early as the sixth month of life, compared to data in adults, this support is rather sparse and thus remains speculative. One reason such speculation is necessary is that in infancy and toddlerhood all available data comes from paradigms that were not specifically designed to examine recollection or separate recollection from other processes, such as familiarity. This is unfortunate and clearly illustrates the need for dual-process models of memory to be recognized and incorporated into the developmental literature.

However, one lesson learned from the history of research on infant memory is not to assume that young children lack a cognitive ability simply due to a methodological impediment. Just because infants and young children are not able to participate in the paradigms of choice for adult memory researchers (e.g., namely, verbal recall) does not mean they lack the ability to remember! The last 30 years of research has generated ample evidence to contrary (see Bauer, 2006; Bauer, 2007b; Hayne, 2004; Rovee-Collier, 1997, for comprehensive reviews). In light of this, alternative datasets were used in the present chapter to begin to address the question of whether recollection may be apparent early in life. This evidence was inferred from tasks in which infants and children showed memory for: (a) objects in specific spatial locations, (b) the temporal order of events, and (c) novel associations between components of arbitrary events. One justification for applying such a "rich" interpretation to these datasets is that evidence for recollection was present in the youngest group (4-year-old preschoolers) tested with traditional paradigms (i.e., process dissociation procedure, see Anoshian, 1999). Thus, it is at least reasonable to suggest that children a few months younger in age also have the ability.

However, one potential pitfall of this rich interpretation is that it may be used (incorrectly) to assert that because recollection may be detectable early in life, no subsequent development occurs. This is certainly not the case. Even in school-aged children, in whom there is clear evidence of recollection (e.g., Ghetti & Angelini, 2008), there is also ample evidence that this ability is not adultlike; in fact, much development occurs. An important avenue for future research will be to examine this developmental change and explain the mechanisms underlying it.

If a more conservative approach is taken regarding the appearance of recollection, conclusions drawn from the evidence reviewed in this chapter would be that recollection is not present in infancy and toddlerhood because paradigms are not able to verify that a recollective experience occurred. One challenge associated with such a conservative interpretation is that then the need arises to identify precisely *when* recollection comes “online.” This presents additional obstacles in that it would require evidence showing that a qualitative transition occurs at some point in development (i.e., verification that children do not have the ability to recollect at age X, but subsequently have the ability to recollect at age Y). To obtain evidence for this, age-appropriate paradigms would still need to be developed to examine recollection using the same techniques across multiple age groups in infancy and toddlerhood. In addition, after indentifying “the age” at which recollection appears, it will then be necessary to explain why a wide gulf exists between children who do not have recollection abilities and those that do. As pointed out in other cognitive domains, under these circumstances, developmental change becomes a rare or exotic event that requires an equally exceptional explanation. Because such explanations are exceedingly elusive, conceptualizing developmental change in this light may actually be detrimental to scientific progress (Siegler, 1994).

Potential Mechanisms of Change

One mechanism that may account for the “rich” interpretation that recollective processes exist in infancy, yet continue to develop throughout childhood, is the prolonged development of the neural circuitry underlying recollection. Prolonged brain development has been reported in multiple regions, including portions of the MTL and PFC (Giedd et al., 1999; Giedd et al., 1996). Because studies in adults have suggested that recollection (as opposed to familiarity) relies preferentially on the hippocampus, the developmental course of this structure may be of particular relevance especially early in development.³

The neural network underlying recollection can only be expected to function at adult levels when each component and all connections between components have reached maturity (Bauer, 2007b). Maturity can be conceptualized on at least two levels: structural and functional. The former refers to when, during ontogeny, a variety of parameters regarding structural elements (e.g., number of cells, cell

3. It is acknowledged that simply because a task involves the hippocampus does not make it recollection.

body size, length of dendrites) become adultlike. The latter refers to when organizational and functional parameters become adultlike, both within individual structures and across integrated networks. It is important to recognize that structural maturity does not imply functional maturity. For example, a brain structure (such as the hippocampus) may have adultlike numbers of neurons at birth (or shortly after). However, simply having adult numbers of neurons does not indicate they are performing like mature neurons. As an analogy, one can think of a new company, which may be considered "mature" once it has hired 100 employees to complete the work. However, just because 100 people have been hired does not mean the company is functioning in a "mature" manner. These employees need to take on specialized jobs, learn how to work together, communicate with each other, and correspond with customers and other companies. Similarly, within the brain it is not only required that a "mature" number of cells be present, but these cells must also function in a "mature" manner (i.e., become specialized, function together as a unit, and communicate effectively and efficiently with each other as well as with other regions). Currently, knowledge regarding structural development of the hippocampus and memory circuitry in general far exceeds knowledge regarding functional development.

Neuroanatomical data regarding structural development of the hippocampus have been obtained primarily from nonhuman primate tissue samples. These data suggest that there is prolonged growth of multiple elements within this structure including the formation and migration of neurons as well as proliferation of its afferent and efferent connections; it is the latter that is most prolonged and dramatic. Specifically, within the hippocampus, although adult numbers of neurons in the dentate gyrus are present by the end of the first year of postnatal life, dendritic development and synapse formation persists until at least 5 years of age (Eckenhoff & Rakic, 1991; Serres, 2001). Thus, although the hippocampal formation of young infants may have the necessary number of cells for rudimentary memory formation at 1 year of age, the number of postnatal morphological changes suggests a significant modification of this circuitry between the first year of life and early childhood (Serres, 2001). For instance, between the third to fifth years of life (in the human), neuronal connections between granule cells of the dentate gyrus and pyramidal neurons of Ammon's horn form, which not only alters the structural circuit, but the function of the hippocampus as well. Because this circuitry is critical for adultlike memory formation, this profile suggests that "mature" memory should not be expected before the fifth postnatal year (Serres, 2001). Data from structural MRI studies of children are consistent with the findings reviewed previously and suggest that within the MTL significant development of the hippocampus occurs even between 4 and 25 years of age. In fact, dissimilar trajectories have recently been shown in posterior versus anterior subregions (Gogtay et al., 2004; Gogtay et al., 2006), which parallel differences in their functional development (Giedd et al., 1996). However, this latter suggestion has not yet been examined empirically.

Such prolonged development of the hippocampus stands in stark contrast to the development of other structures in the MTL, such as the entorhinal cortex

(which has been related to other mnemonic processes, i.e., familiarity, see Ranganath et al., 2004; Yonelinas et al., 2002). At the time of birth, the basic gross anatomic features and topological relationships of the human entorhinal cortex are present, and postnatal development is complete by the end of the first postnatal year (Grateron et al., 2002). However, it is difficult to evaluate the functional importance of such development in human infants and children (Eriksson et al., 1998).

At present, there are no direct data available relating structural and functional development of the hippocampus in humans. However, some researchers have suggested that knowledge of brain development should be used to constrain and inform expectations regarding behavioral performance and have begun to relate changes at the behavioral level to presumed structural changes at the neural level (e.g., Bauer et al., 2007). In an elegant line of research, Patricia Bauer has been relating early changes in brain development to behavioral memory performance in infancy in an effort to evaluate the "fit" between age-related changes in memory behavior and development of the neural substrate responsible for it (Bauer et al., 2006). Specifically, she draws on Goldman-Rakic's (1987) suggestion that characteristic functions of a cortical area should begin to emerge as the number of synapses reaches its peak, whereas attainment of adult levels or mature levels of function should coincide with the period of synapse elimination (Bauer, 2007b). The dentate gyrus of the hippocampus shows increases in synaptic connectivity beginning around 8 months and reaches adult levels around 20 months (Eckenhoff & Rakic, 1991). This region provides an essential link in the trisynaptic circuit that connects the hippocampus with the balance of the temporal-cortical network supporting long-term declarative memory (Zola & Squire, 2000), which ultimately, increases the effectiveness and efficiency of communication between parahippocampal structures and the hippocampus (and the hippocampus and neocortex as well). In short, it is the major "route in" to the hippocampus, where new memory traces are consolidated for long-term storage. Given the developmental timeline and function of the dentate gyrus, Bauer hypothesized that the late development of this structure would mirror development of memory behavior (Bauer, 2007b). In fact, as reviewed previously, her behavioral work with infants has shown dramatic increases in memory for temporal order between 9 and 20 months of age. These improvements have been observed both in terms of the number of infants who are able to recall temporal order (50% at 9 months, 100% at 20 months) and in the length of time over which events can be recalled (9-month-olds remember for 1 month, whereas 20-month-olds remember for up to 12 months). Individual differences in rates of brain development may be reflected in 9-month-olds' recall performance: infants who have increased numbers of synapses in this region may show memory for temporal order early. However, as more infants enter this stage of brain development, more show memory for temporal order. In sum, near the end of the first year of life, coincident with increases in synaptogenesis in dentate gyrus, increases in reliability and robustness of temporally ordered recall are observed (Bauer, 2007b).

Evidence supporting this view of continuity in the role of the hippocampus in recollection across development comes from cases in which early damage to the hippocampus alters recollective processing later in development. These data come primarily from individuals with developmental amnesia (see also work on children with Type 1 diabetes and infants of diabetic mothers, e.g., Ghetti, Lee, Sims, DeMaster, & Glaser, 2010; Nelson, 2007). Developmental amnesia results from hypoxic or ischemic episodes suffered early in life that significantly reduce hippocampal volume bilaterally (Bachevalier & Vargha-Khadem, 2005) and impair episodic memory while leaving semantic memory largely intact. Specific to the purpose of this chapter, detailed studies of one patient with developmental amnesia (Jon) with perinatal-onset bilateral hippocampal pathology (~50% volume reduction) revealed impairments in recollection exclusively. For example, in recognition memory tests requiring remember versus know judgments, Jon demonstrated a preserved ability to make familiarity, but not recollection judgments (Baddeley, Vargha-Khadem, & Mishkin, 2001). Electrophysiological studies of word recognition with Jon revealed normal modulation of familiarity ERP components, but not recollection ERP components (i.e., the late positive component over parietal leads, Duzel, Vargha-Khadem, Heinze, & Mishkin, 2001). Finally, fMRI studies with Jon have shown different patterns of activation in hippocampal-cortical connectivity when he recalled autobiographical events (which likely requires some amount of recollection, Maguire, Vargha-Khadem, & Mishkin, 2001). Based on cases of developmental amnesia such as Jon's, it appears that early onset of selective pathology to the hippocampus impairs recollection during adulthood, suggesting that this ability is crucially dependent on this region throughout life (Bachevalier & Vargha-Khadem, 2005; see also Ghetti, Lee, et al., 2010; Nelson, 2007).

This view, which suggests that memory is attributable to the onset of functioning in the hippocampus, is largely maturational in nature (Johnson, 2001). If the hippocampus is both structurally and functionally mature by 5 years of age (in the human), then what could account for the developmental change reported in behavioral studies with older children (Billingsley et al., 2002; Brainerd et al., 2009; Ghetti & Angelini, 2008; Holliday, 2003; Piolino et al., 2007)?

An alternative to this maturational view is one of interactive specialization (Johnson, 2001), in which postnatal functional brain development involves a process of organizing interregional interactions. According to an interactive specialization account, the onset of behavioral competencies (such as recollection) would be associated with changes in maturity of several regions, not just one region. In the case of recollection, the hippocampus is not the only region involved. An entire memory network is required, involving both MTL and PFC (Ranganath et al., 2004; Yonelinas et al., 2002). The PFC is most notably known for its protracted developmental course (Gogtay et al., 2004). Although increases in synaptogenesis begin in the PFC between 8 to 24 months (Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997), this region continues to develop well into the adolescent years (Gogtay et al., 2004). If functional maturity of the entire neural network underlying recollection is only reached once each component and all

connections between components are mature, then the changes observed during school-age years may be attributable to continued development of the PFC portion of the network and/or its connections with the hippocampus (which is consistent with the fMRI and ERP studies in school-aged children, Cykowski et al., 2003; Menon et al., 2005; Ofen et al., 2007).

Recollection in the Context of Other Developmental Change

Determining what mechanism(s) contribute to developmental change is a complex process and becomes increasingly intricate when the viewing lens is expanded and we are reminded that recollection does not develop in isolation. Within the domain of memory, we also know that general semantic memory processes improve with age, as do metamemory abilities, memory strategy use, etc . . . (Gathercole, 1998). Changes in more general cognitive abilities are also occurring simultaneously (e.g., attention, cognitive control, executive functioning) as are changes in social abilities and motivation. Finally, children's experience in the world is accumulating and feeds back to shape functioning. For example, Hayne and colleagues have shown that when chronological age is held constant, the ability to locomote independently (i.e., crawl) influences memory performance (Gross & Hayne, 2004, June; as cited in Newcombe & Crawley, 2007). Specifically, crawlers show increased flexibility in their memory performance and are able to exploit a wider variety of retrieval cues during a deferred imitation task. Thus, future research should not only examine the development of recollection, but the development of recollection in the context of the whole child (see Bauer, 2007b; Nelson & Fivush, 2004, for similar arguments).

CONCLUSIONS

Based on the empirical studies reviewed in this chapter, evidence exists that the building blocks of recollection are present at least in infants as young as 6 months of age. Data from a variety of paradigms have shown that infants and young children are able to recall "qualitative" information, such the temporal and spatial context surrounding an event and novel associations between different components of the event. These abilities are, by definition, evidence of recollection. However, because this evidence is derived from tasks used to investigate general memory abilities (as opposed to recollection per se) it cannot be definitively concluded that true recollective experiences occur during this time period. Yet, these skills, even in their most rudimentary form, will prove vitally important to investigate as they will ultimately develop into true (or adultlike) recollection over time. When the empirical evidence is constrained to only include data from traditional paradigms that separate recollection from other mnemonic processes, it is apparent that recollection is present in the youngest age group tested to date (i.e., 4-year-olds; Anoshian, 1999). Although recollective abilities are detectable, evidence from all paradigms reviewed overwhelmingly shows that much development occurs in recollection and its building blocks over the first

two decades of life (Billingsley et al., 2002; Brainerd et al., 2009; Ghetti & Angelini, 2008; Holliday, 2003; Piolino et al., 2007).

Many challenges remain for the future of research on the development of recollection. First, dual-process models of memory must be incorporated into developmental literature, both theoretically and empirically. Future investigations must work to design novel tasks in which recollection can be examined directly in younger samples. These paradigms should contain features similar to those found in adults and strive to isolate recollection from other processes (e.g., familiarity). Importantly, nonverbal paradigms will need to be modified in ways that allow for assessment as to whether true recollective experiences are present. It is also important that paradigms be developed for use in infants younger than 6 months in order to examine if the building blocks of recollection are also present during this period of life. One potential methodology that may prove useful in these endeavors is ERPs, which have been shown to be sensitive to recollective processes in adults (and are suggested to reflect the same in both childhood and infancy). Because ERPs can be used across a wide range of ages, this evidence would not only allow for detection of recollection in young age groups, but also perhaps a common metric on which development of recollective processes could be examined from infancy to adulthood. Second, across all ages (including school-aged children and adolescents) the mechanisms underlying developmental change at both behavioral and neural levels need to be examined further and better understood. Finally, studies investigating the development of individual differences in recollective abilities and the consequences of this in other domains (such as social functioning) are needed as they will not only enhance our understanding of recollection per se but will also serve to increase the significance of the development of recollection in the field overall. In closing, much work is needed to improve our understanding of the development of recollection. By delineating how this complex system is assembled, we will ultimately achieve not only a better understanding of recollection itself but also a better understanding of memory in general.

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