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Memory for Emotional Stimuli in Development

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Out of the multitude of daily events, some kinds of events are much more likely to create lasting memories. Emotion is one of the most potent factors influencing the strength and quality of memories (Hamann, 2001; LaBar & Cabeza, 2006). The memory of events associated with strong emotional responses during encoding, such as a thrilling visit to a theme park or a fall off a bicycle, are much more likely to create lasting, vivid memories than similar, neutral events (Rubin, 2005). Memory for emotional events is typically enhanced in several ways, relative to similar but non-emotional events. For example, memory for emotional events is usually more accurate, stronger, and more enduring (Christianson & Safer, 1996). The subjective quality associated with retrieval of emotional memories is also typically more vivid, detailed, and associated with higher confidence in the accuracy of the memory (Phelps, 2006).

Considerable evidence indicates that emotional memories engage cognitive and neural mechanisms that are either not recruited by non-emotional memories or engaged to a much lesser extent. Given these special attributes of emotional memory, a key question that arises is whether there are important developmental differences associated with memory for emotional stimuli. We will examine this fundamental question in this chapter, focusing on the domain of episodic memory (consciously accessible memory for specific events) (Tulving & Thomson, 1973).

Developmental investigations of emotional memory are important for a number of reasons. First, because many episodic memories have an emotional component, especially those that become part of our long-term autobiographical memory, the study of emotional memory is, in an important sense, inextricably intertwined with the study of episodic and autobiographical memory (Conway & Pleydell-Pearce, 2000; Nelson & Fivush, 2004). Thus, the development of emotional memory is an essential facet of the study of the development of episodic and autobiographical memory. Emotional memories and their neurobiological substrates are also frequently implicated in the development of clinical disorders (Howe, Toth, & Cicchetti, 2011; Williams et al., 2007), and potential developmental differences in emotional memory have attracted considerable attention in eyewitness testimony research (Brainerd, Reyna, & Ceci, 2008; Ceci & Bruck, 1993). These are only a few of the many reasons for the importance of this topic (see the chapter by Baker-Ward and Ornstein in this volume for more discussion).

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Scope

The focus of this review will be on the findings of controlled laboratory studies of emotional memory, rather than observational studies, though we will briefly consider the latter type of literature (see the chapter by Baker-Ward and Ornstein in this volume for in-depth discussion of laboratory and observational approaches). Observational studies of memory for naturally occurring emotional events have been summarized in depth in other reviews (Fivush, 2011; Fivush, Bohanek, Marin, & Sales, 2009; Goodman, Quas, & Ogle, 2010; Quas & Fivush, 2009). Although laboratory studies of emotional memory in adults have played an indispensible role in characterizing emotional memory processing, relatively few developmental studies have examined emotional memory in the laboratory using paradigms and stimuli comparable to those used in adult studies. This has created a conceptual gap between these two literatures. Accordingly, a goal of this review is to point out key areas where key findings and concepts from the much more extensive adult literature can inform the study of emotional memory in children.

For the purposes of the current review, in line with other reviews of emotional memory (Buchanan, 2007; Hamann, 2001; LaBar & Cabeza, 2006; Phelps, 2006), we will define *emotional stimuli* broadly as any stimuli that can elicit an affective response in an individual. Although stress is sometimes associated with emotion, particularly highly arousing negative emotional events, the mechanisms of the effects of stress on memory can be distinguished from emotional effects, and are outside the scope of the current review (Roozendaal, McEwen, & Chattarji, 2009).

Dimensional and discrete emotion theories have been the primary frameworks that have guided how emotion is operationally defined in emotional memory studies. Dimensional theories represent emotions in terms of combinations of more fundamental dimensions, rather than as discrete categories such as happiness or fear. The two affective dimensions most commonly proposed are *valence* (pleasantness vs. unpleasantness) and *arousal* (emotion strength or intensity) (Barrett, Mesquita, Ochsner, & Gross, 2007; Russell, 2003). Dimensional representations of emotion have been used successfully to account for many emotional memory effects, and are widely used in emotional memory research (Vytal & Hamann, 2010). For example, a key finding of such studies is that it is emotional arousal, rather than valence, which is the primary factor determining the magnitude of most emotional effects on episodic memory (Murty, Ritchey, Adcock, & LaBar, 2010; Phelps, 2004; Roozendaal & McGaugh, 2011).

In contrast, discrete emotion views propose a small set of basic emotions (most commonly, happiness, sadness, anger, fear, disgust, and surprise) that are universal across cultures and are biologically inherited (Ekman & Cordaro, 2011; Lang & Bradley, 2010). Fewer emotional memory studies have focused on discrete emotions, in part because many emotional events and stimuli are difficult to represent in terms of specific discrete emotions. Most developmental studies have followed the lead of adult emotional memory studies, adopting a dimensional approach (McManis, Bradley, Berg, Cuthbert, & Lang, 2001).

A wide variety of measures have been used to assess emotion and memory in the context of emotional memory studies. Current theories of emotion conceptualize emotion as unfolding simultaneously in three basic domains: subjective emotions, physiological responses, and brain activity (Lang & Bradley, 2010), with each domain providing unique affective information. Subjective emotional reactions are typically assessed using self-report measures such as numerical rating scales indicating emotional arousal and valence (Bradley, Codispoti, Cuthbert, &

Lang, 2001a). Physiological emotion measures typically assess changes related to autonomic nervous system activity, including electrodermal (e.g., skin-conductance responses), cardiorespiratory (e.g., respiration and heart rate), and facial muscle activity (e.g., smiling and frowning). Brain activation changes associated with emotion are most commonly assessed with functional MRI (fMRI) and event-related potentials (ERPs). fMRI measures blood-flow-related changes in magnetization to characterize brain activity in regions and functional networks mediating emotion processes. ERPs, which are based on electrophysiological brain responses, have higher temporal resolution than fMRI, and are more ideal for investigating the temporal unfolding of different emotion processes (Huster, Debener, Eichele, & Herrmann, 2012). Turning to memory measures, emotional memory has been assessed with the same cognitive and brain measures used in cognitive neuroscience studies of memory more generally. Cognitive measures of memory typically assess free recall, cued recall, or recognition for previously experienced stimuli, as well as associated attributes such as source memory and memory confidence. fMRI and ERPs are the most commonly used methods to probe brain activity related to memory encoding and retrieval. The different measures of emotion and memory noted in the preceding text provide powerful tools for probing the component processes involved in emotional memory. However, they can also present interpretative challenges when results obtained from different measures do not concur; also, some measures such as fMRI are more challenging to use in younger children.

This Chapter Will Focus on the Following Questions: What are the key principles and characteristics of emotional memory that have been established in studies of adults? What are the key findings about the status of emotional memory in childhood, as well as age-related changes in emotional memory function?

Although the scope of this chapter precludes comprehensively addressing all of the important studies on emotional memory and development, we will survey selected, key findings that highlight important points, gaps in current knowledge, and current theoretical trends.

Stages of Emotional Memory Processing

Developmental effects can potentially influence the processing of emotional memories at several stages and via multiple routes. Figure 32.1 illustrates the stages of memory processing for an emotional event and highlights some key processes at each stage that may be influenced by age-dependent effects.

Emotional arousal triggers a cascade of cognitive and neural processes that contribute to memory encoding, such as increased alertness and physiological activation (Lane et al., 1998). Emotional arousal also affects basic perception and attention processes during the initial encoding of an event, frequently highlighting emotionally salient information at the expense of less salient information. Emotion can influence memory accuracy in a number of ways, for example, by increasing the number of stimuli that can be recalled from an event or list, increasing the retrieval of contextual information, or increasing recognition accuracy (Kensinger, Garoff-Eaton, & Schacter, 2007; LaBar & Cabeza, 2006).

Emotional memory recruits specific neurobiological and hormonal mechanisms that are not normally engaged by non-emotional stimuli (Roozendaal & McGaugh, 2011). The most important region involved in emotional memory is the amygdala, a structure that boosts memory-related activity in other brain regions, promoting enhanced encoding. These regions primarily include the hippocampus and its closely functionally interconnected neocortical structures (Packard, Cahill, & McGaugh, 1994). A process called *consolidation* gradually converts initially fragile, temporary memory traces initially encoded in this hippocampal memory system into a more permanent form (McGaugh, 2000; Squire, 2004). Consolidation of emotional memories differs from consolidation of non-emotional memories, and both types of consolidation have been shown to increase during sleep (Stickgold, 2005). Finally, during retrieval, retrieval cues participate in the reconstruction of the stored memory (Polyn & Kahana, 2008; Tulving, 2002). This can result in the retrieval of information from the originally encoded episode as well as re-experiencing of emotional responses experienced during the original event (Zald, 2003). Emotion can also influence other aspects of memory retrieval, for example, enhancing the vividness of recollection and increasing confidence in a memory's accuracy.

Memory for Emotional Stimuli in Children

Our primary focus here is on whether particular variables affect emotional memory in a qualitatively similar or different manner across age groups. For example, we will consider whether emotional arousal during encoding enhances episodic memory in children, paralleling arousal's memory-enhancing effects in adults. We will focus to a much lesser degree on whether emotional memory effects are quantitatively equivalent across age groups, largely because relatively few relevant studies exist. Most of the relevant studies of emotional memory have either examined a single age group or have examined a limited age range; very few have examined the entire age range from early childhood to adulthood.

Are there Age-related Differences in Affective Reactions to Emotional Stimuli?

Studies of emotional memory effects depend on the effectiveness of emotional stimuli in eliciting affective reactions. Do these reactions vary systematically with age? Because developmental

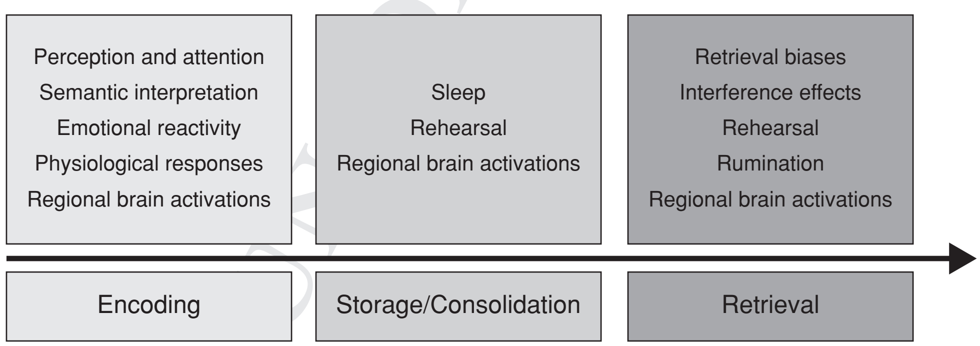

Figure 32.1 An illustration of the three primary stages of memory processing for an emotional event. Key processes at each stage that may be influenced by age-dependent effects are highlighted.

studies need to limit the emotional arousal of experimental stimuli, due to ethical concerns with presenting highly emotional stimuli to children, verifying that emotional stimuli are still effective in eliciting the intended emotional reactions is an even more important concern. A related question is the extent to which children are able to accurately report on their emotional responses using rating scales that assess emotional arousal, valence, and other affective dimensions.

Studies that have investigated these questions have generally concluded that reported emotional reactions are similar for children and adults, and that children interpret and use emotional rating scales in a broadly similar way to adults. These findings suggest that the types of emotional stimuli used in adult studies are also effective for children, supporting the feasibility for comparing emotional memory across ages. For example, McManis et al. (2001) examined subjective and physiological reactions to set emotional pictures widely used in adult emotion studies (the International Affective Picture System; Lang & Bradley, 2007) in children (ages 7–11), adolescents (ages 12–14), and adults (ages 18–23), and found high correlations between the emotional arousal and valence ratings of children and adolescents and those of adults (all correlations > .88). Numerical Likert-type rating scales were used that included stylized cartoon figures illustrating increasing degrees of the respective emotions. The physiological measures of arousal and valence (facial EMG, skin-conductance responses, heart rate changes, and startle blink magnitude) indicated that girls exhibited greater emotional reactivity to negative pictures than did boys, paralleling similar differences previously found between women and men (Bradley, Codispoti, Sabatinelli, & Lang, 2001b). The authors noted that the presence of these sex differences in physiological responses to negative affective stimuli suggest that these sex differences are stable across the lifespan.

Several other subsequent studies have found results generally consistent with McManis et al. (2001), with some exceptions. For example, Vasa et al. (2011) found no significant differences in reported arousal to positive and negative emotional IAPS picture stimuli between adolescents (mean age 15 years, range 12–17 years) and adults (mean age 30 years, range 22–45 years). Similarly, McRae et al. (2012) found no significant differences between children (ages 10–13), adolescents (ages 14–17), and young adults (ages 18–23) in their arousal ratings for negative IAPS stimuli (a 1–4 Likert-type scale ranging from weak negative affect to strong negative affect). Importantly, the arousal rating scale was sensitive in each age group to an emotional reappraisal manipulation that decreased activation in brain regions strongly implicated in emotional arousal, suggesting that the lack of age-related differences in arousal ratings were not due simply to insensitivity of the emotion measure.

An exception to this pattern of similar emotional ratings in children and adults was reported by Hajcak and Dennis (2009) in a study of young children 5–8 years of age that examined valence and arousal ratings in conjunction with ERP responses to positive and negative IAPS pictures. Unlike adults, children rated only positive stimuli as more arousing than neutral stimuli. However, the ERP findings suggest that this atypical rating behavior may have resulted in part from children interpreting the arousal scale in an idiosyncratic manner, rather than reflecting a lack of arousal for negative stimuli. Specifically, the late positive potential, which is sensitive to the emotional content of stimuli, was equivalent in size for both positive and negative stimuli.

In general, these studies suggest that the type of emotional stimuli examined in emotional memory studies typically elicit reliable emotional responses in children. In addition, children can use emotional rating scales to report the emotional valence and arousal associated with their emotional reactions in a way broadly similar to adults. There is some evidence that younger children may interpret rating scales atypically when rating negative emotional stimuli. Additional research is needed to better understand how children make emotion ratings for emotional stimuli using experimental scales, with an eye toward improving the reliability and validity of current measures.

Laboratory Studies of Emotional Memory in Children

To what extent do children and adolescents show evidence of the same kinds of emotional memory effects that have been previously demonstrated in adults? We will examine this question primarily from the perspective of laboratory studies, but will also briefly consider relevant findings and connections with naturalistic studies of real-life emotional events in a final section.

The majority of relevant studies suggest that, for most commonly studied emotional memory effects in adult studies, children and adolescents also exhibit these effects. For example, the most robust finding from adult studies, that emotionally arousing stimuli are better remembered, has also been found in several studies of children and adolescents. For example, Vasa et al. (2011) found that adolescents and adults rated affectively positive, negative, and neutral pictures similarly in arousal and valence, and the enhancement of free recall for negative and positive pictures was also similar for both groups. However, as noted in previous reviews (Hamann, 2001; Howe, Candel, Otgaar, Malone, & Wimmer, 2010), studies have occasionally reported either a lack of enhancement of memory by emotional arousal, or, in some cases, a substantial memory disadvantage for neutral emotional material. For example, in a series of experiments with children and adults, Howe et al. (2010) reported that recall and recognition was significantly better for neutral word lists (*table, apple, tooth*, etc.) relative to negative word lists (*hate, mad, frown*, etc.). What might account for these exceptions?

A commonly overlooked possibility is that a study's emotion manipulation may not have been successful in eliciting the intended emotional reaction. For example, some emotional memory studies with children have not assessed participants' emotional responses, relying instead on ratings from previous studies (Howe et al., 2010; Krauel et al., 2007). However, there are many reasons why stimuli may fail to elicit the intended emotional responses in different subject groups or experimental conditions. Accordingly, studies of emotional memory should assess emotional responses of the study participants wherever possible, to verify the success of the emotion manipulation.

Another possible explanation stems from the fact that emotional arousal is often correlated with other factors that influence memory, such as item distinctiveness and the similarity between items in the list. For example, emotionally arousing stimuli such as *horror*, *murder*, *terror*, *afraid*, and *assassin* share more than simply the property that they tend to elicit emotional arousal. The list items also share common semantic and conceptual properties, and this high inter-item semantic similarity can either boost memory or impair memory, depending on the experimental conditions. In other experimental contexts, the typical high inter-item similarity of emotional word lists can impair memory by inducing increased retrieval interference (Sharot, Delgado, & Phelps, 2004), or reducing the ability to discriminate between list items and semantically similar distractors. Returning to the Howe et al. (2010; LaBar & Phelps, 1998) findings, the negative word lists had high inter-item similarity, whereas the neutral word lists had low inter-item similarity, and this may have contributed to the reversal of the expected advantage for emotionally arousing items.

Functional Neuroimaging Studies of Emotional Memory in Children

To what extent are similar neural mechanisms involved in emotional memory for adults and children? Three relevant fMRI studies from studies using paradigms from adult studies have provided some initial relevant findings.

Krauel et al. (2007) examined regional brain activations associated with emotional and neutral episodic memory in 12 healthy adolescents (mean age 15.2 years) and 12 adolescents (mean age 14.5) diagnosed with attention-deficit hyperactivity disorder (ADHD). In an emotional memory task similar to those used in adult fMRI studies, participants were scanned while they viewed briefly presented negative and neutral IAPS pictures. While viewing the pictures, participants alternately carried out either a semantic encoding task or a perceptual task.

After a short break, recognition memory for all of the studied pictures was assessed. As expected, recognition memory was enhanced for the negative pictures for both groups, following both semantic and perceptual encoding. For the control group, activation related to successful encoding for negative pictures recruited two key regions frequently found in corresponding studies in adults, the right amygdala and bilateral parahippocampal gyri. The ADHD group also showed successful encoding-related activity in the medial temporal lobe, right hippocampus, and right parahippocampal gyrus, though not in the amygdala. Outside of the medial temporal lobe, both groups showed successful encoding-related activation for emotional pictures in other key cortical areas commonly found in corresponding adult studies, including regions in the prefrontal, occipital, and lateral temporal cortices. This study's findings suggest that the successful encoding of negative emotional pictures recruits broadly similar regions in adolescents to those previously reported in similar studies with adults.

Vasa et al. (2011) also examined emotional episodic memory using fMRI, extending this previous study in several important ways. Most notably, this study examined both adolescents (mean age 15 years, range 12–17 years) and adults (mean age 30.2 years, range 22–45 years), allowing age-related differences to be assessed. In addition, behavioral and fMRI responses to both negative and positive emotional pictures were assessed, allowing valence effects to be assessed. As in the study by Krauel et al. (2007), the IAPS was used as the source of normed picture stimuli, facilitating comparison between the two studies. One unusual feature of the experimental procedure was that, unlike most adult studies of subsequent memory effects that present stimuli only once during encoding, stimuli were presented four separate times, and four different encoding tasks were used for each presentation. The rationale for presenting the stimuli multiple times was to increase levels of subsequent recall for the pictures to optimize the analysis of brain activation related to subsequent memory. The four encoding tasks assessed participant ratings of emotional arousal, valence, perceptual characteristics of the picture, or simply asked the participant to passively view the picture. This was followed after approximately 30 minutes by a free recall test in which participants attempted to verbally describe all of the pictures they had viewed during scanning.

Consistent with the findings of previous studies, reviewed earlier, which suggested that adolescents tend to rate emotional stimuli in a similar way as adults, Vasa et al. (2011) found no significant differences between the adolescents and adults in their arousal and valence ratings of the positive, negative, and neutral picture stimuli. The pattern of free recall results was highly similar for adolescents and adults, and was also in line with findings from previous studies with adults. Specifically, both age groups had higher recall for negative and positive pictures than for neutral pictures, and also had higher recall for negative vs. positive pictures.

In contrast to many studies that have assessed brain activations across the entire brain, this study focused only on two brain regions, the hippocampus and amygdala (separately for the left and right hemispheres), in a targeted region-of-interest (ROI) analysis that averaged fMRI activation across anatomically defined ROIs. This approach has the advantage of being more statistically sensitive to effects within the selected ROIs, but has the disadvantage that it does not provide information regarding the recruitment of other brain regions. The key finding of the ROI analysis was that right amygdala activity during encoding predicted later successful free recall of positive emotional pictures to a greater degree for adolescents than for adults. Contrary to predictions based on previous findings suggesting that adolescents may exhibit greater amygdala responses for negative emotional stimuli, no corresponding age-related differences in successful encoding-related activation were observed for negative pictures. The greater-right-amygdala-encoding-related activity for positive pictures for adolescents was interpreted as being potentially related to greater behavioral sensitivity to reward that has been reported in adolescence, associated with increased risk-taking behavior.

These findings are intriguing, yet, as the authors noted, because of a number of limitations of the study, including small sample size, low recall levels for some subjects, and the potential problems introduced by presenting encoding stimuli four times, the findings require replication in a larger and more methodologically optimized study. Such a study would ideally include additional memory measures such as recognition, as in Krauel et al. (2007). Given the limited power of this study to detect age-related differences, the null findings, particularly regarding group differences in encoding-related activations for negative stimuli, should also be interpreted cautiously.

Nelson et al. (2003) used a somewhat different approach to examining age-related differences in the fMRI correlates of successful encoding for emotional stimuli, focusing on emotional facial expressions rather than emotional pictures. Seventeen adolescents (mean age 13 years, range 9–17) and 17 adults (mean age 31 years, range 25–35) were compared on the fMRI correlates at encoding of successful subsequent memory for facial expressions depicting the discrete emotion categories of anger, fear, happiness, as well as neutral expressions. As in the Vasa et al. (2011) study, each facial expression stimulus was presented four times, each time paired with a different rating task. A few minutes after scanning, recognition of pictures of the actors who had posed the emotional and neutral expressions was assessed with a surprise memory test. Recognition memory did not differ across groups for any of the expression types. Turning to the imaging results, increased activity related to subsequent successful memory was found in the adolescent group in the anterior cingulate cortex for angry expressions and the temporal pole for fearful expressions. The corresponding analysis for adults found only one region of greater encoding-related activation, in the subgenual anterior cingulate for happy facial expressions.

Several aspects of this study make its findings difficult to integrate with the other fMRI studies. The memory task was atypical in that only neutral facial expressions were presented at test, so that for neutral faces that had been seen during encoding the exact same stimuli was presented again, but for studied emotional faces, there was a mismatch between study and test stimuli (e.g., the same actor was shown, now with a neutral expression). Consequently, instead of enhancing memory for the studied faces, emotion at study substantially impaired memory because of the mismatch between study and test format. Similarly, the effects of emotion in this paradigm are difficult to disentangle from perceptual effects, particularly because only the neutral expression stimuli were presented unaltered at test. Although the interpretation of the specific findings of this study are complicated somewhat by these design issues, this study is nevertheless important because it was the first study to show that sophisticated subsequent memory-event-related fMRI designs could be applied to study age-related differences in memory for emotional stimuli.

Although few in number, these fMRI studies provide some preliminary information about the brain regions that are recruited in children during successful memory encoding. The Krauel et al. (2007) and Vasa et al. (2011) studies are the most informative in this regard, in part because of the greater procedural overlap between these studies and comparable prior studies with adults. Two key brain regions implicated in prior adult studies, the amygdala and hippocampus/parahippocampal gyrus, were found to also be involved in successful encoding of emotional pictures in children. Vasa et al. (2011) further implicated the amygdala in an age-related increase in encoding-related activity. Outside the medial temporal lobe, Krauel et al. found encoding-related activity in prefrontal, occipital, and lateral temporal cortices, paralleling prior findings from fMRI studies with adults. In addition, Krauel et al. demonstrated that fMRI measures of successful encoding for emotional stimuli were sensitive to and showed significant differences associated with a developmental disorder, ADHD, pointing to the clinical utility of fMRI measures of emotional memory. At the same time, limitations were noted for each of the fMRI studies examined, and these limitations, combined with the small number of studies conducted to date, clearly point to the need for substantially more attention to these questions in future fMRI studies of emotional memory.

Clinical Disorders and Emotional Memory in Children

The differences in emotional-encoding-related fMRI activations between ADHD and healthy age-matched adolescents reported by Krauel et al. (2007) are an example of a growing number of studies that have examined how emotional memory processes are altered in clinical disorders. In the next section, we will briefly survey studies that provide some initial clues regarding similarities and differences between emotional memory effects associated with clinical disorders in children and adults.

In the adult literature on emotional memory, studies of patients with temporal lobe epilepsy (TLE) have provided key information regarding the roles of these structures in emotional memory as well as lateralization of emotional memory function, particularly in patients who have undergone amygdala lesions. Jambaqué et al. (2009) extended this line of research to children and adolescents with unilateral TLE, compared with healthy age-matched control participants (10 left TLE, mean age 13 years; 10 right TLE, mean age 13 years; 40 control participants, mean age 13 years) to determine whether the emotional enhancement of memory was altered, as had been reported in some previous studies of adult TLE patients. All TLE patients had verified hippocampal atrophy or temporal cortical lesions, and eight of the patients had undergone temporal resection surgery and thus had complete unilateral lesions to the amygdala and a variable extent of hippocampal lesions. Emotional memory was assessed using an emotional story task and an emotional word free recall task. The emotional story described a negative emotional event and contained emotional and neutral story elements. The emotional word recall task involved presenting a list containing positive, negative, and neutral words three times, testing recall for each presentation and again after a short delay.

As expected, the healthy control group showed significant memory enhancement for the emotional story material and for the positive and negative words, relative to the neutral material in each task. In contrast, neither of the TLE groups (left or right TLE) showed a memory benefit for the emotional story material or the emotional words. This impairment was found both during learning on each trial and after a short delay interval. These findings suggest that lesions or functional impairment to medial temporal lobe structures involved in emotional memory have a similar impairing effect on the emotional enhancement of memory when these structures are affected in childhood and adolescence as when they are affected in adulthood. However, because this study did not describe the quantitative extent of lesions to the amygdala and other medial temporal structures, and did not separate the behavioral results of patients with surgical lesions from those with atrophy due to TLE, it is not possible to attribute the emotional memory deficits specifically to particular medial temporal brain structures. Also, the emotional memory tasks all used verbal stimuli and used a limited set of stimuli including very short lists and a single emotional story.

Turning from neurological disorders to psychopathology, considerable interest has focused on whether children and adolescents with depression exhibit emotional memory effects that have been demonstrated in adults. Perhaps the most prominent emotional memory effect in this regard is the mood-congruent memory bias, in which memories that are congruent with depressed mood are more likely to be recalled and those that are incongruent are less likely to be recalled.

The findings from studies of clinically depressed children and adolescents are relatively clear-cut. A significant bias toward selectively recalling negative emotional memories has been found in these age groups, and is particularly robust when encoding instructions emphasize encoding emotional material with respect to oneself, just as has been found in corresponding studies with adults (Neshat-Doost, Taghavi, Moradi, Yule, & Dalgleish, 1998; Zupan, Hammen, & Jaenicke, 1987). As with other state-dependent memory effects, these memory biases are observed when memory is assessed with recall tasks but not when recognition memory is assessed, thus implicating bias effects during the process of memory generation and search, rather than biases in decision criteria. These selective recall biases for negative emotional memories have also been found for emotional story recall in children and adolescents aged 5–11 years who were not clinically depressed but who had relatively higher scores on depressive symptoms than age-matched controls who were lower on these symptom measures (Bishop, Dalgleish, & Yule, 2004). This suggests that these emotional memory bias effects are not limited to individuals with clinically diagnosed depression and can be detected within the range of variations in mood states among healthy children and adolescents.

Another clinical disorder in which selective memory biases involving recall of negative memories has been found in adults is post-traumatic stress disorder (PTSD). Only one study has examined this issue in children and adolescents with PTSD, using an emotional word recall and recognition memory paradigm. This study examined 24 children and adolescents aged 9–17 years who all met clinical criteria for a diagnosis of PTSD, comparing them to 25 age- and IQ-matched healthy control participants aged 9–17 years (Moradi, Taghavi, Neshat-Doost, Yule, & Dalgleish, 2000). The negative emotional words were selected to be either trauma-related, depression-related, or related to threat. Positive emotional words and neutral words were selected to match the negative words on word frequency and length.

As predicted, the PTSD group showed a negative memory bias in recall, recalling significantly more negative words than positive words, whereas the control group showed no evidence of a negative memory bias. Consistent with previous studies of mood-congruent memory effects, only recall measures showed emotional bias effects. Although the authors predicted a specific memory bias for words related to threat, the recall bias was observed for all negative word types. Though not predicted in this study, this finding of a general recall bias for negative emotional memories is consistent with the recall biases associated with depression described earlier.

These findings from studies of emotional memory effects in children and adolescents with clinical disorders are generally in line with what has been found previously in similar studies with adults. However, these initial studies require follow-up and replication to assess their generality.

Memory Consolidation Effects on Emotional Memory

Consolidation is difficult to influence except through manipulations that directly influence brain function. A frequently used alternative approach to examining consolidation effects has been to capitalize on the increased consolidation thought to occur during sleep (Stickgold, 2005). For example, in adults, a period of sleep (vs. wakefulness) facilitates long-term episodic retention for a wide variety of stimuli. Sleep has also been shown in some studies to preferentially enhance episodic memory for emotional stimuli (Walker, 2010), with memory for emotional stimuli either showing reduced forgetting or even improvement across a period of sleep relative to neutral stimuli.

Two studies have examined the effects of sleep on emotional episodic memory in children. In the first, Prehn-Kristensen et al. (2009a) examined the effects of sleep on emotional and neutral memory in 20 children in the age group of 10–13 years, in a within-subjects design using an emotional-picture-encoding task. A large number of emotionally negative and neutral pictures were encoded and tested after a several-hour delay that either contained or did not contain a period of nighttime sleep. Recognition memory for negative stimuli was enhanced relative to neutral stimuli, and this effect was magnified when the delay interval included nighttime sleep, paralleling previous findings with adults. These effects could not be attributed to changes in emotional responses to the stimuli, as emotion ratings for the emotional and neutral stimuli were not affected by the sleep manipulation.

In a later study by the same group, Prehn-Kristensen et al. (2011), the neural correlates of these effects were examined in 12 children (ages 10–16 years) diagnosed with ADHD and 12 age-matched control children. The goal of the study was to examine whether alterations in sleep characteristics in children with ADHD were related to impairments in memory consolidation during sleep. There is a higher rate of sleep abnormalities reported in ADHD, suggesting that deficits in declarative memory in ADHD may be related to sleep alteration, particularly in processes linked to the consolidation of declarative memory. This study used the same emotional-episodic-memory-encoding task as was used in the previous study by this group (Prehn-Kristensen et al., 2009b).

The results were generally supportive of a relationship between sleep alteration and consolidation-mediated deficits in declarative memory. First, although declarative memory in both groups benefitted from sleep, children with ADHD derived a significantly smaller benefit to memory from sleep. Although the interaction between the effects of emotion and sleep did not reach significance, it was found in a follow-up analysis that, whereas the control group children had a marginally greater benefit to emotional vs. neutral memory following sleep, the children with ADHD showed no evidence of an emotion-enhanced consolidation effect, and in fact had a numerically opposite effect. Finally, the amount of slow oscillation activity (<1 Hz) was positively correlated with the degree of enhancement of declarative memory by sleep only in the control children, despite the fact that both groups exhibited the same amount of slow oscillation activity. This finding was interpreted as showing that the relationship between the slow oscillation component of sleep is specifically altered in ADHD, and may contribute to observed deficits in declarative memory in this condition. This is consistent with the findings of previous studies that have linked slow oscillation activity to enhancement of declarative memory by sleep in adults, and also to activity in the prefrontal cortex, a region whose activity is known to be altered in ADHD.

Emotion and False Memory Effects

The focus in the foregoing studies has been the effects of emotion on accurate memory for stimuli and events. However, another major topic of memory research in both the adult and child literatures has been the fallibility and malleability of memory. Part of the impetus for this line of research has been the aim of studying how such processes operate in the context of real-life contexts such as eyewitness testimony and memory for highly traumatic events.

One of the most popular lines of experimental inquiry in this field involves studies using the Deese–Roediger–McDermott (DRM) paradigm, a task that reliably generates episodic memories for items that were in fact never presented (Roediger & McDermott, 1995). Typically, a list of semantically related words (e.g., *bed*, *slumber*, *pillow*, *nap*, *siesta*, *rest*, *tired*, *dream*, *drowsy*) is presented auditorily to experimental participants, who encode the words with the intention of remembering them for a later test. Later, on a memory test such as free recall, participants frequently will falsely (incorrectly) recall the word "sleep" as having been presented. One of the leading explanations for this memory illusion is that the semantic overlap between the presented words leads to activation of the concept "sleep," which is common to all of the words on the list, and it is the activation of this semantic "gist" that leads participants to endorse a word that was not actually presented as having been experienced. Though such laboratory effects may seem distant from the real-life contexts of eyewitness memory and trauma, a number of studies have linked individual differences in susceptibility to false memory in the DRM task to real-life phenomena involving suggestibility and memory inaccuracy (Bremner, Shobe, & Kihlstrom, 2000; Clancy, Schacter, McNally, & Pitman, 2000).

A study by Brainerd, Holliday, Reyna, Yang, and Toglia (2010) revealed some important and counterintuitive age-related differences in the effects of emotion on false memory in the DRM paradigm. A large number of developmental studies have established that false memory rates decline with increasing age between childhood and adulthood, as assessed by studies employing misleading post-event suggestions as well as those that did not involve suggestions (Brainerd et al., 2010; Reyna & Brainerd, 2011). However, on the basis of fuzzy trace theory (Reyna & Brainerd, 2011), Brainerd et al. (2010) predicted that this pattern of decreased false memory with increasing age would reverse in situations where false memories tend to occur due to semantic or conceptual similarity across similar events and where it is difficult to use detailed, accurate memory (termed "verbatim" memory in FTT) to counteract these memory distortions (see the chapter by Brainerd and Reyna in this volume for a full description of fuzzy trace theory).

The authors predicted that emotional words would create just this type of situation where the usual age-related decrease in false memory would reverse. The rationale for this prediction was based on two primary ideas. First, there is considerable evidence showing that verbatim processing predominates over gist-based processing in early childhood, and that gist-based processing ability increases across development, leading to an adult pattern of a predominance of gist-based processing.

The second part of the rationale focused on the fact that emotional valence is a conceptual attribute that influences how items are organized and processed during encoding and retrieval. In the DRM paradigm, the formation of false memories is strongly related to the tendency to make meaning-based connections between list items. The authors reasoned that negative and positive emotional words would show higher rates of false memory in this paradigm because the semantic similarity conferred by sharing affective semantic properties would increase the tendency to connect the shared gist between emotional words, more so than for neutral words that do not have affective properties in common. Moreover, based on previous findings suggesting that stimuli with strong negative affective valence promote gist-based processing and suppress detailed, veridical memory processing, they predicted that effects that depended on gist-based processing would be increased for negative stimuli, particularly high-arousal negative stimuli.

Combining the age-related shift from verbatim processing and the predicted effects of emotional valence, Brainerd et al. (2010) predicted that false memory would increase with age for emotional items, in contrast to the typical pattern of false memory decreases with increasing age, and that this effect would be particularly strong for negative stimuli and high-arousal stimuli. Using a modified version of the DRM paradigm that allowed them to independently manipulate arousal and valence, they tested the predictions in three groups, 7-year-olds, 11-year-olds, and young adults (mean age 21 years). As predicted, for emotional stimuli, the proportion of false memories actually increased with age and the overall accuracy, based on the ratio of true to false memory, decreased with age. Also as predicted, there were stronger emotion effects for negative than for positive stimuli, and these effects were stronger for high vs. low-arousal stimuli.

This study is an excellent illustration of how emotional valence can strongly influence the formation of false memories in laboratory context, and how these emotion effects can differ markedly as a function of age. This study also illustrates the importance of considering how emotional stimuli differ from neutral stimuli not just in terms of emotional arousal, but also in terms of semantic and conceptual processing. These semantic category and conceptual effects associated with emotional stimuli complement the emotional-arousal-based memory effects that have been the major focus of this review.

Implicit Emotional Memory

The studies discussed so far have all focused on emotional episodic memory. The amygdala, which plays a key role in the modulation of episodic memory by emotion, is also critically involved in the formation of implicit fear associations (i.e., memories where previous experiences affect behavior without a conscious awareness of previous experiences; Roediger, 1990). Because the amygdala's function is critical for fear conditioning, studies have used fear conditioning as a proxy measure for assessing amygdala function.

Gao, Raine, Venables, Dawson, and Mednick (2010) used this approach, assessing fear conditioning in a longitudinal study of 200 children at ages 3, 4, 5, 6, and 8 years. Fear conditioning was assessed between an auditory conditioned stimulus (a neutral tone) and a mildly aversive auditory unconditioned stimulus (a white noise burst combined with the sound of keys in a can), using a partial reinforcement conditioning procedure, with skin conductance responses (SCR, a commonly used physiological measure of sympathetic arousal) as the primary dependent measure. There was a relatively linear increase in fear conditioning across ages 3–8, with a noticeable increase between ages 5 and 6. These increases, including the relatively greater increase between ages 5 and 6, were paralleled by an increase in the SCR to the unconditioned stimulus, consistent with the established relationship between increased response to an unconditioned stimulus and the magnitude of fear conditioning.

The age-related increase in fear conditioning suggests that, at least for the amygdala functions recruited during conditioning, significant increases occur in early childhood. These changes in fear conditioning also have significant implications for understanding the development of clinical conditions involving fear, including phobias and anxiety disorders. Relatedly, the age-related increase in physiological emotional responses across ages 3–8 to the same mildly aversive auditory stimulus suggests that general physiological emotional reactivity may increase across early childhood, at least to specific types of stimuli. If confirmed by other studies and with other stimulus modalities such as pictures, this age-related increase in emotional reactivity may have important implications for the emotional enhancement of declarative memory, which is also strongly related to emotional arousal.

Memory for Real-life Events

A complementary source of evidence on the development of emotional memory comes from the literature on children's memories for incidentally occurring events. A number of studies have examined children's narratives or descriptions of emotional life events, and how children's descriptions of the events change over developmental time. These studies provide information about how emotion influences memory for experiences that differ from laboratory experiments in that the remembered events are more complex, are of greater personal relevance to the child, and may involve more intense emotional reactions.

A major theme of this research has been to establish how children's memory varies as a function of emotional arousal, particularly whether the relation between emotional arousal follows an inverted-U-shaped function, where moderate arousal is associated with optimal memory performance and very low and very high arousal is associated with relatively low memory performance. Most reviews of the adult emotional memory literature have concluded that there is currently little support for such an inverted-U-shaped relation between arousal and memory (Hamann, 2009; McGaugh, 2000). However, a number of studies with children have reported findings consistent with an inverted-U-shaped function. For example, some studies of children's memory for naturally encountered events that have probed memory for highly negative real-world events have failed to observe the memory-enhancing effect of emotion that is typically observed in the moderate range of emotional intensity. For example, children's memory for hospital visits correlates negatively with levels of emotional distress (Chen, Zeltzer, Craske, & Katz, 2000; Peterson & Bell, 1996). Such memory decreases may be attributed to the high emotional intensity experienced during the event, but may also be influenced by children's willingness to discuss highly stressful events at retrieval. For painful medical procedures and natural disasters, it has been observed that children who were more stressed during the event provided fewer details when freely recalling the event, but were more accurate and less suggestible when responding to direct questions about the event (Fivush, McDermott Sales, Goldberg, Bahrick, & Parker, 2004; Quas et al., 1999).

These studies also reveal insights into the changing developmental status of children's encoding and retrieval of emotional events over time. Across most studies, memory detail and specificity improved with age, independently of the emotional content of the remembered event

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(e.g., Bahrick, Parker, Fivush, & Levitt, 1998; Chen et al., 2000; Fivush et al., 2004; Howe, Courage, & Peterson, 1995; Peterson & Bell, 1996). Results have been mixed as to whether emotionally arousing events from very early in life may be recalled despite the typical boundary of infantile amnesia at around 3–4 years of age. In one study, children experiencing painful medial procedures earlier than 2 years of age showed little memory for the event when tested several years later (Quas et al., 1999), but in another study were able to recall many details of the experience (Peterson & Whalen, 2001).

Divergent findings here may reflect additional complexities associated with examining memory for incidental experiences. Relative to laboratory scenarios, it is more difficult to recruit a group of children who all experienced a similar event, to measure children's initial emotional reactions during the event of interest, to measure children's encoding and retrieval of the event of interest, and to establish an appropriate comparison event such as a neutral or less emotional experience. Studies examining autobiographical memory within the laboratory balance the richness of naturally acquired personal memories with additional control over the encoding and retrieval conditions. One such method is the cue word paradigm, in which participants are asked to generate autobiographical memories in response to emotionally neutral concrete nouns. Whereas studies of incidentally occurring traumatic events such as hospital visits do not easily allow direct comparison of memories for events varying in valence or emotional intensity, the cue word method produces a large body of memories from which comparisons may be drawn (Daselaar et al., 2008; Greenberg et al., 2005). We adapted this method to study the retrieval of emotional autobiographical memories in school-aged children (Bauer, Stevens, Jackson, & San Souci, 2011), directing children to select memories from the past year that were negative, positive, or not associated with a particular emotion. ERP recordings collected during autobiographical recollection showed differential neural responses to the emotional relative to non-emotional autobiographical memories, during late processing phases. Differential neural processing of emotional relative to neutral stimuli during late processing has also been observed in adults' retrieval of picture and word stimuli more typical of laboratory experiments (e.g., Dietrich et al., 2001; Inaba, Nomura, & Ohira, 2005; Weymar, Löw, Melzig, & Hamm, 2009), pointing to similarities in retrieving emotional, autobiographical, and episodic stimuli, in children and adults.

Conclusion

Preliminary answers to many of the questions posed at the beginning of this review have begun to emerge. Although fewer laboratory studies of emotional memory have been conducted with children and adolescents than with adults, these studies have nonetheless provided some key insights about the status of emotional memory in childhood and, to a lesser extent, the status of age-related changes in emotional memory function. In general, in every case in which emotional memory effects found previously in adults have been studied in children, these same memory effects have been found to be present. For example, the enhancing effects of emotional arousal on memory, the enhancement of emotional memory by sleep, memory biases for mood-congruent recall in depression and PTSD, modulation of false memory effects by emotion, fear conditioning, and other emotional memory effects have now been demonstrated in studies of children. Moreover, the available evidence from the few studies of children that have used neuroimaging and neuropsychological approaches also suggests that similar key brain regions and neural mechanisms are recruited in children and adults during successful encoding of memory for emotional stimuli.

In contrast to the findings showing that corresponding emotional memory effects can be demonstrated in children and adolescents, much less is known regarding age-related changes in memory for emotional stimuli. Most studies have not included both children and adults, precluding within-experiment examination of age-related differences. Future studies of these issues will therefore need to include both children and adults to a much greater extent. The studies reviewed here have provided preliminary information about the status of memory for emotional stimuli in children and adolescents. However, the picture outlined by these findings remains relatively incomplete, and the extent to which these findings generalize more broadly remains to be tested.

What are some next steps in the study of memory for emotional stimuli in development? More laboratory studies investigating different aspects of emotional memory in children and adolescents are clearly needed, using methods and approaches comparable to the corresponding adult literature. Such studies will increase knowledge about emotional memory in children and adolescents and forge stronger links with the existing adult literature. The studies reviewed here have laid the groundwork for subsequent research by providing initial demonstrations of key emotional memory phenomena in children. Any of the research topics reviewed here would be fertile ground for further study, particularly from the perspective of examining age-related developmental differences. Combined insights from multiple approaches and methodologies will be essential for a fuller understanding of the cognitive and neural processes that are preferentially recruited by memory emotional stimuli and events across development.

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