Chapter 5
Childhood Memory: An Update from the Cognitive Neuroscience Perspective

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The Emergence of Memory

Children are not simply miniature adults. As such, the memory of a child is significantly different from the memory of an adult. Furthermore, the ability to form memories is not innate and instead develops over the first nearly two decades of life. Consequently, memory researchers working in the developmental domain must carefully design studies to probe memory function using age-appropriate paradigms. This is especially true given the growing range of experimental approaches that can be leveraged to understand the neural underpinnings of memory and its development. Techniques such as functional near-infrared spectroscopy (fNIRS), functional magnetic resonance imaging (fMRI), and high-density electroencephalography (HD-EEG) join workhorse behavioral and neuropsychological methodologies to monitor many aspects of brain function and behavior during memory formation and retrieval.

In the following sections, we provide an overview of childhood memory development and retrieval of childhood memories. In particular, we focus on declarative,

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or episodic, memory, the type of memory that most people think of when defining memory. More specifically, autobiographical memory is one class of episodic memory that is likely to be the most relevant to the types of questions posed by the forensic practitioner. Autobiographical memory refers to the retrieval of events from a person's life. The emergence of reliable autobiographical memory occurs during the first 10 years of childhood. In contrast, implicit memory, such as learning via conditioning, matures in infancy and shows little significant change during development (Murphy, McKone, & Slee, 2003). The development of episodic memory is interrelated with the development of working memory capacity as well. In general, across phonological, visual, and spatial working memory subcomponents, children's working memory capacity reaches adult levels around age 12 (Hulme, Muir, Thomson & Lawrence, 1984; Wilson, et al., 1987; Hitch et al., 1988).

We first briefly note challenges associated with studying memory in children before addressing the time course of neural development that underlies mnemonic function. We subsequently turn to several cognitive accounts of childhood amnesia before turning to the experimental literature to characterize the development of memory in children. Finally, we address the reliability of memory in children and what sorts of effects medical conditions and traumatic experiences may have on children's memory.

Studying Memory in Children

With adult participants it is reasonable to simply ask for freely recalled childhood memories to study events from childhood. For example, there are structured interviews, such as the Autobiographical Memory Interview (Kopelman, Wilson, & Baddeley, 1989) in which participants are asked to provide autobiographical memories and semantic information for different epochs over the life-span. This approach successfully identifies memory disorders such as dementia. More often, episodic memory paradigms classically involve the presentation of a set of memoranda during encoding with memory performance being tested by the accuracy of memory recall. This approach emerged with Ebbinghaus over a hundred years ago and remains in constant use today because it allows the experimenter complete control over the nature of the stimuli and easy ability to assess memory accuracy.

These approaches have limitations. List learning is not particularly ecologically valid and freely recalled memories are difficult to verify. Second, it is difficult to discriminate between memories retrieved from experience versus memories retrieved that were formed from hearing about events. This is true although there is some evidence suggesting that experienced events tend to have stronger imagery, sensory, and emotional components when compared to those acquired from others (Crawley & Eacott, 2006).

These challenges become more difficult when the participants are children. Probing autobiographical memories in children is complicated by a variety of factors including the child's age and emotional maturity, and emotional content of the event. Furthermore, interpreting young children's verbal accounts commonly requires a familiar, trustworthy adult. Such an adult may not always be available. Of primary importance to the issue of childhood autobiographical memory is infantile and childhood amnesia. Infantile amnesia, first described by Freud, encompasses the first 2 years of a child's life and is the complete absence of episodic memory (reviewed in Callaghan, Li, & Richardson, 2014). Childhood amnesia refers to the period of impoverished episodic memory, maturation of brain regions, self-awareness, theory of mind, and executive functioning until around age 7 (reviewed in Bauer & Larkina, 2013). Adults report almost no memories from early childhood and those early memories are impoverished with regard to detail (Usher & Neisser, 1993). But this does not mean that children do not remember events over time during childhood. Between ages 2 and 4 children begin to form lasting long-term memories (Bauer, Hertsgaard, & Dow, 1994; Mcdonough & Mandler, 1994; Rubin, 2000) and by around age 4 they begin to use narrative structure to recount autobiographical events (Fivush, Haden, & Adam, 1995). Events high in emotional content are better remembered. Three and 4-year-old children were tested on their memory for a tragic experience such as a fire (Pillemer, Picariello, & Pruett, 1994). Seven years later, the majority of the older group (57 %) was able to describe event, while only a small portion (18 %) of younger age group succeeded. Other examples of superior memory for emotionally valenced content include superior memory performance for unpleasant doctor's visits (Ornstein, 1995) and for a hurricane rather than an amusement park visit (Hamond & Fivush, 1991). Although memories are formed and shaped by various factors such as emotion, autobiographical memory performance in children does not reach adult levels of performance until around age 16 or older, with girls achieving more accurate performance than boys at this age (Willoughby, Desrocher, Levine, & Rovet, 2012). Indeed, there is some evidence to suggest that sophisticated memory organization such as segmenting events according to lifetime periods does not fully mature until age 18 (Chen, McAnally, & Reese, 2013).

Episodic Memory: Neural Necessities and Implications

Neural Development Underlies Mnemonic Capacity

The human brain is subject to an extended maturation process that continues beyond childhood and adolescence only reaching completion in our 20s (reviewed in Blakemore & Choudhury, 2006; Ofen, 2012). Appreciating this point is important because without an appropriately populated and interconnected brain there is no substrate for memory. Consequently, a primary reason for the absence of episodic memories during the period of infantile and childhood amnesia is due to immature brain function, particularly in prefrontal and medial temporal lobe structures essential for episodic memory. Of primary importance is that throughout the period of infantile amnesia there is immaturity of the hippocampus, particularly the dentate gyrus (reviewed in Ofen, 2012; Richmond & Nelson, 2007). Even more protracted is the maturation process of the inhibitory interneurons within the hippocampus, which continues until around age 8. Without a fully functional hippocampus there is poor memory encoding and retrieval (for a meta-analysis, see Svoboda, McKinnon, & Levine, 2006). Thus, the emergence of lasting episodic memories follows the neuronal development of hippocampal structures. This developmental sequence has been hypothesized to explain the apparent emergence of episodic memory from semantic memory (Mishkin, Suzuki, Gadian, & Vargha-Khadem, 1997). In contrast, semantic memory for factual knowledge about the world is less reliant on the hippocampus and can exist in those with congenitally impaired hippocampi (Vargha-Khadem et al., 1997) and inversely, episodic memory can remain intact in those with semantic memory deficits (Temple & Richardson, 2004).

In addition to hippocampal maturation there are essential increases in connectivity between brain regions and myelination of white matter tracts. The prefrontal cortex (PFC) is critical for executive functioning and the density and thickness of the gray matter in the PFC is significantly correlated with intelligence (Haier, Jung, Yeo, Head, & Alkire, 2004; Narr et al., 2007). During development, the rapid growth and subsequent pruning of neurons takes place later in the PFC than other regions of cortex (Huttenlocher & Dabholkar, 1997). This reduction of synaptic and neuronal density is followed by a growth of dendrites and increases in both gray and white matter density (Tsujimoto, 2008). The PFC continues to develop well into adolescence leading to an increase in executive function abilities (reviewed in Blakemore & Choudhury, 2006; Ofen, 2012). Furthermore, from 4 to 8 months of age there are significant cortical processing speed increases, reflecting the neuronal myelination process (Webb, Long, & Nelson, 2005). The continued maturation of brain regions as well as the increased efficiency in these regions is correlated with the offset of childhood amnesia.

Cognitive Requirements for Autobiographical Memory

Freud's now long abandoned proposal that repression explained infantile and childhood amnesia has been replaced by several competing hypotheses. Importantly, these perspectives are not mutually exclusive and they all require sufficient neural maturation for cognition (reviewed in Cycowicz, 2000). One explanation is based on the need for sufficient language skills to subserve encoding (Schachtel, 1947; recently reviewed in Josselyn & Frankland, 2012) and retrieval processes (Hayne & Rovee-Collier, 1995). For example, once children can verbally describe and discuss their experiences, even during the event itself, they are more likely to remember them and recall them accurately (Fivush, Kuebli, & Clubb, 1992; Tessler & Nelson, 1994). Language development is also influenced by the sophistication of speech heard in the household where exposure to sophisticated vocabulary facilitates the child's language skills (Huttenlocher, 1998; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). In the classic "Magic Shrinking Machine" experiment, researchers placed large objects into the machine and the child removed a miniature version of the same item (Simcock & Hayne, 2003). Follow up testing 6 months and 1 year later, children were asked what items were shrunken in the machine. The children could only retrieve the names of the items they could verbally label at encoding, even if they had more recently learned the item's name. In other words, although they experienced the shrinking machine for all objects, only the ones they could name that day were later remembered.

A challenge for this perspective is the question of whether language performance can be extricated from the development of semantic memory. As mentioned previously, semantic memory refers to world knowledge, for instance, that a ball rolls, or that an apple is a fruit. Categorical representations emerge in infancy. For example, 3–4-month-old infants can discriminate between the categories of dogs and horses (Eimas & Quinn, 1994). Using semantic memory to group items makes it easier to remember a list of similar or semantically related words (Gathercole, 1995; Gathercole, Frankish, Pickering, & Peaker, 1999; Multhaup, Balota, & Cowan, 1996; Roodenrys, Hulme, & Brown, 1993).

A second explanation for childhood amnesia focuses on the development of cognitive abilities such as self-recognition (Howe & Courage, 1993), and theory of mind (Perner & Ruffman, 1995). According to this perspective, memory processes including context specificity, encoding speed, and the length of long-term memory retention must develop first to permit memory storage (reviewed in Hayne & Herbert, 2004). Support for this view comes from research revealing that the durability of long-term memories grows from 1 day in 1-year-olds, <1 week in 2-year-olds, <1 month in 3-year-olds, and up to 6 months in 4-year-olds (Morgan & Hayne, 2011). At a more advanced level, processing speed is linked to working memory span, reaches maturity in adolescence and facilitates episodic memory encoding (Kail, 1991). Both memory durability and the rapid processing of information facilitate memory formation.

A third account relates to the development of metamemory, which is the knowledge and awareness of one's own memory abilities (reviewed in Gathercole, 1998). Metamemory includes awareness of our ability to remember certain things more readily than others, and an understanding of the bounds of our own knowledge and a sense of our memory capacity. There is a strong positive relationship between metamemory and memory performance (reviewed in Gathercole, 1998; Ghetti, Lyons, Lazzarin, & Cornoldi, 2008; Isingrini, Perrotin, & Souchay, 2008). Even in children as young as 4 years old, metamemory knowledge is a strong predictor of memory performance on free recall tasks (Henry & Norman, 1996). This link becomes stronger over early elementary years and by third grade children are better predictors of whether they will remember something later (Henry & Norman, 1996). This is consistent with other observations demonstrating that 6–7-year-old children can distinguish between items that are fully recollected versus those that are simply familiar, but unlike adults they fail to report that false alarm trials contained items that felt familiar (Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011).

A related executive function that is important for episodic memory is the ability to strategically organize information and rehearse memoranda in working memory. The ability to subvocally rehearse information does not mature until ~7 years

(Flavell, Beach, & Chinsky, 1966; Gathercole, Adams, & Hitch, 1994; Hitch, Halliday, Dodd, & Littler, 1989). This coincides with the maturation of organizational ability, which emerges during the elementary years and becomes stronger when children predict that a memory strategy will improve their performance (Moynahan, 1978). Younger children, even toddlers, will spontaneously use memory strategies, particularly in demanding situations (DeLoache, Cassidy, & Brown, 1985), even though they are not able to verbalize the merit of doing so (Henry & Norman, 1996; Schneider, 1986). By fourth grade, however, children apply appropriate grouping (e.g., fruits go together) whereas second graders do not (Schneider, 1986). This is consistent with fMRI data showing that 10-year-old children show activation in prefrontal regions more like adults do and significantly more than 7-year-olds do during challenging memory retrieval tasks in which memory strategy is useful (Chiu, Schmithorst, Brown, Holland, & Dunn, 2006). Importantly, the emergence of both metamemory and strategy use is influenced by the parents' literacy level and education (Grammer, Purtell, Coffman, & Ornstein, 2011). Thus, in cases where the parents' literacy and education is low may be associated with delayed memory development.

Clinical Conditions and Disorders in Children

Once children are able to form long-lasting memories there are a host of other factors that can impair memory. Children's memory function can be compromised by congenital factors including medical conditions, learning, developmental disabilities, and mental health conditions. It is also clear that memory and cognition are sensitive to exposure to alcohol and drugs prenatally or during adolescence, and childhood maltreatment. Because memory requires many other cognitive processes to function properly, e.g., attention, perception, it is possible that a child could have difficulty recalling facts or events without explicit *memory* impairment. In the following sections, we address the nature and implications of congenital and environmental factors.

Congenital Factors: Medical Conditions, Learning Disabilities, and Mental Health

Most medical conditions have primary physical manifestations. However, epilepsy, pediatric-onset multiple sclerosis, and diabetes mellitus are all also associated with cognitive deficits. Children with severe pediatric epilepsy have recurrent seizures, which disrupt cortical development and memory encoding (Widjaja et al., 2013). These children are at increased risk for verbal memory deficits (Hrabok, Sherman, Bello-Espinosa, & Hader, 2013). In pediatric-onset multiple sclerosis (MS), cognitive domains such as attention and visual memory are susceptible to deterioration over time as MS is a progressively degenerating disease (Till et al., 2013). Children diagnosed with type-1 diabetes mellitus are susceptible to deficits in selective attention, visual perception, and working memory (Tolu-Kendir et al., 2012). These cognitive deficits are not globally present in all children with type-1 diabetes, but rather, are modulated by factors such as early onset of diagnosis, frequency of hypoglycemia (i.e., low blood sugar levels), and poor glycemic control (Tolu-Kendir et al., 2012). Finally, very low birth weight children have reduced hippocampal volume and some memory sequelae (Isaacs et al., 2000). These medical conditions serve as examples of those that can directly and indirectly disrupt memory function.

A second congenital factor affecting memory is learning and developmental disability. Children identified as learning or developmentally disabled have cognitive deficits when compared to neurotypical children. For example, children with Williams and Down syndromes have deficits in sustained and selective attention (Costanzo et al., 2013). Children with specific language impairments (SLI) have difficulty encoding verbal information (Coady, Mainela-Arnold, & Evans, 2013), with severity correlating with the degree of memory impairment (Hesketh & Conti-Ramsden, 2013). Children may also have deficits specific to spatial information (Narimoto, Matsuura, Takezawa, Mitsuhashi, & Hiratani, 2013). Children with developmental disorders are susceptible to sleep disorders, which consequently disrupt memory consolidation (Urbain, Galer, Van Bogaert, & Peigneux, 2013) and further impair memory (Csabi, Benedek, Janacsek, Katona, & Nemeth, 2013).

A third congenital factor is mental health status. A number of psychiatric diagnoses are at greater risk for impaired cognitive function and/or impaired episodic memory (Ferreri, Lapp, & Peretti, 2011; Spinhoven, Bamelis, Molendijk, Haringsma, & Arntz, 2009), accompanied by atypical brain structure and function (Toga, Thompson, & Sowell, 2006). For example, children with Autism Spectrum Disorders (ASD) display deficits in executive functioning (e.g., initiating, planning, working memory) and with episodic memory attributed to dysfunction in hippocampal and prefrontal regions (reviewed in Boucher & Mayes, 2012; Boucher, Mayes, & Bigham, 2012). Children with high functioning autism have significantly impaired verbal recall compared to neurotypical children (Andersen, Hovik, Skogli, Egeland, & Oie, 2013). Oppositional defiant disorder is also associated with deficits in executive function and episodic memory (Rhodes, Park, Seth, & Coghill, 2012). It is also worth noting that children diagnosed with Asperger's Disorder recount memories with less detail, specifically with significantly *fewer* perceptual and emotional references (Brown, Morris, Nida, & Baker-Ward, 2012). Early-onset bipolar disorder is also associated with memory problems (Lera-Miguel et al., 2011; Udal et al., 2013; Udal, Oygarden, Egeland, Malt, & Groholt, 2012) and some data suggest that there are greater emotional memory deficits in those with type 1 diagnoses (Schenkel, West, Jacobs, Sweeney, & Pavuluri, 2012). One proposal is that abnormal activity in the fusiform gyrus impairs visual processing of emotional faces (Adleman et al., 2013). Obsessive-compulsive disorder (OCD) and Tourette syndrome both are linked with abnormal function in prefrontal and striatal regions, but OCD alone is associated with memory deficits in adults (Chang, McCracken, & Piacentini, 2007). Children with OCD have deficits in cognitive flexibility and planning and evidence of episodic memory deficits (Andres et al., 2007; Ornstein, Arnold, Manassis, Mendlowitz, & Schachar, 2010; but see Shin et al., 2008). Children with ADHD also show memory deficits (Rhodes et al., 2012) and abnormal patterns of neural activation in limbic and parietal regions during episodic memory retrieval (Krauel et al., 2007). Furthermore, many of the memory deficits linked with these diagnoses are compounded by comorbid attention deficit hyperactivity disorder (ADHD), including autism (Andersen et al., 2013; Yerys et al., 2009), oppositional defiant disorder (Rhodes et al., 2012), and early diagnosis bipolar disorder (Udal et al., 2012, 2013).

Environmental Factors: Drug/Alcohol Exposure and Use, Traumatic Experience

Children exposed to alcohol and illegal drugs in utero are vulnerable to lasting deleterious consequences (recently reviewed in Behnke & Smith, 2013) and broad changes to brain structure and function (reviewed in Toga et al., 2006). Prenatal drug exposure (PDE) to heroin and cocaine is related to changes in hippocampal structure that is negatively related to memory performance (Riggins et al., 2012). This may be primarily driven by heroin exposure, as there is limited evidence suggesting that prenatal cocaine exposure is associated with significant cognitiveproblems (Buckingham-Howes, Berger, Scaletti, & Black, 2013; reviewed in Bandstra, Morrow, Mansoor, & Accornero, 2010). Prenatal exposure to methylenedioxymethamphetamine (MDMA, "ecstasy") has dose-dependent effects with high exposures delaying motor (Singer et al., 2012) and cognitive development (reviewed in Chen & Lin, 2009).

Prenatal alcohol exposure occurs along a spectrum and when severe can cause fetal alcohol syndrome, central nervous system dysfunction, growth deficiencies, craniofacial anomalies, and a cognitive deficits (recently reviewed in Hoyme et al., 2005; Memo, Gnoato, Caminiti, Pichini, & Tarani, 2013; Pruett, Waterman, & Caughey, 2013). Children exposed to high levels of alcohol in utero may have significant difficulty with verbal encoding (Crocker, Vaurio, Riley, & Mattson, 2011), poor recognition and source memory (Kully-Martens, Pei, Job, & Rasmussen, 2012), deficits in memory and executive functioning (Pei, Job, Kully-Martens, & Rasmussen, 2011), and difficulty with language, visual perception, memory, learning, social functioning, and number processing tasks especially with difficult tasks (Kodituwakku, 2009). Neuroimaging studies reveal widespread anatomical brain abnormalities including a small or absent corpus callosum and irregular cortical thickness (Lebel, Roussotte, & Sowell, 2011; Lebel & Sowell, 2011). Functional neuroimaging suggests that some of the cognitive deficits observed in children with prenatal alcohol exposure may be related to widespread atypical activation patterns (reviewed in Coles & Li, 2011) and including prefrontal abnormalities (Norman et al., 2013).

The slow rate of brain maturation means that later adolescent drug and alcohol consumption may also impair memory performance. According to the Center for Disease Control, 70 % of adolescents in the USA have consumed alcohol and ~40 %

have experimented with marijuana (*Trends in the Prevalence of Marijuana*, *Cocaine*, *and Other Illegal Drug Use*, *National YRBS*: *1991–2011*, 2011). Compared to heavy alcohol use, marijuana has a targeted effect on memory and executive function ADDIN EN.CITE with concomitant structural changes in medial temporal lobe and frontal lobe (Batalla et al., 2013). In contrast, heavy alcohol use is associated with deficits in attention and executive function (Thoma et al., 2011). It is important to note that these findings are from a cross-sectional study; the long-lasting cognitive consequences of frequent marijuana use were not assessed. Adolescents who use inhalants have significant deficits in learning, memory, and executive functioning when compared to non-using age-matched peers (Takagi et al., 2011), as do those who use methamphetamine (King, Alicata, Cloak, & Chang, 2010). Little is known regarding the impact of these substances on adolescent brain development. As prenatal and adolescent exposure typically has dose-dependent effects, it is important to identify the extent of contact to predict the memory effects.

Traumatic childhood experiences may include abuse, maltreatment, or neglect. School-aged children who experience early trauma demonstrate worse performance on attention, working memory, and verbal recall tasks compared to matched control participants (Bucker et al., 2012; Chae, Goodman, Eisen, & Qin, 2011) and a series of brain changes including reduced hippocampal volume and changes in the corpus callosum (reviewed in Brietzke et al., 2012); see also De Bellis, Hooper, Woolley, & Shenk, 2010; De Brito et al., 2013). Memory for negative emotional experiences is heightened in maltreated children (Goodman, Quas, & Ogle, 2010; Howe, Toth, & Cicchetti, 2011). Children bullied by peers have more depressive symptoms and higher cortisol (a stress hormone) levels that negatively correlate with memory performance (Vaillancourt et al., 2011). More seriously affected children, and adults, diagnosed with post-traumatic stress disorder (PTSD) after witnessing violence have significantly greater deficits in learning, are more distractible, and impaired at memory rehearsal (Samuelson, Krueger, Burnett, & Wilson, 2010) and also have structural changes primarily in medial temporal lobe regions (reviewed in Bremner, 2006). Abuse may make children more susceptible to dissociative disorders and subsequently they may have greater inaccuracies in recounting personal events (Chae et al., 2011). Furthermore, children who are abused or neglected tend to have overgeneralized autobiographical memories with overrepresentation of negative self-representations than non-maltreated children (Valentino, Toth, & Cicchetti, 2009). Overall, children who have experienced abuse, maltreatment, or neglect are susceptible to various degrees of memory impairment, and memory impairment may revolve around the traumatic event itself.

The Accuracy of Children's Memory: Role as Eyewitnesses

Here, we turn from physical and environmental factors that can influence children's, and adults', memory function to factors that allow them to accurately report recollections of events. This is particularly important when children are providing testimony and are interacting with the judicial system.

Allegations of sexualabuse against children are taken with appropriate gravity. Given the legal ramifications associated with allegations of child sexual abuse, a variety of psychological factors become relevant during the course of an investigation and subsequent legal proceedings. For instance, given that corroborating evidence is often unobtainable, the only remaining available evidence in child sexual abuse cases may be the child's memory of the event (Roberts & Powell, 2001). Children are asked to recall details from the event in question during interviews with law enforcement, child psychologists, and, in testimony on the witness stand. Empirical evidence, however, indicates that similarly to adults, child eyewitness memory is susceptible to a variety of social and psychological factors that influence the process by which they encode, store, and retrieve information about events (Ceci & Bruck, 1993). Careful examination of this evidence is imperative to convict perpetrators while avoiding wrongful convictions of the innocent.

Post-event Suggestibility of Children

Events are not encapsulated in memory and instead are subject to interference and conflation from outside events. One source of contamination is post-event information, which can have long-lasting effects (London, Bruck, & Melnyk, 2009) and can occur during encounters such as formal interviews during which children are asked about an event (Zaragoza & Lane, 1994), conversations with parents (Poole & Lindsay, 2002) or conversations with peers (Schwarz & Roebers, 2006), or even by conflating life events involving some overlapping context (Powell, Roberts, Ceci, & Hembrooke, 1999). The types and sources of post-event information to which children are exposed during interviews has provided a wealth of knowledge pertaining to the social-cognitive factors contributing to accurate and inaccurate memory reports from children for past events.

Three leading experimental paradigms used to examine child suggestibility borrow from the work of cognitive psychologists in false memory and misinformation. In the misinformation effect paradigm, participants first witness an event (e.g., a car accident involving two cars). Second, they receive suggestive questions prompting exaggerated retrieval of details regarding the event (e.g., "how fast were the cars going when they: (a) smashed? (b) crashed? (c) bumped into one another?"). Finally, they are tested regarding their memory for the original event (Loftus, 1975; Loftus & Hoffman, 1989). Misinformation can distort memory, causing people to report exaggerated details regarding a previously witnessed event (e.g., answering (a) 65 mph, (b) 45 mph, (c) 25 mph to the example above). Implanting false memories, on the other hand, can involve scenarios similar to the now famous "lost in the mall" paradigm (Loftus & Pickrell, 1995). In this paradigm, participants are led to believe that they had been lost in a shopping mall when they were young. When interviewed by researchers, a significant proportion of participants produce details about an event that never occurred.

A frequently used laboratory approach to induce false memories involves the retrieval of verbal information and is referred to as the Deese-Roediger-McDermott

(DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995). Here, participants are first presented with a list of semantically related words (e.g., *bed*, *dream*, *pillow*, *dark*, *nighttime*, and *drowsy*). After a delay, participants are asked to freely recall as many items as they can remember from the list of previously presented words. Importantly, many participants falsely recall words semantically related to words from the list, referred to as "critical lures" (e.g., *sleep*), which were never presented. Participants often feel highly confident that these critical lures were present in the list. Each paradigm has been used to probe the inconstancy and malleability of human memory in adults. Additionally, these paradigms have been applied to empirical investigations of child eyewitness memory, in particular to examine the suggestibility of children.

Child Suggestibility During Interviewing

A common finding from experiments employing variations of these paradigms is that suggestive or false information given to children prior to or during an interview can result in the inclusion of that information within the child's statement (Ceci & Bruck, 1993); reviewed in Ceci, Kulkofsky, Klemfuss, Sweeney, & Bruck, 2007). For example, mentioning a false, but plausible, detail (e.g., playing in the sandbox) that could have been part of a real past event (e.g., going to the beach) is likely to be incorporated into the child's subsequent report of the event (e.g., "I stopped to play in the sandbox"). Importantly, suggestibility decreases with development, as older (e.g., ages 5–6) children are more likely to report veridical information despite being exposed to suggestive statements compared to younger (e.g., ages 3–4) children (Leichtman & Ceci, 1995). Older (e.g., ages 11–12) children may still report false details that include plausible information (e.g., schoolmate choking on a piece of candy). However, they appear to be more resistant to implanted false information for highly implausible events (e.g., UFO abduction) compared to younger (e.g., ages 7–8) children (Otgaar, Candel, Merckelbach, & Wade, 2009).

Careful control over interactions with child eyewitnesses, however, can mitigate memory-related errors associated with child suggestibility to misinformation and leading questions. For instance, two main approaches are typically used during interviews with child eyewitnesses. The first, and more traditional category of approaches, involves a verbal-based interview, often conducted by law enforcement officials. To date, there are a variety of interviewing techniques, recommendations, and even protocol guidelines for conducting forensic verbal interviews with child eyewitnesses (Lamb, Hershkowitz, Orbach, & Esplin, 2008). For example, the National Institute of Child Health and Human Development (NICHD) has created structured interview protocols designed for use in real-world forensic interviews with children (Orbach et al., 2000). Empirical examination of the NICHD structured interview protocols indicates that these strategies are effective at extracting useful and accurate memory-related evidence during interviews with child witnesses (reviewed in Lamb, Orbach, Hershkowitz, Esplin, & Horowitz, 2007).

Other strategies are centered on techniques used by child psychologists and involve the use of props that are believed to serve as memory cues to facilitate retrieval of information regarding the event (Price et al., 2013).

Each approach entails a number of advantages and disadvantages with regard to obtaining accurate memory-related evidence from interviews with children. During verbal police interviews, which focus on free recall questions (e.g., "tell me what you remember from that day"), children have difficultly reinstating context when attempting to retrieve details from their memory of an event (Keary & Fitzpatrick, 1994). When police do ask specific questions during an interview, children often change their responses in the event that the same questions are repeated. For instance, an empirical investigation of question repetition on memory retrieval consistency found that children alter their responses to the same question even within the same interview (Krahenbuhl & Blades, 2006). Another problem with police interviews is that children may be apprehensive to share their memories of an event with law enforcement officials. In documented cases of sexual abuse, child victims often refuse to report details or admit that any abuse occurred during an initial interview with police (Leander, 2010). These authors suggest that two or three separate interviews with police are often necessary to build rapport and elicit thorough and accurate memory evidence from child victims of sexual abuse (Leander, 2010). On the other hand, repeated interviews can be problematic if misinformation is introduced and reinforced during subsequent interviews (Brainerd & Reyna, 1996; Melinder et al., 2010); reviewed in Brainerd, Reyna, & Ceci, 2008).

Aside from verbal reports taken by law enforcement officials, prop-assisted interviews are commonly used when interviewing child eyewitnesses in sexualabuse cases (review in Poole & Bruck, 2012). Children may have details stored in episodic memory from an event involving sexual abuse, but may not be able to retrieve those details without cues or may be too embarrassed to verbalize details from their traumatic experience (Russell, 2008). As such, forensic interviewers often employ props to elicit information from child eyewitnesses during interviews. The main concern regarding the use of props (e.g., anatomically detailed dolls, body diagrams/drawings) as retrieval cues during forensic interviews is that children may engage in fantasy play, increasing their suggestibility and potentially contaminating their memory of the event (Ceci & Bruck, 1995). Another issue with prop-assisted interviews regards the age of the child eyewitness. Three- and 4-year-olds often have a difficult time reporting details from events (e.g., "show me on the doll where they touched you") using both dolls and body diagrams (reviewed in (London, Bruck, & Wright, 2008). While 5–7-year-olds are relatively better than 3–4-year-olds at using props to retrieve details from memory regarding events involving sexual abuse, they still have issues understanding the purpose of the task and require correction and repeated instruction (Brown, Pipe, Lewis, Lamb, & Orbach, 2007). Moreover, even when older children understand the task demands, the introduction of props to facilitate questioning may lead to the generation of either suggested or spontaneous false responses (Poole & Bruck, 2012; Poole & Dickinson, 2011). Recent empirical comparisons of the traditional forensic verbal strategies and prop-assisted interviewing strategies have been conducted. This evidence suggests that, under certain conditions, prop-assisted strategies may produce more memory-related errors compared to carefully structured verbal interviews with child eyewitnesses (Melinder et al., 2010). As such, the benefits of prop-assisted interviewing strategies are limited and some suggest they are no better at eliciting accurate information from children than simply asking them questions about an event (Salmon, Pipe, Malloy, & Mackay, 2012). Clearly, the development of novel solutions is a necessary step toward improving the quality of child eyewitness memory reports obtained during the forensic interview process (review in Poole & Bruck, 2012).

Other Factors Influencing Child Suggestibility and Eyewitness Memory

Outside of formal interviews, children's memory for events can be contaminated via interaction with a variety of extra-interview factors (reviewed in Principe & Schindewolf, 2012). These social-cognitive influences on child suggestibility can influence memory retrieval accuracy even under unbiased, ideal interviewing conditions and typically emerge from post-event interactions with parents (Poole & Lindsay, 2002), peers (Schwarz & Roebers, 2006), co-witnesses (Principe & Ceci, 2002), or media exposure (e.g., television: Principe, Ornstein, Baker-Ward, & Gordon, 2000). Resulting from these interactions, children may incorporate details into their reports that they never experienced but someone else did, are completely false, or are highly exaggerated.

While many of these extra-interview factors (e.g., exposure to parents, peers, television) are difficult to control for in legal scenarios, limiting or preventing post-event exposure between children who were witnesses to the same event can control for co-witness influences. Witnesses to crimes and accidents often discuss the incident with other witnesses who are in close proximity to them after the event has occurred (Paterson & Kemp, 2006). Moreover, law enforcement officials often question witnesses simultaneously (Garven, Wood, Malpass, & Shaw, 1998). This contaminates eyewitness memories of the event. Indeed, when co-witnesses discuss their distinct memories of the same event, their reports are more likely to converge (Gabbert, Memon, & Allan, 2003). This "co-witness influence" can actually be more harmful to accurate memory recall than exposure to misinformation during a poorly conducted forensic interview (Paterson & Kemp, 2006; Principe, Guiliano, & Root, 2008; Principe & Schindewolf, 2012).

Like adults, child eyewitnesses are likely to discuss an event with their peers or other children who witnessed the same event (Candel, Memon, & Al-Harazi, 2007; Principe, Kanaya, Ceci, & Singh, 2006; Schwarz & Roebers, 2006). The relatively sparse number of empirical examinations of co-witness influence to date has found that children tend to conform to descriptions given by a co-witness. For instance, in a study in which child co-witnesses (ages 3–5) were exposed to different versions of an event, when child co-witnesses are interviewed together, the details they reported about the event converge (Bright-Paul, Jarrold, Wright, & Guillaume, 2012). Interestingly, when interviewed in private, the children still reported inaccurate information, even in the absence of social pressure to conform to co-witness reports.

As such, the influence of social conformity on the accuracy of child eyewitness reports only accounts for 32 % of the total amount of errors, leaving the remaining 68 % of errors made due to contaminated memory reconstruction of the event details based on prior social influence (Bright-Paul et al., 2012).

Another interesting form of suggestive social influence on child eyewitness memory comes in the form of rumors exchanged between child peers (Principe et al., 2006; Principe, Tinguely, & Dobkowski, 2007). In these instances, children produce false memory reports of an event that they overheard from another source, but never actually witnessed (Principe et al., 2006). For example, in the "magic trick" scenario used by Principe and colleagues (2006), four groups of preschool children (ages 3–5) received different levels of information about an event. One group witnessed a magic show involving a rabbit that never actually emerged from a magician's hat. Another group was exposed to false information by overhearing a conversation between two adults indicating that the rabbit escaped from the hat. The other two groups were either classmates of the group who overheard the rumor from adults or children who were not exposed to the rumor (control group). During either a neutral or suggestive interview nearly all of the children from each of the groups, with the exception of the control group, falsely reported that the rabbit was loose at the school (Principe et al., 2006).

Autosuggestibility and False Memory in Children

A related form of rumor-mongering that has recently been investigated relates to autosuggestibility, or rumors that emerge from the internal cognitive processes underlying the expectations or beliefs held by children (Brainerd & Reyna, 1995). In this form of child suggestibility, children create a rumor (akin to a false belief) based on observed evidence that converges with their recent experiences or preexisting beliefs about an event. For instance, Principe and colleagues (2008) developed a modified paradigm of the "magic trick" scenario used in one of their previous studies (Principe et al., 2008).

In this scenario, one group of children (ages 3–6) viewed the same "magic show" as previously described (false report of an escaped rabbit). After the magic show, the children walked back to class, one at a time, and passed by a bundle of carrots with bite marks (which nearby researchers confirmed the children noticed). A week later the children who viewed the magic show and clues, their classmates who did not view the magic show, and a control group of children at a different school were interviewed regarding the events that transpired on the day of the magic show. Compared to control subjects a significant proportion of both children who witnessed the magic show and the clues and their classmates falsely remembered details from the event (e.g., escaped rabbit ate the carrots). Not surprisingly, the 3–4-year-old classmate's memories were more susceptible than 5–6-year-olds to the influence of the rumors propagated by their classmates who witnessed the magic show and clues. Interestingly, compared to the 3–4-year-olds, a greater proportion of the 5–6-year-olds who witnessed the magic show and clues were more susceptible to autosuggestibility, and were responsible for generating the rumors from internal false memories of the event (Principe et al., 2008). Applied to real-world situations involving child co-witnesses, this evidence points to the need for to minimize co-witness influences on child eyewitness memory.

This pattern of results indicates a reverse developmental trend, wherein older children actually show greater susceptibility to the generation of false memories based on suggestive evidence (Principe et al., 2008). In the last decade, a wealth of research has produced evidence in support of developmental reversals within the child false memory literature. Similar to adults, children are susceptible to false memories when exposed to semantically associated lists of words as used in the DRM paradigm (Brainerd, Reyna, & Forrest, 2002; Sugrue, Strange, & Hayne, 2009).

Recent evidence, however, suggests that the commonly held perspective that younger, compared to older, children are more susceptible to the generation of false memories has not necessarily been validated empirically (reviewed in (Brainerd & Reyna, 2012). For example, in modified DRM paradigm tasks, older children (e.g., age 11) exhibit higher percentages of false recognition and recall compared to younger children (e.g., age 5) when tested on lists containing words from the same category (Brainerd, Holliday, & Reyna, 2004; Howe, 2006). Moreover, in ecologically pertinent examinations of child false memory, developmental reversals are observed. These ecologically valid examinations range from the generation of spontaneous false memories (e.g., using facial expressions, Fernandez-Dols, Carrera, Barchard, & Gacitua, 2008), false memories for complex events (e.g., false facts embedded in stories, Fazio & Marsh, 2008), as well as implanted false memories using modified versions of the Lofus (Loftus, 1975) misinformation paradigm (e.g., Ceci et al., 2007; Connolly & Price, 2006; Ross et al., 2006). In each of these examinations of false memory in children of various ages, older, rather than younger, children reported a higher proportion of false details. One explanation for these findings, borrowing from Fuzzy Trace Theory (FTT; Brainerd & Reyna, 1998; Ceci & Bruck, 1998), is that as children age, they develop a greater understanding of semantic "gist" and begin to store "gist-based" rather than verbatim episodic memory representations of events. As such, as children develop they are actually more susceptible to producing false memories of details of events due to a reliance on "gist-based" representations rather than verbatim representations (Reyna, 2012; Reyna & Brainerd, 1995). This theoretical explanation accounts for a great deal of empirical evidence from the extent literature regarding this reverse developmental trend showing that, under certain conditions, older children actually produce a greater amount of false memories than younger children.

Implications for Research in Child Eyewitness Memory

These recent findings are important, as existing dominant developmental, legal, and lay perspectives have adhered to the notion that young (e.g., preschool aged) children are the most susceptible to memory contamination and therefore are the least reliable eyewitnesses (Brainerd & Reyna, 2012). Indeed, empirical evidence regarding mock-juror perceptions of child eyewitnesses indicates that adults find the reports and testimony of children, younger children especially, to lack credibility (Melinder, Goodman, Eilertsen, & Magnussen, 2004; Newcombe & Bransgrove, 2007). The extant literature regarding child eyewitness memory, however, supports the notion that these perceptions of children as necessarily less reliable than older eyewitnesses are not entirely supported by empirical evidence. Our understanding of the malleability of human memory continues to evolve. Nevertheless, the goals of obtaining accurate memory reports from child sex abuse victims in order to enact justice, while simultaneously avoiding wrongful convictions of the innocent, remain at the forefront of these important areas of applied human memory research.

Conclusions

In closing, it is safe to say that there are many questions left to address regarding memory, both in children and adults. Here, cognitive neuroscience can serve as a bridge between psychological and neuroscientific observations and leverage new techniques to address the neural underpinnings of memory. The coming decades will then require clinicians to bring these findings into application. A real challenge going forward will be to foster interdisciplinary communication and research groups targeting the development of memory in children.

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