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A Complementary Processes Account of the Development of Childhood Amnesia and a Personal Past

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Personal-episodic or autobiographical memories are an important source of evidence for continuity of self over time. Numerous studies conducted with adults have revealed a relative paucity of personal-episodic or autobiographical memories of events from the first 3 to 4 years of life, with a seemingly gradual increase in the number of memories until approximately age 7 years, after which an adult distribution has been assumed. Historically, this so-called *infantile amnesia* or *childhood amnesia* has been attributed either to late development of personal-episodic or autobiographical memory (implying its absence in the early years of life) or to an emotional, cognitive, or linguistic event that renders early autobiographical memories inaccessible to later recollection. However, neither type of explanation alone can fully account for the shape of the distribution of autobiographical memories early in life. In contrast, the complementary processes account developed in this article acknowledges early, gradual development of the ability to form, retain, and later retrieve memories of personally relevant past events, as well as an accelerated rate of forgetting in childhood relative to adulthood. The adult distribution of memories is achieved as (a) the quality of memory traces increases, through addition of more, better elaborated, and more tightly integrated personal-episodic or autobiographical features; and (b) the vulnerability of mnemonic traces decreases, as a result of more efficient and effective neural, cognitive, and specifically mnemonic processes, thus slowing the rate of forgetting. The perspective brings order to an array of findings from the adult and developmental literatures.

Keywords: autobiographical memory, childhood amnesia, development, episodic memory, forgetting

For better or for worse, we all have a personal past. We have an historical self who has experienced a lifetime of events. Some of the events are mundane and have a short tenure in memory. For example, though we encode where we parked the car when we arrived at work in the morning, after retrieving the information at the end of the day, we commit no further effort to retaining it. Others of our experiences are defining moments in our lives, such as graduation from college, the birth of a child, or the death of a parent. Memories of these types of events not only are long lasting, they also are critically important to our sense of self—our sense of continuity over time rests on memories of events and experiences that took place in the past. In essence, we believe that we are the same person yesterday and today because we have memories of ourselves from the past. However, there is a striking discontinuity in our personal past. That is, most adults have few if any memories from the first 3 to 4 years of life. There is what appears to be a gradually increasing number of memories from the years of age 3 to 7, after which an adult-like distribution of personal memories is assumed. In this review, I advance a novel account of this discontinuity in terms of complementary processes that contribute to increases in the quality of personal memories and to decreases in their vulnerability to forgetting; thus, producing the characteristic distribution that is the hallmark of childhood amnesia.

Since the "amnesia" for events from the first years of life was first identified in the literature at the end of the 19th century (Henri & Henri, 1896, 1898; Miles, 1895), and named at the beginning of the 20th century (Freud, 1905/1953), there have been a number of empirical studies that establish its robust nature. As well, a number of theories as to the source of the amnesia have been proposed. As elaborated below, though the theories differ in specifics, they fall into one or the other of two categories. Some accounts emphasize late development of the ability to remember the past. They suggest that adults suffer from amnesia for early life events because in the period that eventually becomes obscured by the amnesia, children lack the capacity to create personal memories. It is only after the development of some criterial attribute that children begin to form and retain personal memories. By other accounts, early memories are formed but as a result of an emotional, cognitive, or linguistic change, they later become inaccessible to recall and functionally disappear. Thus, these accounts recognize a developmentally early capacity to form and retain personal memories and hypothesize causes for their later loss to recollection.

As will become apparent, a corollary implication of existing theoretical accounts of childhood amnesia is of discontinuous processes in personal memory. In the case of theories that emphasize late emergence of a new ability to remember, there is thought

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to be a period of time before onset of the new ability during which individuals are unable to form, retrain, and later retrieve personal memories. In the case of theories that emphasize the later functional disappearance of early memories, there is thought to be a change in emotional, cognitive, or linguistic processes that renders early events inaccessible to later recollection. The discontinuity inherent in these accounts stems from the fact that they emphasize one or the other side— but not both sides— of the mnemonic coin. That is, theories that posit late development of the capacity to create personal memories do not take into account the possibility that memories of early life events were formed but then were lost to recollection. Absent a focus on processes that contribute to the later inaccessibility of memory traces, in these accounts, the cause of later amnesia is failure to form memories in the first place. Conversely, theories that posit events that cause the later functional disappearance of early memories do not take into account the possibility that the memories that subsequently disappeared may have been especially vulnerable to forgetting because of poor quality of the traces themselves. Absent recognition of differences in the qualities of memories that are formed early versus later in life, the cause of later inaccessibility is an event that renders early memories lost to later recollection.

The purpose of the present theoretical review is to advance a novel account of the phenomenon of the amnesia of childhood that draws from each of these traditional categories of explanation, yet is not a straightforward integration of them. Unlike the traditional categories of explanation—that emphasize one or the other, but not both sides of the mnemonic coin—the account I develop is explicitly complementary. On one side of the mnemonic coin are developmental changes in a number of factors and processes that facilitate encoding, consolidation, and later retrieval of memory traces, eventually resulting in a corpus of personal memories. On the other side of the mnemonic coin are a number of factors and processes that undermine the integrity of memory traces, eventually rendering some inaccessible to later recollection. More important, it is only by considering both the processes that function to increase the quality of memory traces and the processes that function to undermine them that we can explain the phenomenon of childhood amnesia—neither set of processes alone is sufficient to account for the full pattern of data summarized in this review.

The complementary processes account also departs from traditional explanations of childhood amnesia in its emphasis on essential continuities in memory over the course of development. That is, the complementary processes account recognizes the roots of personal memory even in infancy, and a continuous course of development throughout childhood. Over time, the developmental changes permit formation of representations of personally relevant past events that feature more, better elaborated, and more tightly integrated, personal-episodic or autobiographical elements, relative to those formed earlier in life. In other words, the capacity to form personal memories does not emerge later in development, but gradually improves over the course of childhood. The account also recognizes normative forgetting processes that operate throughout the period eventually obscured by childhood amnesia (and beyond). Because early in development, memory processes are carried out by a relatively immature neural substrate, memory representations formed early in life are especially vulnerable to forgetting. In other words, early memory representations do not become inaccessible as a result of an event or qualitative change, but are lost as a result of normative forgetting processes that weaken memory traces over time. The interaction effect is childhood amnesia—the result of lower quality raw materials operated upon by relatively inefficient and ineffective mnemonic processes. The complementary processes account brings order to an array of findings from the adult and developmental literatures. It is grounded in contemporary understanding of neural, cognitive, and specifically mnemonic developmental processes that help to explain the later inaccessibility of memories of early life events and experiences.

Personal-Episodic or Autobiographical Memories: Definition and Importance

Personal memories are not alone in the vast corpus of representations of past events available to healthy adults and children alike. Rather, they are but one of many types or forms of memories. In the parlance of an influential taxonomy of types of memory (Tulving, 1972, 1983), they are episodic memories: memories of specific past events that happened at a particular place and time. Retrieval of memories of these events often is accompanied by a sense of mentally placing oneself in the past as if reliving the experience. This *autonoetic awareness* (e.g., Baddeley, Eysenck, & Anderson, 2009; Tulving, 2002, 2005) of the experience as having taken place in the past is accompanied by vivid recollection of what happened, when, and where. Episodic memory frequently is operationalized in terms of an individual's recall or recognition of items from a studied list, recall of a passage of text, memory for faces, and so forth.

Episodic memory typically is contrasted with semantic memory (Tulving, 1972, 1983), the latter of which comprises our store of world knowledge. Unlike episodic memories, semantic memories are not located in a particular place or time. For example, we may know that the capital of Georgia is Atlanta, yet unless there was something especially noteworthy or significant about the episode during which we learned this fact, we do not have memory for when or where it was acquired. Even more phenomenologically distant from episodic memory is so-called nondeclarative or implicit memory (e.g., Squire, 1987; Squire, Knowlton, & Musen, 1993). These representations are based on past experiences that, like semantic memories, are not located in specific place and time. However, unlike semantic (as well as episodic) memories, they can influence behavior without conscious recollection. Instead, nondeclarative memories are of motor patterns for how to ride a bicycle, for example, or conditioned or reflexive responses to stimuli. They influence our behavior, to be sure, but they do so without being brought to consciousness (see for, e.g., Bauer, 2013 and Squire et al., 1993, for further development of distinctions among types or forms of memory in the developmental and adult literatures, respectively).

The distinctions among different types or forms of memory are critically important to the effort to explain childhood amnesia because the amnesia does not obscure all types of memories. Even infants and very young children learn and remember a great many things. Infants recognize their caregivers over time and across contexts, they learn to walk and talk, and by the preschool years, children have accrued a great deal of semantic or factual knowledge about the world. These mnemonic accomplishments persist beyond infancy and childhood—they are not obscured by childhood amnesia. Rather, childhood amnesia is the relative paucity of *episodic* memories for events and experiences from the first years of life. However, it is more than amnesia for items on a list or passages of text, for example. It is the relative paucity of episodic memories of events and experiences that are about one's self, and about which one has emotions, thoughts, reactions, and reflections. Because of their reference and relevance to the self, these memories are considered not only episodic, but self defining and *autobiographical* (see Bauer, 2013, 2014; Fivush & Zaman, 2014). Thus, the period that is obscured by the "peculiar amnesia of childhood" (Freud, 1920/1935) is one from which we are lacking autobiographical memories.

The absence—or at best, sparse representation—of autobiographical memories from the first years of life leaves a salient void in one respect in particular, namely, continuity of self. As noted briefly above, it is on the basis of memories for past events that we recognize ourselves as continuous in time (e.g., Habermas & Köber, 2014). In general, the ability to remember one's self in the past is a precondition for a sense of personal continuity (e.g., Prebble, Addis, & Tippett, 2013), and personal memories ground a stable and enduring representation of the self over time (e.g., Bauer, Tasdemir-Ozdes, & Larkina, 2014; Bluck & Alea, 2008; Conway, 2005; McAdams, 1995; Wilson & Ross, 2003). The fact that most adults suffer a paucity of autobiographical memories from the first years of life means that although they had a physical existence before their earliest memory, they experience a discontinuity of psychological self. The importance of autobiographical memories helps to explain why they have been the focus of significant research attention, as well as why their absence from the first years of life has been of sustained interest for more than a century.

At this point it is important to recognize that there is not universal agreement on the definition of autobiographical memory. There is consensus that to be "admitted" into the category of autobiographical memories, episodic memories must be of specific past events and experiences that are about one's self, and about which one has emotions, thoughts, reactions, and reflections. However, some perspectives would consider these criteria to be necessary, though not sufficient. Additional criteria suggested in the literature are that autobiographical memories are (a) of discrete, one-time-only or unique events, as opposed to recurring events; (b) expressed verbally; and (c) long lasting (e.g., Nelson, 1993; see Bauer, 2007, 2014, for reviews). By other definitions, even this larger set of criteria would be considered insufficient to differentiate autobiographical from episodic memory. In the literature on self identity, for example, autobiographical memory is defined as a capacity that permits construction of a sequence of memories of temporally linked events, such as expressed in a life story or autobiography (e.g., Fivush, Habermas, Waters, & Zaman, 2011; Fivush & Zaman, 2014; Habermas & Bluck, 2000; McAdams, 2001; see also Conway & Pleydell-Pearce, 2000; Thomsen, 2009). From this perspective, retrieval of an autobiographical memory involves *autobiographical consciousness*, defined as a form of consciousness of a present self who is different from—yet temporally linked to—the past self who experienced the event (Fivush, 2012; see also Fivush & Zaman, 2014). It is only in adolescence that individuals begin to create narratives of past events that bear these features, leading to the suggestion that autobiographical memory is a capacity that emerges only in adolescence.

The perspective adopted in this review is that autobiographical memory is adequately defined as a system that supports formation, retention, and later retrieval of episodic memories of specific events that are spatially and temporally localized, as well as self-referential, as evidenced by personal perspective on or evaluation of the experience. It need not be restricted to discrete, one-time only or unique events: recurring events, such as "Sunday dinners at grandma's when I was a kid," can be localized (albeit on a larger temporal scale) and also are self-referential and defining (e.g., Waters, Bauer, & Fivush, 2014). Moreover, Rubin and Umanath (2015) argue that merged representations of recurring events are the psychological equivalents of single events (see also arguments by Brewer, 1986). Verbal expression is important to investigation of autobiographical memory because it makes it easier to determine whether representations of past events feature evidence of self-reference, and whether retrieval is accompanied by autonoetic awareness of the experience as having taken place in the past. When these features are expressed verbally, we can be confident that the underlying memory representation bears these characteristics. However, verbal descriptions are not isomorphic with memory representations. As such, the absence of verbal expression of these features should not be taken as evidence that memory representations are lacking of them. The criterion that episodic memories must be long-lasting to be considered autobiographical lacks specificity (how long is "long"?) and is potentially circular, owing to the tendency to equate "long-lasting" with "personally relevant"—if the memory is not long-lasting, then it must not have been important to the self.

The final suggested definition of autobiographical memory in terms of developments in narrative self expression in adolescence is useful for understanding changes in narrative production that occur at that time. However, I argue that it is not useful to the goal of understanding childhood amnesia. As elaborated below, among adults, childhood amnesia is dense for the first 3 to 4 years of life and then begins to "lift," as evidenced by a steadily increasing number of memories that are available for recollection. In light of this distribution, we must admit either that autobiographical memories are apparent well before adolescence, or that none of the preadolescent memories retained by adults is autobiographical. If one accepts the latter, then a necessary corollary is that autobiographical memory has virtually nothing to do with childhood amnesia. Given the substantial theoretical departure this would represent, it seems better advised to view the developments taking place in adolescence as reflective not of the emergence of autobiographical memory, per se, but of construction of an autobiography, life story, or life narrative, which takes autobiographical memories as its raw materials. This perspective is consistent with Rubin and Umanath's (2015) view that narrative organization is a characteristic of autobiographical memory, but it is not necessary for it.

Discontinuity in the Personal Past: Childhood Amnesia

Since the beginning of the 20th century, the amnesia that adults experience for early life events has been known as *infantile* or *childhood amnesia* (Freud, 1905/1953). It is recognized as having two phases (Pillemer & White, 1989; see Bauer, 2007, for updated discussion), which are schematically depicted in Figure 1. From the first phase—before age 3 to 4 years—most adults have few if any autobiographical memories (solid gray bars). From the second phase— between the ages of 5 and 7 years—adults have a smaller number of autobiographical memories than would be expected based on forgetting alone (striped bars). It is only from later in the first decade of life that most adults are able to recall a significant number of past events that are spatially and temporally localized, and which have some degree of personal relevance or significance (solid black bars). Although this "peculiar amnesia of childhood" (Freud, 1920/1935) is considered an adult phenomenon, as discussed in a later section, there is a small but increasing body of evidence that by the end of the first decade of life, children also begin to experience it. Before reviewing that literature, I elaborate on the two major phases of childhood amnesia among adults.

Average Age of Earliest Memory

The earliest research on the phenomenon of childhood amnesia among adults was published at the close of the 19th century. Miles (1895) conducted a survey of adults' childhood experiences and among other things, asked them to think about the earliest event they could remember, and how old they were at the time. This and subsequent such surveys (e.g., Dudycha & Dudycha, 1933a, 1933b; Henri & Henri, 1895, 1896, 1898; Kihlstrom & Harackiewicz, 1982) have produced one of the most consistent and robust findings in the psychological literature, namely, that the average age of earliest memory among adults in Western cultures is age 3 to 4 years (see, e.g., Wang, 2006, 2014, for discussions of cross-cultural differences in average age of earliest memory). Moreover, the same average age of earliest memory is found whether the source of data is a survey, free recall (e.g., Bauer et al., in press; Waldfogel, 1948; Weigle & Bauer, 2000; West & Bauer, 1999), or response to a cue word prompt (e.g., Bauer & Larkina, 2014; Rubin & Schulkind, 1997; though see Wang, Conway, & Hou, 2004, for evidence that repeated probes can produce earlier estimates). The effect also is impervious to age-cohort effects: the same general pattern is obtained from individuals 20 years of age at the time the memories are prompted and individuals 60 to 70 years of age at the time the memories are elicited (see, Rubin, 2000, for review), even though for older adults, many more years have passed since childhood. The same average age of earliest memory is found even when respondents are asked to remember a specific event the date of which is clearly known, such as the birth of a younger sibling (e.g., Sheingold & Tenney, 1982; Usher & Neisser, 1993).

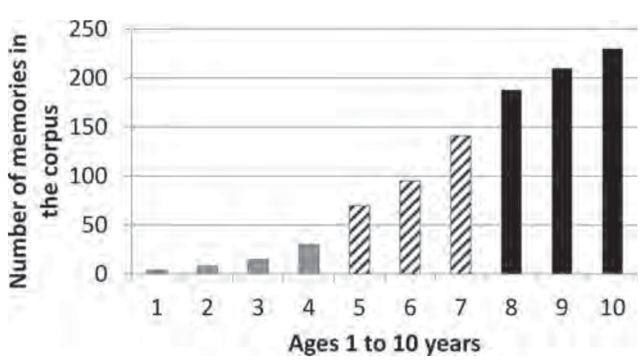

Figure 1. Schematic depiction of the distribution of memories across the first decade of life from a traditional perspective, suggesting a gradually increasing number of memories with age.

The robust nature of the average age of earliest memory among adults obscures the substantial individual differences in the phenomenon. From the beginning of research on the topic, individual differences in the age of earliest memory have been apparent. In reports that provide information on variability, most feature at least a small number of instances of memories from before the age of 2 years (e.g., Bauer et al., in press; Dudycha & Dudycha, 1933a, 1933b; Henri & Henri, 1896, 1898; West & Bauer, 1999). Memories from at least some respondents from age 2 years are more the rule than the exception (e.g., Eacott & Crawley, 1998; Usher & Neisser, 1993). Conversely, some adults have earliest memories from later in childhood: their "earliest" memories are from as old as 6 to 9 years of age (e.g., Bauer & Larkina, 2014; West & Bauer, 1999). There also are individual differences among adults in the density of early memories. Some adults recall many memories from their childhood years, whereas others remember only a few, with many months between them (Bauer, Stennes, & Haight, 2003; Jack & Hayne, 2010; Weigle & Bauer, 2000; West & Bauer, 1999).

Characteristic Distribution of Early Memories

The second component of the definition of childhood amnesia is that from the ages of roughly 3 or 4 to 7 years, the number of memories that adults are able to retrieve increases gradually yet is smaller than the number expected based on forgetting alone (Pillemer & White, 1989). After age 7 years, a steeper, more adult-like distribution becomes apparent. The underrepresentation of memories from before age 7 years was empirically demonstrated in a seminal article by Wetzler and Sweeney (1986), using data from Rubin (1982). Rubin asked young adults to think of past events related to each of over 100 cue words (e.g., *cup*, *chair*, and *tree*), and to estimate their age at the time of the event. To the data, Wetzler and Sweeney fitted a power function that in many investigations (e.g., Crovitz & Schiffman, 1974; Rubin & Wenzel, 1996; Rubin, Wetzler, & Nebes, 1986) has been shown to capture the distribution of memories across the life span. As discussed by Rubin and Wenzel (1996), the power function (e.g., Wickelgren, 1974, 1975) implies that equal ratios of time ($t_1/t_2 = t_3/t_4$) will result in equal ratios of recall ($recall_1/recall_2 = recall_3/recall_4$). Thus, for example, if Time 2 recall was 90% of Time 1 recall, then Time 4 recall would be 90% of Time 3 recall (i.e., assuming equal ratios of time). As a result of the constant ratio, over time, forgetting actually slows (i.e., smaller absolute numbers of memories are lost over each unit of time), presumably as a result of memory trace consolidation (see, e.g., Wixted, 2004, for discussion). Wetzler and Sweeney found that the power function was a poor fit to data from birth to age 6 years, implying accelerated forgetting of memories from ages 6 and below. Memories from age 7 years were excluded from the analysis because age 7 years was considered the "inflection point" for childhood amnesia: after age 7 years, the rate of forgetting is assumed to be adult-like. Consistent with this suggestion, Wetzler and Sweeney found that the power function was a good fit to data from age 8 to adulthood (see Bauer, 2007, for additional discussion).

Traditional Explanations of Childhood Amnesia

Given the relevance and importance of autobiographical memories to the self—and the robustness of the finding of a paucity of such memories from the first years of life—it is fitting that childhood amnesia has received a great deal of theoretical attention. Though there are a number of theories that differ in their specifics (see Bauer, 2007, for a review), the explanations can be summarized as belonging to two general categories (Bauer, 2014). As introduced earlier, one category of accounts emphasizes the late emergence of autobiographical memory. By these explanations, adults experience amnesia for early childhood events because as children, they lacked the fundamental capacity to form such memories. By these accounts, autobiographical memory is a later developing achievement, one dependent on general or specific cognitive changes that permit personal memories to be formed, retained, and later retrieved. It is only once the capacity emerges that autobiographical remembering begins.

The second category of accounts of childhood amnesia emphasizes the functional disappearance of early memories—that is, changes that render once accessible memories inaccessible to recollection. By these explanations, autobiographical memories of events from the first years of life are formed and presumably can be recollected by children while they are in the period that eventually becomes obscured by childhood amnesia, yet the memories later become inaccessible and thus functionally disappear.

Traditional explanations of childhood amnesia differ in their emphasis, yet what they have in common is that they implicate one or the other side of the mnemonic coin, but not both. That is, they explain childhood amnesia *either* in terms of something that must develop to permit the capacity for self-referential memories of past events, *or* in terms of something that happens to make early memories inaccessible to later recollection—they fail to take into account the complementary mnemonic processes. That is, the former category puts all of its explanatory eggs into a basket that emphasizes late emergence of autobiographical remembering; the possibility that autobiographical memories are formed early in life but subsequently forgotten is not part of the explanation. The latter category puts all of its explanatory eggs into a basket that emphasizes the later functional disappearance of autobiographical memories; there is no recognition of relative vulnerabilities in the memory traces formed during the period eventually obscured by childhood amnesia. After reviewing these traditional categories of explanation of childhood amnesia, I advance a novel account that integrates the complementary processes implicated in the explanations, by emphasizing increases in the quality of autobiographical memories over the course of development, as well as decreases in the vulnerability of autobiographical memory traces. The account emphasizes the essential continuity of the processes over developmental time.

Emphasis on Late Emergence: Memories Are Not Accessible Because They Were Not Formed

The first major category of perspectives on the source of childhood amnesia is that adults have few autobiographical memories from before the ages of 5 to 7 years because during this period, they lacked the capacity to form and retain them, because of general or more specific cognitive deficits.

The suggestion that general cognitive deficits explain the relative paucity of memories from early in life is perhaps most notably associated with Piaget (1962). Though Piaget did not advance a theory of childhood amnesia, per se, his theoretical perspective provided a compelling explanation for it nonetheless. He maintained that for the first 18 to 24 months of life, infants and children did not have the capacity for symbolic representation. As a result, they could not mentally re-present objects and entities in their absence. Thus, they had no mechanism for recall of past events. Beyond 24 months and through ~5 to 7 years, children were thought to lack the cognitive structures that would permit them to organize events along coherent dimensions that would support later retrieval. One of the most significant dimensions that Piaget suggested preschool-age children lacked was an understanding of temporal order. Specifically, he suggested that it was not until children were ~5 to 7 years of age that they developed the ability to sequence events temporally (Inhelder & Piaget, 1958). Lacking this organizational device, children were not able to form coherent memories of the events of their lives.

A contemporary version of a general cognitive deficit account has been advanced by Olson and Newcombe (2014). They suggest that before the age of 2 years, children lack the ability to bind together or relate elements of representations of events, a prerequisite for formation of episodic memories (discussed in more detail in a later section). Between the ages of 2 and 6 years, children may bind elements of events together, yet do so in a manner that fails to ensure persistence of memories over time. Consistent with this suggestion, Olson and Newcombe highlight young children's difficulties remembering the correct sources of their experiences (so-called source memory, e.g., Drummey & Newcombe, 2002; Riggins, 2014), and their difficulties creating conjunctions between items and their locations (e.g., Bauer, Doydum, Pathman, Larkina, Güler, & Burch, 2012; Sluzenski, Newcombe, & Kovacs, 2006; though see Bauer, Stewart, White, & Larkina, in press).

There also are suggestions that specific conceptual, linguistic, or mnemonic changes play a role in the explanation of childhood amnesia, rather than global cognitive change. By some accounts, adults have few memories from infancy because for the first 2 years, infants lack the concept of a self around which memories can be organized (e.g., see Howe & Courage, 1993, 1997, for reviews). By other accounts, beyond a physical sense of self, development of autobiographical memory awaits a subjective self who evaluates and takes personal perspective on life events (e.g., Fivush, 2014). Absent these developments, there is no *auto* to lend the *auto*biographical character to episodic memories. By other accounts, for the first 5 to 7 years of their lives, children lack autonoetic consciousness, rendering it impossible for them to recognize that the source of their mental experience is a representation of a past event (e.g., Perner & Ruffman, 1995), or to engage in the subjective mental time travel that accompanies episodic and autobiographical memory retrieval (e.g., Suddendorf, Nielsen, & van Gehlen, 2011; Tulving, 2005; Wheeler, 2000). Each of these explanations implicates a different specific component ability. However, what the suggestions have in common is the perspective that as a result of some deficit, although children may remember past events, their memories are lacking in the qualities that typify the autobiographical memories formed by older children and adults. It is only once the general or specific cognitive or conceptual ingredients that are missing from early memories become available that children begin to form, retain, and later retrieve memories that are autobiographical.

A well-articulated example of this perspective was provided by Nelson and Fivush (2004). As depicted in Figure 2 (reproduced from Nelson & Fivush, 2004), they suggested that it is not until 5 years of age that the many cognitive dimensions required for encoding, retention, and later retrieval of memories have reached a sufficient level of development to support autobiographical memory. They noted the necessity for autobiographical memory of developments in self concept, language and narrative, theory of mind, understanding of time and place, subjective sense of self, mental time travel, and autonoetic awareness, and others, all of which undergo development from infancy through early childhood, culminating in the capacity to form autobiographical memories. Until that time, children may have semantic and perhaps even episodic memories, but their memories are not autobiographical. In summary, what these perspectives have in common is the assumption that the reason adults are unable to recollect early childhood is because the memory system available to them as children was lacking in ingredients essential for formation, retention, and later retrieval of autobiographical memories. As a consequence, not only adults—but also children—lack autobiographical memories from the first years of life.

Emphasis on Functional Disappearance: Memories Are Formed but Become Inaccessible

The second major category of perspectives on the source of childhood amnesia is characterized by the assumption that young children and perhaps even infants form memories of the events of their lives, but that the memories subsequently become inaccessible. Perhaps the best known (and most infamous) of such accounts is Freud's (1905/1953) psychodynamic theory. He remarked that "We forget of what great intellectual accomplishments and of what complicated emotions a child of four years is capable . . . Yet, in spite of this unparalleled effectiveness they (memories of early life events) were forgotten!" (Freud, 1905/1953, p. 64). Freud suggested that the memories became inaccessible as a result of repression of inappropriate or disturbing content of early, often traumatic (because of their sexual nature) experiences. Memories of events that were not repressed were altered to remove the offending content. Freud suggested that the negative emotion in these memories was screened off, leaving only bland skeletons of once-significant experiences (Freud, 1916/1966).

More contemporary accounts also makes the assumption that memories of early life events are formed but become inaccessible, but for cognitive or linguistic rather than emotional reasons. These perspectives have in common the suggestion that different times or phases of life are experienced through different cognitive structures or "lenses." The structures of one life period are considered sufficiently different from those for another that memories created with one set of structures are inaccessible once new structures become dominant. By some accounts the structures differ in the extent to which they are reliant on language (e.g., Neisser, 1962). Because infants lack language and very young children lack many nuances of language, they encode memories visually or imaginally, but not symbolically. The suggestion is that with the advent of language skills, exclusively nonverbal encoding gives way to primarily verbal encoding. As the system becomes more and more saturated with language, it becomes increasingly difficult to gain access to memories encoded without language (Neisser, 1962). The result is that early memories become inaccessible.

Different lenses or cognitive structures may result not only from the linguistic revolution, but from changes over life periods, each of which has a distinctive sense of self, with different hopes, fears, and challenges, for example. Life periods may correspond to elementary versus secondary school versus college, or before

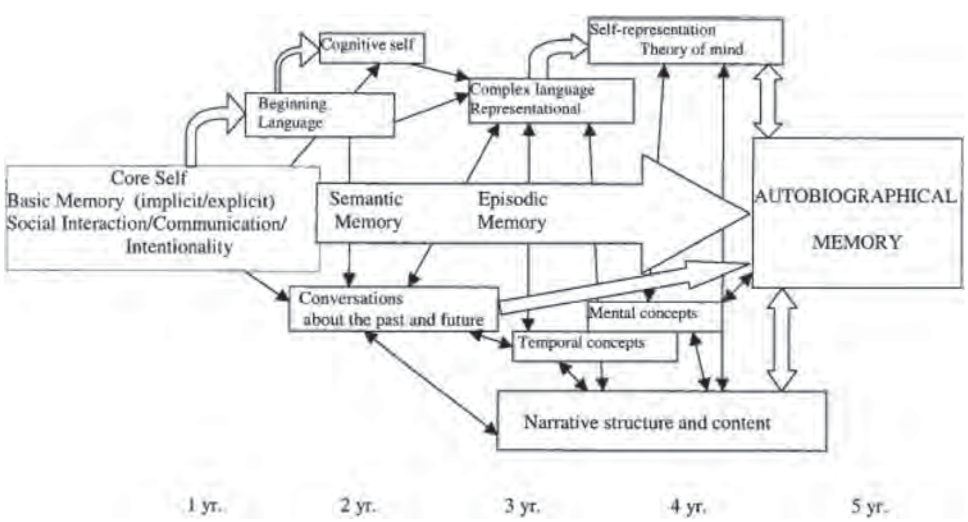

Figure 2. Depiction of contributors to and course of development of autobiographical memory provided in Nelson and Fivush (2004). Autobiographical memory is characterized as emerging at ~5 years of age, when developments in requisite contributing domains reach criterial levels. From "The Emergence of Autobiographical Memory: A Social Cultural Developmental Theory," by K. Nelson and R. Fivush, 2004, *Psychological Review*, *111*, p. 490. Copyright 2004 by the American Psychological Association.

versus after marriage, or before versus after retirement (Conway, 1996; Conway & Pleydell-Pearce, 2000). Memories from prior lifetime periods may differ from those from the current period not only because time has passed, but because of the new sense of self that is associated with changes in thinking or world view. Though these perspectives differ in the specific causes of change in accessibility that they invoke, they have in common the assumption that the capacity to form memories of personally relevant events is present, even early in development. Some emotional, cognitive, or linguistic force renders the early memories inaccessible and functionally forgotten. Thus, unlike the category of explanations discussed above, in these explanations, there is nothing lacking in early memory. Instead, something happens later in development that renders early memories inaccessible.

Explanation of Childhood Amnesia in Terms of Complementary Processes

As just described, traditional accounts of childhood amnesia make one of two assumptions—either that early life is devoid of the ability to form autobiographical memories or that memories are formed in childhood but later become inaccessible to recollection. Thus, they emphasize either positive changes in memory (emergence of a new memory system) or negative changes (loss of accessibility), but neglect the complementary process. The result is that each faces challenges to the adequacy of the explanation of childhood amnesia that it offers. The category of explanations that emphasizes positive changes in memory adopts the stance that autobiographical memory is a developmentally later achievement, one that emerges only with either general or specific cognitive developmental changes. A corollary of the assumption is that memories formed before the target development(s) are not "autobiographical." Rather, they lack a feature or features considered defining of the category. At issue for these accounts is the fact that, as outlined below, features associated with autobiographical memories are apparent in memory behavior before the end of the second year of life; they become more and more prominent over the course of the preschool years. The challenge then becomes how to explain why memory representations that look and feel autobiographical, are not part of the autobiographical record.

The category of explanations that emphasizes functional disappearance of memories makes the assumption—either implicitly or explicitly—that autobiographical memories are formed, even early in life. Its challenge is to explain why autobiographical memories of early childhood become inaccessible to later recollection. Typical forgetting processes cannot be the answer because, as described earlier, the distribution of memories from early childhood is not well characterized by normal forgetting (Wetzler & Sweeney, 1986). Rather, the rate of forgetting is accelerated. Based on adult data alone—which is the empirical foundation from which these accounts were advanced—there is not a ready explanation for accelerated forgetting.

The perspective I advance in the balance of this review is that elements of both of these perspectives are part of the explanation of childhood amnesia. The amnesia can be understood in terms of the complementary processes that improve memory traces and that degrade them. The perspective highlights developments that result in formation of memory traces that bear more, better elaborated, and more tightly integrated autobiographical features. It also highlights developmental changes in the rate of forgetting associated with normative neural, cognitive, and mnemonic processes that result in decreases in the vulnerability of memory traces (i.e., at least through young adulthood). When considered together, the complementary processes—and their developmental dynamics—provide a ready explanation for the characteristic distribution of autobiographical memories across the life span and a more compelling explanation of the phenomenon of childhood amnesia (see also Bauer, 2007, 2008, for previews of this perspective).

The Quality of Memory Traces Increases Over Development

There are pronounced changes in memory behavior over the course of early childhood. There also are different perspectives on the implications of the changes. In traditional accounts of childhood amnesia, one or more of the changes is considered criterial for the emergence of autobiographical memory. A major source of evidence as to whether the criterial element (or elements) is present is children's verbal accounts or narrative descriptions of past events (e.g., Nelson & Fivush, 2004). For much of early development, children's memory reports omit some of the elements that are associated with autobiographical memory, leading to the conclusion that the elements also are missing from the underlying memory representations, thus rendering them nonautobiographical. The complementary processes perspective takes exception to these arguments on the bases that (a) verbal behavior alone is an insufficient source of evidence as to whether children "have" autobiographical memory; and (b) salient elements of autobiographical memory are apparent early in development—in verbal as well as nonverbal behavior—and that the capacity does not await an hypothesized criterial feature that is late to emerge. Rather than of late emergence of autobiographical memory, in the complementary processes perspective, changes in both verbal and nonverbal memory behavior are interpreted as evidence of gradual increases in the quality of memory traces—including autobiographical ones—over development, such that with development, memory traces bear more, better elaborated, and more tightly integrated personal-episodic or autobiographical features. These perspectives are presented in turn.

Developmental change in children's verbal behavior. A full autobiographical report features a number of elements, including *who* participated in the event, *what* happened, *where* and *when* the event took place, and *why* the sequence of actions unfolded as it did. It also features information about *how* the participants in the event reacted to it in terms of their emotions, thoughts, or evaluations of the event. The latter element is especially important to establishing the self-referential nature of autobiographical memories. Furthermore, the elements are presented in a coherent manner, allowing the listener (or reader) to understand the theme of the event, the context in which it took place, and the chronology of actions (Reese, Haden, Baker-Ward, Bauer, Fivush, & Ornstein, 2011).

There are marked changes in children's verbal behavior throughout early childhood. In their earliest verbal reports of past events, young children frequently omit one or more elements of a complete and coherent story. Instead, they typically merely confirm or deny information provided by another. For example, an adult mentions a recent visit to the zoo and offers the observation that the child enjoyed the animals, and the child responds with an enthusiastic "Yes!" At around the age of 3 years, children begin contributing memory content. However, they frequently include only the most crucial elements such as who and what ("I played"). They omit many of the elements that make for a good story, such as where and when the event occurred, and why it happened as it did (see Bauer, 2013, 2014; Nelson & Fivush, 2004, for reviews). Over the course of the preschool and early school years, children take on increasingly active roles in conversations. They contribute more of the elements of a complete verbal report (i.e., the *who*, *what*, *where*, *when*, *why*, and *how* of events), more descriptive details, and more evaluative information, thereby adding texture and obvious self-relevance to their narratives (e.g., Bauer & Larkina, 2014; Haden, Haine, & Fivush, 1997).

Traditional interpretation of omissions from children's verbal behavior. By traditional criterial accounts, because children's early memory reports lack some of the features associated with autobiographical memories, their memories may be considered episodic (or even semantic, Nelson, 1993), but not autobiographical. This provides a ready account for childhood amnesia: memories formed in the first 5 to 7 years are not autobiographical, thus explaining the relative paucity among adults of autobiographical memories from this life period. Autobiographical memory is recognized only with verbal evidence that the event being recalled is located in specific time and place and is self-referential, as indicated by personal or evaluative perspective, or even that the event is part of an extended life narrative (e.g., Fivush, 2012; Fivush & Zaman, 2014).

Exception to the traditional criterial view. As previewed above, the complementary processes account developed here takes exception to the traditional criterial view on the grounds that absence of evidence does not constitute evidence of absence. In other words, the fact that young children's verbal reports do not feature all of the elements that are associated with autobiographical memories does not mean that the elements are missing from the memory representations and does not license the conclusion that the memory is not autobiographical. Moreover, though one or more elements characteristic of autobiographical memory may be missing from *any given* report that a young child provides about a past event, there does not seem to be a single element or feature that is missing from *all* reports. This calls into question the suggestion that young children lack a criterial or defining feature of autobiographical memory. In addition, as reviewed below, features characteristic of autobiographical memory are apparent at least by the end of the second year of life; they become increasingly obvious over childhood, such that reports feature more personal-episodic or autobiographical elements and the elements are better elaborated and more tightly integrated with one another. Based on this evidence, I suggest that autobiographical memory is best conceived not as a classical concept with defining features, but in terms of a prototype or family resemblance with characteristic features (see also Bauer, 2007, 2008, 2012, 2014). The essence of the argument is that, as more and more of the features associated with autobiographical memory are included in the memory trace, memories become increasingly autobiographical.

Absence of features from verbal reports does not imply absence from memory. As just discussed, the fact that early verbal accounts of past events typically omit features associated with autobiographical memories—especially location in time and place and a subjective personal perspective—has been interpreted to suggest that these elements are missing from the representation and thus that early memories are not autobiographical. Verbal reports and memory representations are not isomorphic, however. When elements of autobiographical memory are featured in verbal reports, it is reasonable to conclude that the elements also are part of the representation. However, memory representations may include features not expressed in verbal form. I offer two sources of evidence to make the case—one from children and the other from adults—as well as an argument regarding sufficiency.

One source of evidence that memory representations may include mnemonic features that are not expressed 2012 verbally comes from a prospective study of children's recall of early life events (Bauer & Larkina, 2013). At the age of 3 to 4 years, children were asked to recall a number of events from the recent past. They featured an average of 3.59 narrative elements in their reports (out of a possible of eight narrative features: *who*, *what-object*, *what-action*, *where*, *when*, *why*, *how-description*, and *how-explanation*). Seemingly consistent with the interpretation that their memories were not autobiographical, they included only 1.10 mentions of where events occurred, 0.16 temporal markers, and 0.35 subjective evaluations. However, when the same children recalled the same events at 9 years of age (6 years later)—to the extent that they remembered the events (more about this in a later section)—they included the features so saliently omitted from their early verbal accounts. At 9 years of age, they more than doubled the number of indicators of where events took place (to 2.29), showed a fourfold increase in the number of temporal markers included (to 0.72), and featured more than twice the number of subjective evaluations (to 0.78). Thus, later in development (with additional verbal competence), memories from the age of 3 years were expressed with strong autobiographical flavor. This suggests that the memory representations formed early in life included the mnemonic features that render memories autobiographical, even though evidence of them was missing from the relatively impoverished verbal reports produced earlier in development (see Tustin & Hayne, 2010, for a consistent discussion of the episodic nature of children's early memories).

A second, and complementary, source of evidence that memory representations may include mnemonic features that are not expressed verbally comes from adults' narratives, which not infrequently *lack* the features of autobiographical reports. For example, in Bauer and Larkina (2014), college students and middle-age adults included an average of only 5.32 and 5.88 of eight narrative features (specific features mentioned above), respectively. They frequently omitted information about where events took place and why they happened as they did. Strikingly, college students and middle-age adults provided a subjective perspective on the events only 46% and 53% of the time, respectively. The fact that the verbal reports of adults frequently omit information that clearly marks events as autobiographical makes it difficult to justify an argument that because children's reports lack these features, the memory representations that gave rise to them are not autobiographical. Indeed, were we take the argument to its logical conclusion, then we would "disqualify" many of the memory reports that adults provide as well. We do not make this claim because—when adults are the subjects—we recognize that verbal reports do not necessarily convey the full richness of memories.

A final source of concern with reliance on verbal reports as the index of when event memories become autobiographical stems from the fact that there are continuous changes in verbal and narrative behavior throughout childhood and into adolescence. This makes it challenging to identify a time in development when verbal reports have "enough" autobiographical features to consider them indicative of the memory type. The point here is that developmental changes in verbal behavior do not end at 5 to 7 years of age. Throughout the school years there are changes in the breadth of reports that children tell and in the coherence of their accounts. For example, between the ages of 7 and 11 years, there are increases in the length and complexity of children's autobiographical reports (e.g., Habermas, Negele, & Mayer, 2010). The amount of information that children include nearly doubles over this period (Van Abbema & Bauer, 2005), as does the temporal organization of the reports that children produce (Morris, Baker-Ward, & Bauer, 2010). Ten- to 12-year-old children also produce verbal reports that more effectively orient the listener to the time and place of the event, and they maintain and elaborate on topics more effectively than 7- to 9-year-old children (e.g., O'Kearney, Speyer, & Kenardy, 2007; Reese et al., 2011). However, even at age 11 to 12 years, children's reports still are lacking in the causal connections (e.g., *because*, *so that*) that characterize older adolescents' and adults' narrative accounts (e.g., Bauer, Stark, Lukowski, Rademacher, Van Abbema, & Ackil, 2005; Habermas et al., 2010). In adolescence, individuals use their autobiographical memories to construct an extended life story or personal history (e.g., Bohn & Berntsen, 2008; Fivush & Zaman, 2014; Habermas & Bluck, 2000; Thomsen, 2009; see Bohn & Berntsen, 2014). The point of summarizing these changes is to illustrate the seeming arbitrariness of selecting any single development in verbal narrative behavior as indicative of the "onset" of autobiographical memory. The evidence is more consistent with characterization of autobiographical memory as developing gradually and continuously.

Features of autobiographical memory are apparent early in development. The inadvisability of relying exclusively on verbal data as the source of evidence as to whether memories are autobiographical compels examination of other expressions of memory by children, with special emphasis on whether they remember specific past events located in place and time, and whether they show evidence of the personal relevance of the events. As will become apparent, they do; both behaviorally and verbally, the features become more and more prominent over the course of childhood. This pattern is part of the foundation upon which rests the suggestion that rather than as a classical concept with defining features, autobiographical memory is better characterized as a family resemblance concept with characteristic features (e.g., Bauer, 2007). Another component of the foundation is the observation that although any single expression of memory may be lacking in some features associated with autobiographical memory, there is no one element consistently missing from all expressions of memory. In other words, though there is evidence that some features are less frequently expressed, there is a lack of evidence that any given criterial feature is missing from early memory representations.

The ability to recall specific past events is readily apparent before the end of the second year of life—well before children provide verbal evidence of autobiographical memory. Some of the strongest evidence of the capacity comes from studies using nonverbal imitation-based tasks in which props are used to produce novel actions or sequences of actions that infants are invited to imitate (e.g., Bauer & Mandler, 1989; Bauer & Shore, 1987; Meltzoff, 1985). As discussed in detail elsewhere (Bauer, 2007, 2013; Bauer, Wenner, Dropik, & Wewerka, 2000; Carver & Bauer, 1999; McDonough, Mandler, McKee, & Squire, 1995; Squire et al., 1993), the task is an accepted analogue to verbal report. Using this technique, researchers have found evidence of memory for unique events even in the first year of life. Infants as young as 6 months of age reliably imitate novel actions they observe produced by an experimenter (see Lukowski & Bauer, 2014, for a review). By 9 months of age, they remember unique actions and sequences of action over delays of at least 1 month (Carver & Bauer, 1999, 2001). By 20 months of age, the length of time over which recall is apparent has increased to 12 months (Bauer et al., 2000). In the same period, the robustness of memory increases such that infants remember more, based on fewer experiences of events (Bauer & Leventon, 2013; see Bauer, 2007, 2013, for reviews). In addition, recall over long delays is more reliably observed. Whereas at 9 months of age only roughly 50% of infants show evidence of long-term recall (e.g., Carver & Bauer, 1999), by 20 months, individual differences in whether or not infants recall are the exception rather than the rule (though there remain individual differences in how much is remembered; Bauer et al., 2000).

Because the actions and sequences on which infants are tested are novel to them, their behavior provides evidence that they remember unique events. Moreover, several other features associated with autobiographical memories also are apparent in nonverbal behavior and even in early verbal behavior; the features are evident well before children provide narrative evidence of autobiographical memory. For example, because infants recall both the individual target actions (*what-action*) and the temporal order in which they occurred (*when*; e.g., Bauer et al., 2000), there is evidence that they have some capacity for organization of event representations. Infants under 1 year of age demonstrate temporal organization for events that are logically (or causally) ordered (e.g., Carver & Bauer, 1999, 2001); by 20 to 24 months of age, they also reliably order events without this inherent structure (e.g., Bauer, Hertsgaard, Dropik, & Daly, 1998). One- to 2-year-olds also remember the specific locations in which events occurred (*where*), even over substantial delays (Lukowski, Lechuga, & Bauer, 2011). Infants under 2 years of age also demonstrate that they remember specific features of events, in that they reliably select the correct objects from arrays including objects that are different from, yet perceptually similar to, those used to produce event sequences (i.e., *what-object*, *how-description*; Bauer & Dow, 1994; Lechuga, Marcos-Ruiz, & Bauer, 2001; see also Wiebe & Bauer, 2005). At least by 20 months of age, memory for the specific props used to produce an event is related to memory for the event itself (Bauer & Lukowski, 2010). Infants under 2 years of age also evidence behavior that indicates that they have some understanding of *why* events unfold as they do (e.g., Bauer, 1992)—from their reproductions of event sequences they exclude actions that are irrelevant to the outcome. Finally, as they approach and enter the third year of life and gain the fluency to provide verbal descriptions of events experienced in imitation-based tasks, children spontaneously verbalize about who took part in the events (*who*) and they provide evaluative comments on the activities in which they engaged (*how-evaluation*; Bauer & Wewerka, 1997).

These behaviors make clear that sometimes well before they provide linguistic evidence, children encode, retain, and later retrieve memory representations that feature each of the individual elements associated with autobiographical memory (see Bauer, 2007; Bauer & Leventon, 2013, for discussions).

Over the preschool and early school years, memory processes improve to the point that children remember unique experiences, even over substantial delays. Children also provide more frequent and consistent evidence that they remember the events from their own personal, self-referential perspective. For example, Hamond and Fivush (1991) found that children who experienced a trip to Disneyworld when they were 36 or 48 months of age remembered the event even 18 months later. In Bauer and Larkina (2013), children 3 years of age at the time of events remembered in excess of 60% of them over delays of as many as 3 years. The preschool and early school years also are marked by developments in the ability to locate events in a particular time and place. Children become increasingly accurate and reliable in determining which of two events occurred earlier and in justifying their choices (Pathman, Larkina, Burch, & Bauer, 2013). They also show growing command of the use of conventional indices of time, such as calendars (e.g., Friedman, Reese, & Dai, 2011) and seasons (Bauer, Burch, Scholin, & Güler, 2007; Bauer & Larkina, 2014), to locate when personally relevant event occurred. Such markers serve as a timeline along which records of events can be ordered (see Friedman, 2014; Pathman & St. Jacques, 2014, for reviews). Children also become increasingly proficient at remembering the location in which they experienced specific past events (Bauer, Doydum, et al., 2012, Bauer et al., in press). These changes mean that more events are stored with more, better elaborated, and more tightly integrated elements of autobiographical memories: unique events, with distinctive features, accurately located in time and place.

For memories to be considered autobiographical, they also must be self-referential. As such, a self concept is a necessary ingredient for an autobiography (see Fivush & Zaman, 2014; Howe, 2014). Children first begin to make reference to themselves in past events at about the same time as they begin to recognize themselves in a mirror, namely, between 18 and 24 months (Howe & Courage, 1993, 1997, for discussions). Children who recognize themselves in the mirror have more robust event memories and over subsequent months, they make faster progress in independent autobiographical reports, relative to children who do not yet exhibit self recognition (Harley & Reese, 1999; see Reese, 2014). Throughout the preschool years, children develop a more self-oriented or subjective perspective on experience, as evidenced by increasingly frequent references to their own (and others') emotional and cognitive states (see Fivush & Zaman, 2014). References to the emotional and cognitive states of the experiencer indicate the sense of personal ownership and unique perspective that is characteristic of autobiographical memories.

Memory traces are increasingly autobiographical with development. As this literature review makes clear, elements of autobiographical memory are apparent before the end of the second year of life. Indeed, review of the corpus of studies with infant participants reveals evidence of memory for all of the features or elements characteristic of autobiographical memory: *who*, *what-action*, *what-object*, *where*, *when*, *why*, *how-description*, and *how-evaluation*. In other words, even before the end of the second year of life, memory behavior does not seem to be lacking any single defining or criterial element of autobiographical memory, even though, as represented in Figure 3, Panel a, no one memory may feature all of the elements (subpanels i, ii, and iii, represent separate memory traces, none of which features all of the elements characteristic of autobiographical memory). As infants become children, more and more representations feature all of the elements associated with autobiographical memory (Figure 3, Panel b); the features become better elaborated and more tightly integrated with one another (Figure 3, Panel c). As discussed elsewhere (Bauer, 2007, 2012, 2014), the net effect is that over the course of development, memory traces of past events become more and more prototypical of the category—they become more and more autobiographical. Expressions of memory that feature many of the elements we associate with autobiography (Figure 3, Panel c)—and that are highly prototypical of the category—will be readily recognized as members of the class (the "robins" of autobiographical memory). Expressions of memory that feature fewer of the elements (Figure 3, Panel a)—and that are less prototypical of the category—are less readily recognized as members of the class (the "ostriches" of autobiographical memory). The argument put forth here is that, just as ostriches are birds even though they cannot fly, many of the memories formed early in life have a sufficient number of autobiographical features to merit recognition of them as members of the autobiographical class. From this perspective, autobiographical memory does not emerge at 5 years of age (Nelson & Fivush, 2004; or even later, as suggested by, e.g., Fivush, 2012; Fivush & Zaman, 2014). Rather, over the course of development, memories become more and more typical exemplars of the category—they feature more and more of the attributes we associate with the category and the attributes become better elaborated and more tightly integrated with one another.

Summary. The developmental literature features extensive evidence of changes in memory for personally relevant past events over the course of early childhood. In traditional criterial accounts, children's early memories lack one or more defining features of autobiographical memory and thus are not considered to be autobiographical. In a prominent traditional account, for example (Nelson & Fivush, 2004), autobiographical memory emerges at age 5 years, coincident with development of a number of features considered defining of autobiographical memory. The complementary processes perspective developed in this review recognizes elements of autobiographical memory in the behavior of infants even before the end of the second year of life; the number and variety of elements increases over early childhood (and beyond) and the elements become better elaborated and more tightly integrated with one another. As a result, it becomes easier and easier to "see" autobiographical memory.

The Paradox of Childhood Amnesia

If memory just gets better and better and more and more autobiographical, why is it that so few memories from the first years of life survive (i.e., memory seems to get worse and worse)? I suggest that the solution to this paradox can be found by considering the complementary function of increases in the quality of memories, namely, the vulnerability of memories, especially those formed early in life (when the memories are of lower quality, as just discussed). In effect, events are remembered, but they also are

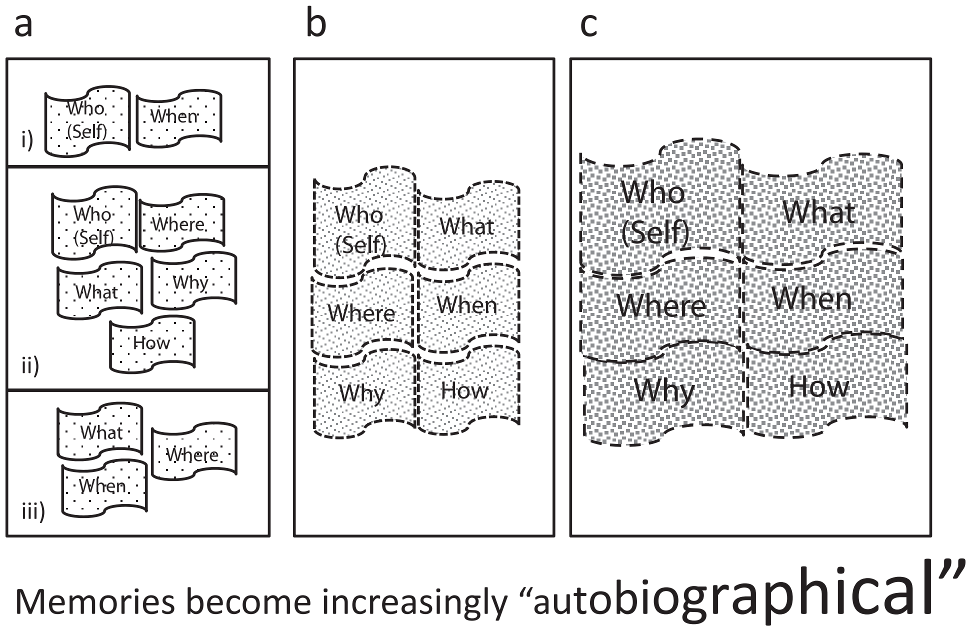

Figure 3. Depiction of course of development of autobiographical memory from the complementary processes perspective. The elements characteristic of autobiographical memory include who (self), what, where, when, why, and how (evaluative or subjective perspective). Early in development, individual memory representations (represented in Panel a, subpanels i, ii, and iii) may feature only a subset of the elements characteristic of autobiographical memories, yet no one element is missing from all memory traces. With development, memory traces feature more elements (Panel b). The elements also become more elaborated (depicted with increases in size and texture), and the elements become more tightly integration with one another (depicted with reduction in the spacing between elements, Panel c). As a result, over the course of development, memories of personally relevant specific past events take on more and more of the features of autobiographical memory.

forgotten (even by adults), and children forget at a faster rate, relative to adults. Essentially, youth is a risk factor for autobiographical memories. More important, events are not functionally forgotten because they are repressed (Freud, 1916/1966). Nor do they become inaccessible because of the onset of language (e.g., Neisser, 1962), or different senses of self associated with different life periods (e.g., Conway, 1996). Rather, early memories are forgotten because of normative processes involved in transformation of labile representations of experience into enduring memory traces. These suggestions are supported in the next section.

The Vulnerability of Memory Traces Declines Over Development

The suggestion that patterns of what we remember can be explained in part by patterns of what we forget is not new. There is a long tradition of work on forgetting functions in the adult literature (e.g., Ebbinghaus, 1885; Rubin & Wenzel, 1996; Wixted & Ebbesen, 1991, 1997) and in the developmental literature there have been examinations of the variance in long-term recall that can be explained by forgetting shortly after experience of an event (e.g., Bauer, 2005; Bauer, Van Abbema, & de Haan, 1999; Howe & O'Sullivan, 1997; discussed in more detail below). However, until the beginning of the 21st century, there were virtually no data that directly addressed the suggestion that the characteristic distribution of autobiographical memories across the life span—including the phenomenon of childhood amnesia—could be explained in part by the relative vulnerability of memory traces formed early in life. To do so requires documenting memories created in the period eventually obscured by childhood amnesia and then prospectively tracking them across the boundary of the amnesia, to determine whether they are still remembered. However, throughout most of the century-plus of research on childhood amnesia, virtually all of the studies on the phenomenon were with adults; none of the studies was prospective. Early reports involving child subjects were retrospective—they asked what was retained from childhood, but not what was lost. As a result, though the possibility that memory trace vulnerability was part of the explanation of childhood amnesia had been implicated theoretically (Bauer, 2007, 2008; Olson & Newcombe, 2014; Peterson, Warren, & Short, 2011; Tustin & Hayne, 2010), there has been little opportunity to evaluate its role empirically.

One of the small number of prospective investigations of childhood amnesia in childhood was conducted by Cleveland and Reese (2008). To investigate the process of loss of (or loss of access to) memories for early life events, they recorded conversations between mothers and their children about past events at each of ages 19, 25, 32, 40, and 65 months. The fact that, during these interviews, the children provided unique information about the events—information that had not been given by their mothers—provided evidence that they had formed memories of them (a criterion of at least two unique pieces of information is typical in this literature). When the same children were 66 months of age, they were tested for memory for events from each of the prior data collection points. Thus, at 66 months, children were asked for their memories of events from 1, 26, 34, 41, and 47 months in the past. The number of events that the 5.5-year-olds remembered decreased steadily as the retention interval increased. They recalled roughly 80% of events from only 1 month in the past but fewer than 40% of events from 47 months in the past. Fivush and Schwarzmueller (1998) reported a similar trend, albeit higher rates of retention, from 8-year-olds interviewed about events from ages 3.5 and 4 (77% of events remembered) versus 5 and 6 (92% of events remembered) years of age. Both studies provide evidence that as time goes by, forgetting (or loss of access) becomes more pronounced. However, in both studies, events with the longest delays between the initial and later tests also were events with the earliest age of encoding (i.e., 19 months in Cleveland & Reese, 2008). Thus, it is not possible to determine whether forgetting was a result of the length of the delay or the age of the children at the time of experience of the events. Furthermore, only Fivush and Schwarzmueller (1998) documented the fates of memories over the boundary of childhood amnesia (i.e., beyond age 7 years).

In Bauer and Larkina (2013) and Van Abbema and Bauer (2005), we held the age at encoding constant and varied the retention interval, thereby allowing for examination of fates of early memories over time. Specifically, we recorded conversations of dyads of 3-year-old children and their mothers as they discussed a number of events from the recent past. As for the studies just discussed (Cleveland & Reese, 2008; Fivush & Schwarzmueller, 1998), children's own unique contributions to the conversations made clear that they had formed memories of the events. Thus, we had documentation of memories from the age period corresponding to that from which adults report their earliest memories. We then tested different subgroups of the children again roughly 2, 3, 4, 5, or 6 years later, at the ages of 5, 6, 7, 8, or 9 years of age—ages at which, based on adult data, we would expect to see evidence of childhood amnesia. The later interviews were conducted by experimenters (rather than the children's mothers). The data are strongly suggestive of a role for forgetting in explanation of the onset of the amnesia. Whereas the children 5 to 7 years of age remembered more than 60% of the events from age 3 years, the 8- and 9-year-olds remembered fewer than 40% of the events. The difference in levels of recall was apparent even though all children were provided with prompts and cues to aid their memories, as determined to be necessary when free-recall failed. Moreover, the number of children who recalled none of the events from age 3 years also suggested a change in the accessibility of early memories after age 7 years. Whereas a maximum of 6% of children ages 5, 6, and 7 years recalled none of the events from age 3 years, 37% of 8-year-olds and 25% of 9-year-olds recalled none of the early life events. Again, the difference in levels of recall was observed even though all children received prompts and cues, as necessary.

There also is evidence that younger children forget more rapidly than older children. Morris et al. (2010) examined recall after a 1-year delay of events originally experienced at ages 4, 6, and 8 years. Children's contributions to the experimenter-conducted interviews made clear that they remembered the events. One year later, when the children were 5, 7, and 9 years of age, children's recall was tested again. As in the studies just discussed (Bauer & Larkina, 2013; Van Abbema & Bauer, 2005), children were given prompts and cues to aid their memories, as determined to be necessary when free-recall failed. The children who had been the youngest at the time of the events remembered ~70% of them 1 year later. In contrast, the children who had been the oldest at the time of the events remembered 90% of them 1 year later. This pattern is strong evidence that within the period eventually obscured by childhood amnesia, the rate of forgetting is more accelerated among younger relative to older children.

Accelerated rate of forgetting. The facts that (a) even young children form memories of early life events but then seemingly forget them over time, and (b) younger children forget more rapidly than older children, demand an explanation of childhood amnesia that recognizes accelerated forgetting in childhood. Wetzler and Sweeney (1986) provided suggestive evidence of this phenomenon based on adult data. As noted earlier, they fitted a power function to data obtained by Rubin (1982) using cue word elicitation. The power function was a good fit to data from age 8 to adulthood. In contrast, it was a poor fit to data from birth to age 6 years, implying accelerated forgetting of memories from ages 6 and below.

In two studies, my colleagues and I have provided direct evidence of accelerated forgetting in childhood; the pace of forgetting is accelerated well beyond age 6 years. In Bauer et al. (2007), we used the cue word technique to examine the distribution of autobiographical memories in children 7 to 10 years of age. The children successfully generated memories in response to the cue words and accurately dated them, based on parental report. The distribution of memories produced by the children was better fit by the exponential than by the power function (see Table 1). The same pattern was obtained in an independent study by Bauer and Larkina (2014). We tested 20 children at each of the ages of 7, 8, 9, 10, and 11 years (100 children total), as well as two groups of adults: college students and middle-aged adults. As reflected in Table 1, the data from the children provided a replication of the results of Bauer et al. (2007). For the entire sample of children and for each group of children (7-, 8-, 9-, 10-, and 11-year-olds) separately, the best fitting function to the distribution was the exponential. In contrast, for both adult samples, the best fitting function was the power. The relative fits are illustrated in Figure 4. These data clearly suggest that as old as age 11 years, the distribution of children's autobiographical memories is not adult-like. In contrast to adults, children experience exponential forgetting.

Functional outcome of exponential forgetting. The exponential function implies a constant half-life. That is, over each unit of time (e.g., a month) the number of memories in the corpus decreases by one half. To use the earlier example, if Time 1 recall was of 100 memories, then recall at Times 2, 3, and 4 would be of 50, 25, and 12.5 memories, respectively. This pattern implies that the pool of memories available for recollection is ever-shrinking, suggesting that memories do not consolidate (see Bauer, 2012; Bauer et al., 2007; and Bauer & Larkina, 2014, for discussions). The contrast between a distribution of memories characterized by the exponential function relative to the power function is provided in Figure 5. The distributions differ both in terms of the initial rate of forgetting (also apparent in Figure 4), and in terms of the number of memories lost from the corpus with each unit of time. Consider that for both adults and children, many events are lost from memory virtually immediately after experience of them (see T2 in Figure 5). More important, for adults, the rate of forgetting slows over time, with individual memories becoming less vulner-

Table 1
Fit Indices for Power and Exponential Functions of the Distribution of Autobiographical Memories Elicited by Cue Words for Children 7 To 11 Years of Age and Adults

	Age group		Fit by function	
Study	Overall	Individual age groups	Power	Exponential
Bauer et al. (2007)	Children 7 to 10 years		.95	.98
Bauer & Larkina (2014a)	Children 7 to 11 years		.82	.94
		7-year-olds	.94	.97
		8-year-olds	.87	.92
		9-year-olds	.84	.89
		10-year-olds	.82	.88
		11-year-olds	.72	.86
	Adults		.91	.65
		College students	.84	.61
		Middle-age adults	.93	.70

Note. For each age group, the best fit function is highlighted by a box.

able to disruption and interference, resulting in a relatively stable corpus (e.g., Wixted, 2004, for discussion). In contrast, children experience a sharp initial decline in the number of memories in the corpus (T2) and unlike for adults, for them, the rate of forgetting does not slow down—it is exponential.

The apparent fact of the exponential form of forgetting in childhood has two important implications for the fates of memories formed in the first decade of life. First, over a given unit of time, children lose more memories than adults do. Second, because the rate of forgetting is constant, the memories that survive the initial ravages of time may nevertheless eventually succumb to forgetting. Over time, the corpus or pool of memories of early life events shrinks. Moreover, because the rate of forgetting does not slow down, the pool of memories is ever-shrinking, contributing to the appearance of a “childhood amnesia component” (Pillemer & White, 1989)—a smaller number of memories than expected by normal forgetting (i.e., with “normal” forgetting equated with an adult rate, characterized by the power function). We may think of the process as one that reduces “pools” of memories to isolated “puddles” of memories, resulting in a sparse representation. More isolated representational structures are more difficult to retrieve.

Understanding children’s “earliest memory” data. Thinking in terms of “pools to puddles” of memories over the course of the first decade of life aids in understanding of the patterns of recall of early autobiographical memories by adults that is associated with childhood amnesia. It also aids in understanding of the emerging body of data on “earliest memories” of children. As noted above, studies of children’s recall of their earliest memories are a relatively new addition to the literature and the number of studies is small. They reveal that by the end of the first decade of life, children’s earliest memories show the same distribution as adults. Specifically, queries about the age of earliest memory among children as young as 6 years of age and as old as 19 years have produced estimates of the average age of earliest memory at 38 months, with a range of 28 months to 45 months (Jack, MacDonald, Reese, & Hayne, 2009; Larkina, Merrill, Fivush, & Bauer, 2009; Peterson, Grant, & Boland, 2005; Reese, Jack, & White, 2010). The estimates fit comfortably around the 3- to 4-year (36 to 48 month) range obtained from adults.

In contrast to the adult-like distribution of memories among older children, younger children’s recall of their earliest memories differs from the patterns seen in adulthood in at least two ways: age-cohort effects and instability in the memory identified as “earliest.” First, age-cohort effects are apparent in children but not in adults. Two studies have revealed age-cohort effects within childhood, such that the age of earliest memory is earlier for younger children relative to older children. For example, in Tustin and Hayne (2010) the average age of earliest memory among 5-year-old children was 1.7 years, whereas the average age of earliest memory among 12- to 13-year-old children was 2.5 years. Similarly, in Peterson et al. (2005), the average age of earliest memory among 6- to 9-year-old children was 3 years, whereas the average age of earliest memory among 10-year-olds was 3.5 years. In contrast, as noted earlier, among adults, there are not age-cohort effects. Whether tested at 20 years of age or 70 years of age, the average age of earliest memory among adults is 3 to 4 years (Rubin & Schulkind, 1997).

There also is evidence of less stability in the “earliest memory” among children relative to adults, both in terms of the memory identified as the earliest and in terms of the age of earliest memory. Peterson et al. (2011) interviewed children 4 to 13 years of age about their earliest memories. Two years later, they asked the same children to once again report their earliest memories. Strikingly, among children 4 to 7 years of age at the first interview, there was little overlap in the memories nominated at the two time points: only 7% of 4- to 5-year-olds and 13% of 6- to 7-year-olds nominated the same earliest memory, whereas 12- to 13-year-olds were consistent 39% of the time. When the events were the same, the children were inconsistent in their estimates of their ages at the time of the events. Between queries, the estimated age of earliest memories increased from 32 to 39.6 months. In contrast, over a 3-year period, 82% of adult women identified the same memories as their earliest and they varied by only 0.3 months in dating the event that gave rise to the memory (38.9 vs. 38.6 months; Bauer et al., in press). Thus, there is substantially less consistency in the corpus of earliest memories among children relative to adults. The pattern is to be expected of a pool of memories that is ever-shrinking and ever-changing.

Summary. Throughout most of the history of research on childhood amnesia, the sole participants were adults. Without exception, the studies were retrospective. As a result, the field lacked the most relevant data on the source of the phenomenon, namely, documentation of memories formed in the period eventually obscured by the amnesia, and tracking of the memories across the boundary. With the

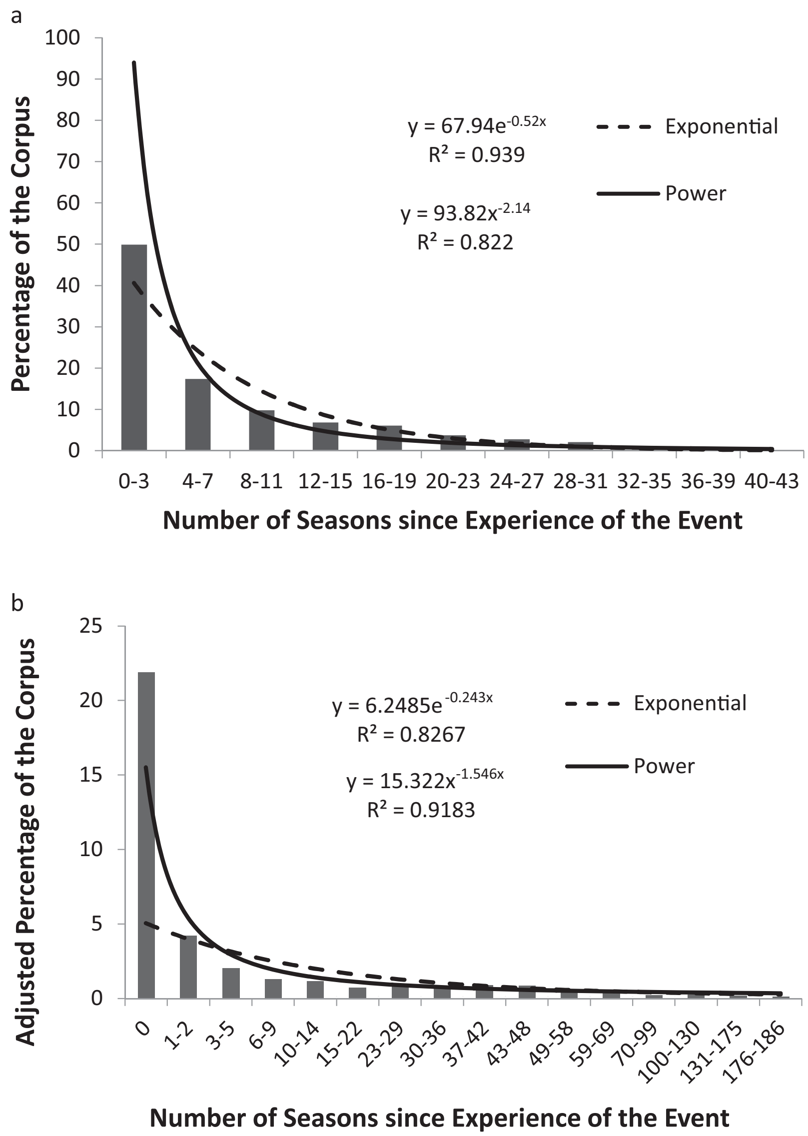

Figure 4. The power function and exponential function fitted to the distribution of memories generated by children 7 to 11 years of age as a function of the number of seasons since experience of the event (Panel a, based on 1,995 memories). The power function and exponential function fitted to the distribution of memories generated by college-age and middle-age adults (Panel b, based on 800 memories). For adults, the figure represents adjusted data such that the horizontal axis is the time (the mean number of seasons to the middle of the bin) since experience of the event, and the vertical axis is the percentage of data averaged across the seasons included in the bin (see Bauer & Larkina, 2014, for discussion). Adapted from "Childhood Amnesia in the Making: Different Distributions of Autobiographical Memories in Children and Adults," by P. J. Bauer and M. Larkina, 2014, *Journal of Experimental Psychology: General*, *143*, p. 605. Copyright 2014 by the American Psychological Association.

advent of such data, it has become clear that childhood amnesia emerges by middle childhood. Specifically, by the time children are 8 to 9 years of age, they have forgotten a substantial proportion of early childhood events they once remembered (Bauer & Larkina, 2013; Van Abbema & Bauer, 2005). The available data strongly suggest that the amnesia emerges as a result of exponential forgetting in childhood, relative to adulthood. A consequence of exponential forgetting by children is that the pool of autobiographical memories they have formed eventually diminishes to isolated puddles of memories; isolation makes the remaining memories even more difficult to retrieve. Findings of exponential forgetting in childhood explain the emergence of childhood amnesia in childhood. They also bring order to an array of findings on children's earliest memories, and help to explain why in some cases they are different, relative to adults. In the next section, I take up the question that now demands to be addressed, namely, why childhood is a period of accelerated forgetting, in the

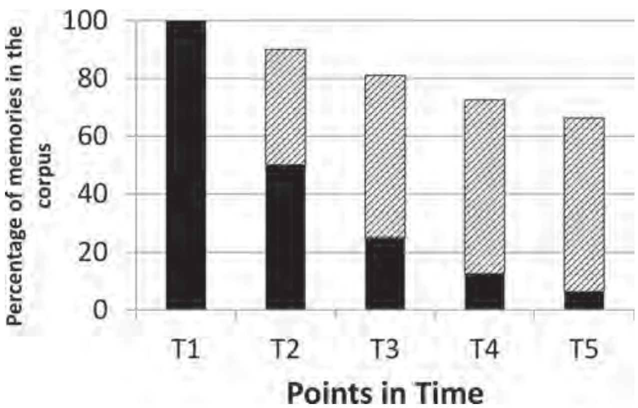

Figure 5. Schematic depiction of the number of memories in the corpus that survive over each hypothetical unit of time (T1-T5) in distributions characterized by the exponential function (dark bars) and the power function (hashed bars).

face of salient increases in the quality of memory representations that are formed.

The Dynamics of Increases in the Quality and Decreases in the Vulnerability of Memory Traces and Mechanisms of Developmental Change

The theoretical argument I have advanced recognizes the complementary processes involved in the creation, retention, and later retrieval of memories (glossed as increases in the quality of memory traces) and in the loss of representational traces from memory (glossed as vulnerabilities in memory traces). In this section, I make explicit the interaction of these processes. Specifically, I highlight improvements in the quality of the representations that are formed. Over developmental time, memory representations include more of the features that characterize autobiographical memories, and the features are better elaborated and more tightly integrated. The result is mnemonic materials that are of higher quality. At the same time, there are developments in the neural substrate operating on the available representations, both in terms of the structures involved and in the level of connectivity of the network of structures. The developments herald more efficient and effective cognitive and mnemonic processing, resulting in decreases in the vulnerability of memory traces to forgetting. Put another way, over developmental time, less and less negatively impacts the mnemonic representations that are formed. The net effect is that with development, more and more memories of higher and higher quality survive to be recalled at later points in time, producing the characteristic distribution of autobiographical memories across the life span. I first summarize the processes involved in the formation of memory representations, before discussing the developmental interactions.

Processes Involved in the Formation of Memory Representations

The layperson's view of memory is of a file cabinet stuffed full of file folders, the contents of each of which is a memory representation. To recall, one finds the right folder, pulls it out of the cabinet, opens it, and reads off what happened to whom and when. In actuality, of course, memory is nothing like a file cabinet or folder. Rather, memory representations are made up of individual bits and pieces of experience that are encoded in synaptic connections between individual neurons distributed across the cortex. They begin their lives as patterns of neural activity that give rise to conscious experience of events. Their continued existence as "memories" depends on subsequent processing carried out by a multicomponent neural network that includes structures in the medial-temporal lobe, as well as the neocortex. Their subsequent retrieval entails recreation of the pattern of neural activity that gave rise to the event in the first place. Each of these steps is elaborated below (see Eichenbaum & Cohen, 2001; Kandel & Squire, 2000; Manns & Eichenbaum, 2006; Nadel, Samsonovich, Ryan, & Moscovitch, 2000; Rubin, 2005, 2006; Winocur & Moscovitch, 2011; Zola & Squire, 2000; for reviews of these processes).

Memory begins with encoding of experience into a memory trace. Encoding, in turn, begins with the initial registration of information in the brain. The whole of experience does not impinge upon the brain at once in the same time and place, but is distributed across multiple cortical areas. For example, cell fields in primary somatosensory cortex register object or event-related tactile information from the skin and proprioceptive inputs from the muscles and joints. Simultaneously, fields in primary visual cortex register the form, color, and motion of the object or event, and fields in primary auditory cortex respond to the various attributes of the sounds associated with the object or event. Inputs from these primary sensory cortices are sent (projected) to unimodal sensory association areas where they are integrated into whole percepts of what the object or event feels like, looks like, and sounds like, respectively. Unimodal association areas in turn project the information to polymodal (also termed multimodal) posterior-parietal, anterior-prefrontal, and limbic-temporal association areas. The coordinated activity of these cortical areas gives rise to experience of a coherent event.

For the experience of an event to endure as a memory, the pattern of neural activity giving rise to the experience must undergo a process of stabilization into a memory trace and integration of the trace into long-term storage. This process—known as *consolidation*—depends on neurochemical and neuroanatomical changes that create a physical record of the experience (McGaugh, 2000). It results from the coordinated actions of structures in the medial-temporal lobes and cortical association areas. Specifically, inputs from the association areas are projected to structures in the medial-temporal lobes, with inputs that specify the nonspatial or "object" features of experience projected to perirhinal cortex, and inputs that specify the spatial or "contextual" features of experience projected to parahippocampal cortex (see, e.g., Manns & Eichenbaum, 2006, for a review). These cortices are thought to hold the still-segregated streams of experience (i.e., nonspatial and spatial) in an "intermediate-term memory" on which the hippocampus proper operates. The information is held in the medial-temporal cortices temporarily (over periods of at least several minutes), presumably as a result of prolonged neuronal firing (e.g., Suzuki, Miller, & Desimone, 1997).

To be stabilized into a coherent memory trace, information must make its way into the hippocampus proper. It does so via the connecting link of the entorhinal cortex. Specifically, the perirhinal and parahippocampal cortices project their highly processed sensory inputs to the lateral and medial aspects of the entorhinal cortex, respectively. The entorhinal cortex projects these inputs into the hippocampus proper where all of the different components of the event are bound into a single representation (see Manns & Eichenbaum, 2006, for additional discussion). This "binding" of the elements of experience depends upon iterative processing of the conjunctions and relations among the stimuli that gave rise to the event. That is, the pattern is regularly "refreshed" by additional neural signaling among the hippocampus, the surrounding medial-temporal cortices, and the association areas. It also maintains and strengthens the linkages between the distributed cortical representations that make up the entire event. As it does so, it strengthens the intracortical connections between the different elements of the event representation. By some accounts, representations may strengthen to the point that, eventually, they no longer require the activity of the hippocampus for their maintenance (Alvarez & Squire, 1994; McClelland, McNaughton, & O'Reilly, 1995; Reed & Squire, 1998; Squire, 1992; Zola & Squire, 2000). By other accounts, memory traces remain dependent on the hippocampus, especially for retrieval (e.g., Moscovitch & Nadel, 1998; Nadel et al., 2000; Winocur & Moscovitch, 2011).

Iterative processing of the conjunctions and relations among event-related stimuli in the medial-temporal structures not only serves to stabilize new memory representations—it also supports the integration of the new information with that previously stored (e.g., McKenzie & Eichenbaum, 2011). The basis for integration is overlapping or shared elements. To the extent that a new event memory shares elements with memories already in storage, the representations will be simultaneously activated. Neurons that are repeatedly activated together (synchronous convergence) tend to become associated. The result is an entire pattern of interconnection of new information with old.

Finally, the *raison d'etre* for the consolidation and storage of memories is so that they can be retrieved at some later time. Retrieval is, in essence, a reactivation of the neural network that represents the event. Reactivation occurs because "An internal or external stimulus, whose cortical representation is part of the network by prior association, will reactivate that representation and, again by association, the rest of the network" (Fuster, 1997, p. 455). Specifically, retrieval of information from long-term stores is accomplished by the same circuits as were involved in initial registration of the experience. In the case of autobiographical memory, neuroimaging studies have revealed that retrieval is carried out by a distributed network involving the hippocampus and surrounding cortices, amygdala (for emotional events), retrosplenial cortex, posterior parietal regions (including precuneus), visual cortex, and lateral and medial prefrontal cortex (Addis, McIntosh, Moscovitch, Crawley, & McAndrews, 2004; Cabeza et al., 2004; Greenberg, Rice, Cooper, Cabeza, Rubin, & LaBar, 2005; see Gilboa, 2004; Rubin, 2005, 2006; Shimamura, 2011, for reviews; see Maguire, 2001; Svoboda, McKinnon, & Levine, 2006, for meta-analyses). During the initial phases of memory search, the more anterior, frontal-temporal components of this network are especially active, whereas in the later phases of retrieval—as the trace is elaborated—the more posterior, occipital, and parietal regions are especially active (e.g., Daselaar, Rice, Greenberg, Cabeza, LaBar, & Rubin, 2008; McCormick, St-Laurent, Ty, Valiante, & McAndrews, 2013; St. Jacques, Kragel, & Rubin, 2011;).

Developmental Interactions Involved in Increases in the Quality and Decreases in the Vulnerability of Memory Traces

Recognition that memory traces are distributed representations of loosely affiliated elements awaiting consolidating "glue" to hold them together, aids in understanding of the importance of considering both the number and the richness of the elements of the experience that are available for inclusion in the memory trace and the efficiency and efficacy of the neural processes implicated in memory formation—as well as their interaction—to explanation of childhood amnesia. To the extent that the distributed representations become more complete, elaborated, and more intimately tied to related constructs and representations, the larger and more numerous the surfaces upon which to apply the consolidating glue. To the extent that the glue that works to hold the representations together become more efficient and effective, fewer of the elements of experience will escape the bonds and be lost from the memory trace. I discuss each element of the equation, beginning with the glue.

Development of the glue: The neural substrate of memory. The glue is a metaphor for the stabilizing "efforts" of the medial-temporal and cortical structures that work to transform transient, labile representations of experience into enduring traces. The efficiency and efficacy of those processes is intimately tied to the developmental status of the neural substrate responsible for them. As explained in detail elsewhere (see, e.g., Bachevalier, 2014; Bauer, 2007, 2009a, 2013; Ghetti & Bunge, 2012; Ghetti & Lee, 2014; Nelson, de Haan, & Thomas, 2006, for reviews), portions of the neural network implicated in episodic and thus autobiographical memory develop early, whereas many of the structures (or aspects thereof), as well as the connections between and among the structures, undergo a protracted developmental course that continues well into adolescence. This leads to expectations of changes in the way in which the network functions throughout infancy and childhood (and even beyond). Early changes support the emergence of the capacity to form, retain, and later retrieve self-relevant memories of past events; later changes herald more efficient and effective function and a concomitant reduction in the rate of forgetting.

Early changes. As outlined above, over the first months of life there are salient changes in the robustness, reliability, and temporal extend of infants' memories. The changes likely are related to postnatal changes in brain that take place over the course of infancy (as well as other influences, such as the social environment in which early development takes place; e.g., Fivush, 2014; Reese, 2014). Whereas much of brain development occurs prenatally, there also are pronounced changes in the first years of postnatal life.

With regard to the structures implicated in memory for specific past events, as summarized by Seress and Ábrahám (2008), in the medial-temporal lobes, hippocampal cells are generated during the first half of prenatal development and have migrated to their final destinations by birth. Synapses are apparent by about 15 weeks gestation. The number of hippocampal synapses and synaptic density increases until about 6 months of age, at which time adult levels are reached. At this same time, glucose utilization (an indicator of energy use) also reaches adult levels, likely in relation to the increased number of synapses (Chugani, 1994; Chugani & Phelps, 1986). By the end of the first year of life, the volume of the hippocampus has doubled (Gilmore et al., 2012).

Within the hippocampus, the development of the specific region of the dentate gyrus is more protracted (Seress & Ábrahám, 2008). This area of the brain includes about 70% of the adult complement of cells at birth; the remaining cells are produced postnatally (neurogenesis in this region has been confirmed in childhood and beyond; Tanapat, Hastings, & Gould, 2001). Morphologically the structure is adult-like around 12 to 15 months after birth. Increases in synaptic density also are somewhat protracted relative to what is observed in other regions of the hippocampus; synaptic density in this region increases starting around 8 to 12 months after birth and peaks around 18 to 20 months (Eckenhoff & Rakic, 1991). Prefrontal cortex undergoes its early development at a similar pace. Synaptic density in this region increases beginning around 8 months after birth and reaches its peak between 15 and 24 months (Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997). Synapses appear adult-like in their morphology by 24 months (Huttenlocher, 1979).

Achievement of the peak number of synapses in both the hippocampus and prefrontal cortex has important implications for behavior. As argued by Goldman-Rakic (1987), with this development, we should expect to see the emergence of what she termed the "signatory" (or characteristic) functions of the neural substrate; attainment of mature levels of function would coincide with the period of synapse elimination in the network. Though Goldman-Rakic made this argument with respect to cortical regions, extension of the suggestion to the entire temporal-cortical network leads to the prediction of emergence of the signatory function of long-term memory for specific past events by the end of the second year of life, with continued development for years thereafter. Specifically, the cortical components of the network, and the connections both within the medial-temporal lobe (i.e., those involving the dentate gyrus of the hippocampus) and between the cortex and the medial-temporal components, would be expected to reach functional maturity over the course of the second year of life, coincident with estimates of achievement of the peak of synaptogenesis by 20 months in the dentate gyrus, and by 24 months in the prefrontal cortex. The expectation of developmental changes for months and years thereafter stems from the schedule of protracted pruning both in the dentate gyrus (until 4 to 5 years; e.g., Eckenhoff & Rakic, 1991) and in the prefrontal cortex (throughout adolescence; e.g., Huttenlocher & Dabholkar, 1997). These estimates are consistent with the behavioral data summarized above, which indicate the ability to recall multiple episodic features (e.g., *what*, *where*, and *when*) at least by the end of the second year of life.

Later changes. Postnatal changes in the neural substrate that supports memory for specific past events and thus autobiographical memory continue well beyond the first 2 years of life; the changes have implications for memory behavior. At the level of the brain as a whole, children's brains have reached roughly 90% of adult volume by the time they are 5 years of age (Kennedy, Makris, Herbert, Takahashi, & Caviness, 2002). There are further volume increases through puberty (Caviness, Kennedy, Richelme, Rademacher, & Filipek, 1996). Beyond puberty, there is actually a reduction in gray matter volume, likely associated with synaptic pruning and other regressive processes (Gogtay et al., 2004; Huttenlocher, 1990; Jernigan, Trauner, Hesselink, & Tallal, 1991). In contrast, white matter volume increases linearly with age (Giedd et al., 1999). The increases are associated with greater connectivity between brain regions and with myelination processes that continue into young adulthood (e.g., Johnson, 1997; Klingberg, Vaidya, Gabrielli, Moseley, & Hedehus, 1999; Schneider, Il'yasov, Hennig, & Martin, 2004).

Different cortical structures undergo changes in gray matter volume at different rates. Specifically, longitudinal data (e.g., Østby, Tamnes, Fjell, & Walhovd, 2011) indicate that the nonlinear changes in cortical gray matter occur earlier in the frontal and occipital poles, relative to the rest of the cortex, which matures in a parietal-to-frontal direction. The superior temporal cortex is last to mature (though the temporal poles mature early; Gogtay et al., 2004). Prefrontal cortex undergoes an especially protracted development, with adult levels of synapses not reached until late adolescence or even early adulthood (Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997), and myelination processes continuing well into adolescence or young adulthood (e.g., Johnson, 1997; Klingberg et al., 1999; Schneider et al., 2004). It is not until adolescence that neurotransmitters such as acetylcholine reach adult levels (discussed in Benes, 2001).

The volume of the hippocampus also undergoes changes, with gradual increases into adolescence (e.g., Gogtay et al., 2004; Østby, Tamnes, Fjell, Westlye, Due-Tønnessen, & Walhovd, 2009; Pfluger et al., 1999; Utsunomiya, Takano, Okazaki, & Mistudome, 1999). In addition, myelination in the hippocampal region continues throughout childhood and adolescence (Arnold & Trojanowski, 1996; Benes, Turtle, Khan, & Farol, 1994; Schneider et al., 2004). It also is subregion specific, with some subregions achieving mature patterns of myelination in infancy (i.e., in the fimbria), childhood (i.e., CA1 and CA3 subfields), and after puberty (i.e., hilus of the dentate gyrus; Ábrahám et al., 2010). There also are marked developmental changes in connectivity between the hippocampus and other neural regions (see, e.g., Schahmann & Pandya, 2006, for a review).

Implications for behavior. Developmental changes in the structures that subserve memory as well as in the connections among them can be expected to have implications for memory behavior (see Bauer, 2007, 2009a, 2009b, 2013, for other reviews). Late development of aspects of the hippocampal formation may be especially critical because of their role in stabilization and integration of memory traces into long-term storage. The immaturity of these structures and connections between them would present challenges to these processes. The challenges may be most pronounced until 4 to 5 years of age, when the schedule of protracted pruning of synapses in the dentate gyrus of the hippocampus has largely been reached (e.g., Eckenhoff & Rakic, 1991).

The suggestion that the processes involved in stabilization and integration of memory traces into long-term storage are a source of variance in recall in infancy and early childhood is supported by behavioral and electrophysiological data. Specifically, using both behavioral measures (e.g., Bauer, 2005; Bauer, Güler, Starr, & Pathman, 2011; Bauer et al., 1999) and measures of recognition obtained from event-related potentials (ERPs; Bauer et al., 2006; Bauer, Wiebe, Carver, Waters, & Nelson, 2003), my colleagues and I have probed the integrity of memory traces at various points post encoding, ranging from minutes after experience of an event to 2 weeks later. We then examined the proportion of variance in long-term recall explained by the measures obtained shortly after encoding, as memory traces presumably are undergoing consolidation. In these cases, the measure is not of forgetting, per se, but of what is retained. However, because what is retained hours to days after experience of an event is inversely related to the amount forgotten, the logic holds. We have found that estimates of memory obtained hours to days after experience of events are predictive of infants' recall after subsequent delays of weeks to a month. The measures account for significant unique variance above and beyond that explained by measures of encoding, and in some cases, render encoding-related variance nonsignificant (Pathman & Bauer, 2013). Similar effects are observed for children as old as 3 and 4 years of age (Bauer, Larkina, & Doydum, 2012). Indeed, as summarized in Howe and O'Sullivan (1997), throughout childhood, memory failure at the level of consolidation and/or storage accounts for the largest proportion of age-related variance in children's recall of laboratory stimuli.

The data discussed earlier on the distribution of autobiographical memories across the first decade of life (Bauer et al., 2007; Bauer & Larkina, 2014) indicate that failure at the level of consolidation and/or storage extends beyond laboratory stimuli to personally relevant events. They suggest that at least until the age of 11 years, memories may be lost because they fail to consolidate. Failed consolidation in turn provides an explanation for the accelerated rate of forgetting of autobiographical experiences in childhood (Bauer et al., 2007; Bauer & Larkina, 2014). Failed consolidation and exponential forgetting may stem not only from the relative immaturity of the neural network involved, but also may be linked with hippocampal neurogenesis, which is argued to play a role in forgetting (e.g., Frankland, Köhler, & Josselyn, 2013). Rates of neurogenesis decline with age (e.g., Kuhn, Dickinson-Anson, & Gage, 1996), raising the possibility that higher rates in the first years of life may contribute to exponential forgetting in childhood. Consistent with this suggestion, in infancy, when rates of neurogenesis are high, decreasing neurogenesis (either genetically or pharmacologically) after new memory formation mitigates forgetting in the mouse model (Akers et al., 2014). We also may speculate that consolidation processes would be impacted by sleep parameters that change over the course of development (e.g., Ohayon, Carskadon, Guilleminault, & Vitiello, 2004). Changes in slow-wave sleep, in particular, may have implications for memory consolidation and the form of forgetting (e.g., Rasch, Büchel, Gais, & Born, 2007). Conversely, data from Østby et al. (2011) and DeMaster, Pathman, Lee, and Ghetti (2012) suggest that increases in the reliability of consolidation processes may be related to changes in hippocampal volume (see also Ghetti & Lee, 2014 and Sowell, Delis, Stiles, & Jerningan, 2001, for discussion). Region-specific activation in the hippocampus—specifically, in the anterior region—has been linked with better memory for the types of associations among stimuli that are part-and-parcel of episodic memory (Paz-Alonso, Ghetti, Donohue, Goodman, & Bunge, 2008; Ghetti, DeMaster, Yonelinas, & Bunge, 2010).

Cortical structures also are implicated in the consolidation processes that effectively stabilize memory traces and accomplish their integration into long-term storage, as well as in their initial encoding and later retrieval. As such, protracted development of cortical structures can be expected to be related to memory behavior. Consistent with this suggestion, Østby and colleagues (2011) found correlations between the thickness of left orbitofrontal cortex and encoding success in children 8 to 19 years of age. Studies of encoding-related activation indicate age-related increases in recruitment of prefrontal cortical regions across childhood. For instance, Wendelken, Baym, Gazzaley, and Bunge (2011) found that among children 8 to 13 years of age, older children had higher levels of recruitment of the dorsolateral prefrontal cortex during encoding of faces and scenes, which in turn modulated subsequent memory (see also Ofen, Kao, Sokol-Hessner, Kim, Whitfield-Gabrieli, & Gabrieli, 2007). Finally, though the necessary studies have not been done, it is logical to assume that developmental changes in medial prefrontal cortex, posterior parietal cortex, and precuneus would impact the efficiency with which autobiographical memories are accessed and elaborated (e.g., Cabeza et al., 2004; Daselaar et al., 2008; McCormick et al., 2013).

Summary. The efficiency and efficacy of the processes by which transient, labile representations of experience are transformed into enduring memory traces is closely tied to the developmental status of the neural substrate responsible for them. In the first several months of life, the substrate develops rapidly such that as infants approach the end of second year, the neural structures and network connections seemingly have reached a level of maturity sufficient to support their signatory function. Though the function is apparent, it is far from fully mature. Over the subsequent period of childhood and early adolescence, the structures and network continue to develop, heralding increases in the efficiency and thus the efficacy with which it glues or binds together the elements of experience into enduring traces. The rate of progress is relatively slow, such that at least for the first full decade of life, effective loss from memory is faster than the rate in adolescence and adulthood.

Development of the "surface": The raw materials of memory. Of course, the power of the consolidating glue is only as good as the raw materials to which it is applied. In terms of memory representations, simply put, if there is less available to start with, less will survive the ensuing encoding and consolidation processes, and less will be available for retrieval. As discussed above, the elements associated with autobiographical memory are apparent in memory behavior even early in childhood. That is, there does not seem to be any one criterial feature "missing" from young children's representations of past events that would preclude them from forming autobiographical memories. However, young children's memories nevertheless seem rather atypical of the category—they are more ostrich-like than robin-like. They have this quality in part because any given memory trace may lack information that is prototypical of the category of autobiographical memories, such as specific location in place and time, for example (Bauer, Doydum, et al. 2012; Pathman et al., 2013, respectively). The net effect is that within memory traces, there are fewer features to be associated and between and among which conjunctions are formed. There also are fewer features to differentiate one event or episode from another. Seemingly paradoxically, there also are fewer opportunities for integration of new representations with memory traces already in long-term storage. As memory representations become more and more populated by temporal and spatial features, for example, the number of distinct events and experiences represented in memory increases. As the memory traces become integrated with one another, they enable formation of a timeline of past events.

Early in development, opportunities for integration of new memory traces with those already in long-term storage also are lessened by the relative immaturity—and lack of elaboration—of the concepts upon which autobiographical memory depends. For example, the self to which early formed memories are referenced is not as elaborated or stable a construct as it will be later in development (Fivush & Zaman, 2014; Howe, 2014). As such, it provides a less coherent reference point for memories about the self. As well, children's relatively immature understanding of the representational nature of the human mind may make it more challenging for them to adopt a unique or subjective perspective on events. As these concepts and understandings are elaborated, they become ever-more integral elements of the memory representations that are formed of the distinct events and experiences that make up the life timeline of events. Greater elaboration of the concepts upon which autobiographical memory depends may even operate to facilitate consolidation and reduce the vulnerability of new memories to forgetting. In a mouse model, Tse and colleagues (Tse et al., 2007) found that the rate of systems-level consolidation of new learning was accelerated in mice that had previously acquired a relevant "schema" to which the new information could be assimilated. These findings indicate that the contents of long-term memory may have functional consequences for the incorporation of new memories. Together, these suggestions imply that as the concepts upon which autobiographical memory depends are more fully elaborated and stabilized, they become more integral to mnemonic traces of personally relevant events and simultaneously may work to accelerate the incorporation of the new traces into long-term stores.

Finally, children's less well developed verbal and narrative skills also may negatively impact the quality of the raw materials for memory. As discussed above, younger children's verbal descriptions of events feature fewer of the elements that make for a good personal story, relative to older children. Their narratives also are less well organized and coherent. Again, as discussed above, this does not necessarily imply that their memory representations suffer these same deficiencies. However, it does mean that younger children miss out on the opportunities afforded by verbal retelling of an event. Incomplete narratives also tend to be less well organized (Reese et al., 2011), and retelling of them affords less rehearsal benefit (Bauer & Larkina, 2013). Incomplete narrative rehearsal may even result in retrieval-induced forgetting, the phenomenon by which retrieving some elements of a memory trace may result in forgetting of nonretrieved elements (e.g., Anderson, Bjork, & Bjork, 1994), with resultant further trace degradation. Thus, developments in verbal and narrative skill herald cognitive benefits of rehearsal and organization, which are advantageous to memory. Beyond individual memories, developments in narrative skills also make possible construction of a life story or autobiography that weaves together the individual experiences of one's life into a sequence of temporally linked events (e.g., Brewer, 1980; Fivush et al., 2011; McAdams, 2001). Narrative evidence of this development becomes apparent only in adolescence (e.g., Bohn & Berntsen, 2008, 2014; Fivush & Zaman, 2014; Habermas & Bluck, 2000).

Summary and implications. Memory representations are the products of the activity of large populations of individual neurons that are widely distributed across large tracts of neural tissue. Both the number of elements of experience that are featured in the representation and the extent to which the elements are successfully integrated with one another and with existing memory representations influence the integrity of the traces and their longevity and later accessibility. Early in development, any given memory representation is less populated by the features that typify autobiographical memories. The features that are represented are less fully elaborated. Moreover, the representations that already exist in memory and are available for integration with newly formed traces are themselves less well populated and elaborated. The result is that the raw materials for formation of new memories are suboptimal.

Adding insult to injury is the fact that the less-than-optimal raw mnemonic materials are operated upon by less-than-optimal neural, cognitive, and mnemonic processes. Many of the structures as well as the network of structures that supports memory undergo a protracted course of development lasting well into adolescence. For much of the first 2 years of life, encoding, consolidation, and subsequent retrieval of long-term memories of specific past events are fragile processes owing to immaturity of the neural substrate that supports these signatory functions. For years thereafter, the substrate operates relatively inefficiently and ineffectively. The result is that elements of experience that are the raw materials for memory are not effectively stabilized or integrated into long-term memory stores. Together, these forces create a dynamic such that memories of the first years of life are formed and may survive over some period of time, but they are challenged to survive for the long term.

Over developmental time, individual memory representations include more and more of the features that characterize autobiographical memories and the features themselves are better elaborated and more tightly integrated with one another. The result is mnemonic materials that are of higher quality. At the same time, there are developments in the neural substrate operating on the available representations, both in terms of the structures involved and in the level of connectivity of the network of structures. The developments herald more efficient and effective cognitive and mnemonic processing, resulting in decreases in the vulnerability of memory traces and, thus, in the rate of forgetting. The net effect is that more and more memories of higher and higher quality survive to be recalled at later points in time, producing the characteristic distribution of autobiographical memories across the life span.

Summary and Conclusions

Autobiographical memory is an important source of "evidence" for continuity of self over time. It is with us virtually for our lifetimes, even though, by late childhood, many memories of early life events are obscured by childhood amnesia. Numerous studies conducted with adults have revealed a relative paucity of memories of events from the first 3 to 4 years of life, with a seemingly gradual increase in the number of memories until approximately age 7 years, after which an adult distribution has been assumed. Historically, the amnesia was attributed to late development of the autobiographical memory system or to inaccessibility resulting from repression or emergence of new cognitive structures. Because they emphasized one or the other—but not both—sides of the mnemonic coin, traditional theories had difficulty accounting for all of the data. Theories that postulate late development of the autobiographical memory system are challenged by data that indicate autobiographical memories within the period eventually obscured by childhood amnesia. Theories that postulate an event or change that renders early memories inaccessible to later recollection are challenged to explain why memories from the first years of life are differentially forgotten.

The Complementary Processes Involved in Increases in the Quality of and Decreases in the Vulnerability of Memory Traces

The alternative complementary processes account advanced in this review recognizes both sides of the mnemonic coin: processes that contribute to increases in the quality of memory traces and to decreases in their vulnerability to forgetting. Rather than defining autobiographical memory in terms of criterial features, which necessitates exclusion of seemingly appropriate members of the category, it defines autobiographical memory in terms of characteristic features. Over the course of development, memories bear more and more of the features that are characteristic of the class (see Figure 3). The perspective also recognizes that memory traces weaken to the point of forgetting. However, forgetting is not an event that renders early memories inaccessible to later recollection. Rather, forgetting is the result of inefficient and ineffective cognitive and mnemonic processes performed by an immature neural substrate. The net effect is a perfect storm: the raw materials are less-than-optimal and they are operated upon by a system that itself is less than efficient and effective. The result is an accelerated rate of forgetting relative to that which characterizes adulthood; the specific form of forgetting is exponential. Exponential forgetting reduces the pool of early memories children have formed to a few isolated puddles, making them even more difficult to retrieve. Eventually, with concomitant increases in the quality of the raw materials and the operating system, forgetting slows to the rate observed in adulthood.

The complementary processes conceptualization prompts a change in perspective on the distribution of autobiographical memories across the life span. In Figure 1 is the typical representation

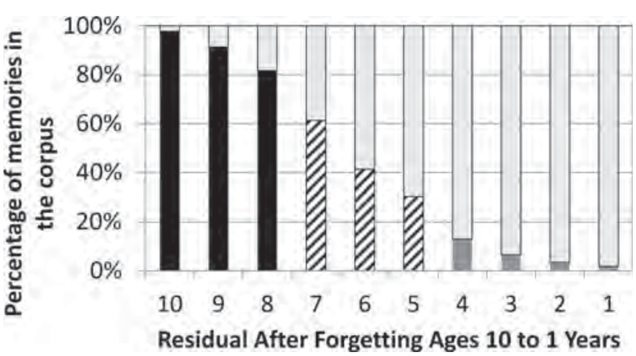

Figure 6. Schematic depiction of the distribution of memories across the first decade of life from the complementary processes perspective, suggesting a residual number of early memories remaining after forgetting. For each year of life from ages 1 to 10 years, what is represented is the total corpus of memories formed (100%, represented in light gray bars) and the percentage of the corpus that remains accessible to recollection (dark gray bars for ages 1–4 years, striped bars for ages 5–7 years, and solid black bars for ages 8–10 years).

of the distribution of memories over the first decade of life. It lends itself to description in terms of a gradual increase in the density of memories over the first 7 to 10 years of age. However, recognition of early development of autobiographical memory (albeit in a less prototyical, ostrich form) coupled with early vulnerability of those memories in terms of exponential forgetting, prompts a change in the perspective. A more appropriate characterization may be in terms of a decrease in the number of memories as a result of exponential forgetting associated with failed consolidation. This perspective is depicted schematically in Figure 6, which is the mirror image of Figure 1. For each year of life from ages 1 to 10 years, what is represented in the figure is the total corpus of memories formed (100%, represented in light-gray bars) and the percentage of the corpus that remains accessible to recollection. The very short dark gray bar on the far right of the figure indicates that only a very small percentage of memories formed in the first year of life remains in the corpus—most of these very early memories have been lost as a result of failed consolidation and exponential forgetting. In contrast, the tall solid black bar on the far left represents the large percentage of memories formed in the 10th year of life that remain accessible. From this perspective, the tail of the distribution apparent on the right of the figure is the small residual after forgetting, not the start of remembering, as suggested by the corresponding bars on the left side of Figure 1.

Thinking of the tail of the distribution in terms of the residual after forgetting also helps to make sense of the small—yet critically informative—body of literature on childhood amnesia in childhood. By the end of the first decade of life, the average age of earliest memory among children is roughly on par with that among adults—age 3 to 4 years. However, within the preschool years, the average age of earliest memory is substantially earlier, with one estimate as early as 18 months (Tustin & Hayne, 2010). Moreover, children's earliest memory also seems to be inconsistent both in terms of the event nominated as the source of the memory and in terms of the date of the event, which increases systematiclly over time (Peterson et al., 2011). These patterns are different from those observed among adults (Bauer et al., in press). They are precisely what is to be expected from a pool of memories that is ever shrinking, eventually diminishing to isolated puddles of memory traces.

Directions for Future Research

By the measure of the ability of the perspective to bring order to the existing literature, the value of the complementary processes account outlined here is clear. Another index of heuristic value is the extent to which a perspective guides future research. In this regard, the message also is clear—future research should feature measures of increases in the quality of memory traces over the course of development, measures of the rate at which memory traces are weakened and lost, and how they relate with one another.

There have been numerous studies of increases in the quality of memory traces over the course of development. Indeed, virtually all of the research on the early development of autobiographical memory involves assessment of changes in how adequately children recall past events. However, most of the studies have asked how the verbal reports or narrative descriptions of memories of past events change with development. They have not asked whether with development, children's memory representations tend to include a larger number of event features, better elaborated event features, more tightly related or integrated features, and so forth. These two questions are related, to be sure. However, as argued elsewhere in this article, verbal reports and memory representations are not one in the same. Examinations of the integrity of memory traces that do not rely on verbal expression would inform the question of whether the strength of memory representations changes in the manner implied in this review. An example of this approach from the infancy literature is available in Bauer and Lukowski (2010). We tested infants' recognition of the specific features of objects used to produce multistep sequences in an imitation-based task and how the specificity of feature memory related to recall of the events 1 month later. Infants who had higher levels of accurate recognition of the particular objects actually used—from among highly perceptually similar distractor objects—had higher levels of long-term recall. Analogous tests with older children would provide valuable information on the nature and pace of change in what is represented in memory—in this case, the specificity of the representation—and how it relates to recall of personally relevant past events over long delays.

Another promising line of research is suggested by studies of developmental changes in children's abilities to create conjunctions between items and their locations (e.g., Bauer, Doydum, et al., 2012; Bauer et al., in press; Sluzenski et al., 2006), or information and the source from which it was acquired (e.g., Cycowicz, Friedman, Snodgrass, & Duff, 2001; Drummey & Newcombe, 2002; Riggins, 2014). The ability to form these conjunctions is a crucial step in the process of transition of labile patterns of neural representation into enduring memory traces. Studies of various conjunctions in memory find age-related differences across early childhood (see Olson & Newcombe, 2014, for a review), suggesting that memory representations strengthen in this manner. Because these studies typically are conducted with controlled laboratory stimuli (e.g., pictures of common objects such as animals and kitchen utensils; Cycowicz et al., 2001), the developmental course for conjunctions among the elements of naturally occurring, personally relevant past events is not known. Moreover, how the ability to create and maintain conjunctions among the elements of experience relates to developments in autobiographical memory has yet to be examined.

Future research on developmental increases in the quality of memory representations will tell only part of the story. There also is need for future research on how developmental changes in the rate of forgetting relate to autobiographical memory. To date, relevant evidence comes primarily from the cue word technique and findings that in childhood, forgetting is better characterized by the exponential than by the power function (Bauer et al., 2007; Bauer & Larkina, 2014). Such studies provide an estimate of forgetting in a population; they are not revealing of the rate of forgetting among individuals. Once again, a model for future investigation is available in the infancy literature. As discussed above, my colleagues and I have examined the rate of forgetting in infancy and the preschool years by probing the integrity of memory traces at various points post encoding, ranging from minutes after experience of an event to 2 weeks later. We then examine the proportion of variance in subsequent long-term recall explained by the measures obtained shortly after encoding, as memory traces presumably are undergoing consolidation. We have found that measures of memory obtained hours to days after experience of events are predictive of recall after delays of weeks to months (e.g., Bauer, Larkina, et al., 2012; Pathman & Bauer, 2013). Similar designs could be used in tests of older children's memories of specific past events to determine how the rate of forgetting relates to long-term recall.

Future research also is needed to more accurately pin-point the transition from a rate of forgetting that it better characterized by the exponential function to a rate that is better characterized by the power function observed in adults. In Bauer and Larkina (2014), we found that the power function provided a good fit to data obtained from college students as well as middle age adults. In contrast, the exponential function was a better fit to the data obtained from children 7 to 11 years of age as a whole (see also Bauer et al., 2007) and for each of the age groups separately. However, there also was evidence of a deceleration in the rate of forgetting even within childhood. Specifically, between 7 and 11 years, the rate of forgetting, represented by the b parameter of the power function (e.g., Wixted & Ebbesen, 1997), decreased from 2.21 to 1.62; there was a further decrease to 1.01 by the college years. A productive direction for future research would be to obtain estimates of forgetting across the childhood years and use the estimates to predict the rate of forgetting of events experienced at different points in development.

Another direction for future research is to examine factors that have been found to relate to increases in the quality of memory traces and to declines in their vulnerability to forgetting, and examine their influence on the complementary process. For example, one of the most robust determinants of developmental improvements in autobiographical memory—as measured by the quality of narratives about past events—is the conversational style used by children's parents. As summarized by Fivush (2014), adults exhibit two different styles when they engage in memory talk with their children. Parents who frequently engage in conversations about the past, provide rich descriptive information about previous experiences, and invite their children to "join in" on memory conversations, are said to use an *elaborative* style. In contrast, parents who provide fewer details and instead pose specific questions to their children (e.g., "What was the name of the restaurant where we had breakfast?"), are said to use a *repetitive* or *low elaborative* style. Numerous studies have found that children of parents using the elaborative style report more about past events than children of parents using the repetitive or low elaborative style (see Fivush, 2014, for a review). Relations are observed both concurrently and over time (e.g., Reese, Haden, & Fivush, 1993). In future research it would be informative to test whether maternal narrative style also is predictive of changes in rates of the forgetting of memory traces.

Research on the complementary approach of examining determinants of "forgetting" to see how they relate to developmental improvements in autobiographical memory is underway. As outlined in this review, an important determinant of forgetting is the integrity of the neural substrate responsible for memory trace formation, consolidation, and subsequent retrieval. In the adult literature, there have been numerous tests of relations between neural function and episodic encoding and retrieval (e.g., Nyberg et al., 2000) as well as autobiographical memory retrieval (e.g., Cabeza et al., 2004; Daselaar et al., 2008; McCormick et al., 2013). There are even studies that test relations between the integrity of memory traces during the period of consolidation and subsequent recall success (Bosshardt et al., 2005). The developmental literature on relations between neural structures and neural function and episodic memory behavior is substantially smaller than that on relations in adulthood (see Ghetti & Lee, 2014, for a review). The literature on relations to recall of personally relevant past events is nonexistent. Clearly, further research is needed.

Conclusion

The distribution of autobiographical memories across the life span has been a matter of considerable scientific curiosity and debate since the end of the 19th century. Typical depictions of the distribution (see Figure 1) plot the event of birth on the left and show what appears to be a gradually increasing number of memories from birth through the first 7 to 10 years of life, after which an adult-like distribution is assumed. In the context of this article, I have argued that from the perspective of development, a better characterization is achieved by "flipping" the chart and plotting the event of birth on the right of the distribution (see Figure 6). The plot then shows the large number of autobiographical memories of events experienced in older childhood (and adulthood, on the left of the graph), and the relatively small residual number of memories of early life events that remain in the corpus. The residual are the puddles of memories that are spared from the constant rate of forgetting that characterizes mnemonic life during childhood. This perspective assumes relatively early development of the ability to form, retain, and later retrieve memories of personally relevant past events. Early in life, the event memories bear relatively fewer of the features that we associate with adult-like autobiographical memory. Over the course of development, more and more memories take on more and more of the features of autobiographical memory, rendering them both more obvious members of the class, and more impervious to the ravages of forgetting. This perspective recognizes the complementary processes involved in increases in the quality of memory traces and decreases in their vulnerability to forgetting, and the developmental dynamics of both. It accounts for the distribution of autobiographical memories across the life span, which forms the basis for construction of a personal past.

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