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The developmental status of emotional memory in school-age children

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An abstract submitted to the Faculty of the
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In partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in Psychology
2014

Abstract

The developmental status of emotional memory in school-age children

By Jacqueline S. Leventon

From birth through adulthood, our lives are filled with emotion not only in day-to-day experience, but in pictures, stories, words, and of course, memories. As adults, we show better memory for emotional over neutral experiences. The effect is attributed to emotional arousal at encoding, and suggests a strong integration of emotion and memory processes in adults. Children also experience and remember emotional events, yet it remains unclear how tightly connected emotion and memory processes are in development. That is, do children encode and remember emotional experience similarly to adults, or, is emotional experience separate from subsequent memory processes? In Study 1, event-related potential (ERP) and behavioral measures were used to assess 5- to 8-year-olds' encoding and subsequent recognition of negative, positive, and neutral scenes from the International Affective Picture System (IAPS). Across the sample, children demonstrated emotion effects in their ERPs to and ratings of the stimuli, with more robust emotion effects in older children (> 7.5 years). Further, emotion effects on recognition began to emerge for older but not younger children, suggesting that emotion and memory processes become more integrated in the school-age years. Measures of depressive symptomatology clarify the group pattern, suggesting that greater withdrawn/depressed behavior was associated with stronger ERP recognition responses to positive scenes and weaker ERP recognition responses to negative scenes. In Study 2, a reappraisal manipulation was used to examine the explanatory role of arousal at encoding on the enhancing effect of emotion on subsequent memory in 8-year-old girls. Children’s ERPs indicated down-regulation of arousal for reappraised negative stimuli and subsequently reduced recognition of reappraised negative stimuli (in both ERPs and behavioral responses). The finding supports the integration of emotion and memory processes by middle childhood, as well as the explanatory role of arousal at encoding on the enhancing effect of emotion on subsequent memory. Together, the findings suggest developmental emergence of emotion effects on memory in the school-age years, and support the explanatory role of emotional arousal on subsequent memory.

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The developmental status of emotional memory in school-age children

Our everyday lives are situated in emotional contexts that regulate our current and future behavior. Specifically, emotions are transient feelings that reflect underlying motivations (e.g., approach, avoidance) and mark significant experiences to remember and guide behavior in future encounters. In adults, emotional events, both positive and negative, are often better recalled and the memories are more enduring than neutral events ("emotion effect", e.g., LaBar & Cabeza, 2006). The emotion effect is attributed to emotional arousal at the time of encoding, which grants the memory privileged status over the course of the memory process. Given its adaptive value, it would be useful to have a working emotional memory system early in life. Infants and children certainly experience emotion, but it is not clear how and when emotional experience is integrated with memory processes, and if there is a developmental trajectory of emotional memory to the adult-like form.

The group pattern of adults' emotional memory may be explained in part by state-like attributes (i.e., arousal at the time of emotional experience), yet trait-like attributes may also play a role. That is, at the time of the initial encoding of an event, individual differences in the experience of emotion, including individual differences in emotional reactivity and emotion regulation, may be obscured by group patterns of emotional memory. Emotion regulation skills are critical to the development of appropriate and adaptive social behavior and individuals who cannot adequately regulate their emotions may demonstrate externalizing or internalizing behaviors, such as aggression or social withdrawal, respectively (e.g., Eisenberg et al., 2004). Importantly, emotion is not isolated from cognition, as illustrated by the "emotion effect" in memory, for example.

Early emerging individual differences in emotion regulation can continue into adolescence and adulthood, and may contribute to biases in emotional memory and other cognitive processes, for example, enhanced memory for negative events in cases of depression (Caspi & Silva, 1995; Kagan & Snidman, 1999; Leppanen, 2006). Thus both state- and trait-attributes of emotional experience are involved in emotional memory.

Although we know that children experience emotion and are capable of remembering personal emotional experiences, we do not have a clear understanding of the processes at the time of encoding that are at the forefront of the memory process, and if emotion effects are present in children's memory patterns. Further, we do not know how variations in emotion processes affect the initial encoding of emotional experiences (e.g., individual differences in emotional reactivity and regulation, manipulations of arousal at the time of encoding). In this dissertation, I examined these questions in school-age children, capitalizing on ERP methodology to capture real-time neurophysiological processing during the encoding and retrieval of emotional stimuli.

Event-related potentials (ERPs) are the ideal methodology to measure emotion and memory. Emotion processes, including emotion regulation, and memory processes have distinct effects on the underlying neural processing that are reliably revealed in ERP signal. Further, ERPs have exceptional temporal resolution, and as such, they are ideal for examining processing of emotional stimuli given the nearly-immediate neural response to emotional stimuli, reflecting changes in the allocation of attentional resources, for example (Banaschewski & Brandeis, 2007; Hajcak, Moser, & Simons, 2006). Because ERPs represent the summation of underlying neural activity, amplitude measures of the ERP response are interpreted as direct representations of the size of the underlying neural response to a discrete stimulus. They can be easily measured in a diversity of participants, from infancy to adulthood, and as such, ERPs are an ideal tool to compare responses to the same stimuli across the span of development. This feature is exploited in the present research.

There are two ERP components that emerge over posterior sites that are commonly examined as representing emotional reactivity and emotion regulation processes: the P300 (positive peak around 300 ms post-stimulus onset, as measured in adults) and the late positive potential (LPP) (Hajcak, MacNamara, & Olvet, 2010). Emotional stimuli to which responses have been collected include words, facial expressions (e.g., expressions of fear, sadness, happiness, etc.) and images of scenes (e.g., an open-mouthed shark, a kitten walking through grass, etc.) from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2008). The P300 is expressed as a larger positive peak in amplitude toward emotional versus neutral stimuli and seems to represent an automatic attentional response toward emotional stimuli. Because the P300 has been observed in paradigms including emotional stimuli as well as non-emotional stimuli (e.g., oddball paradigms), and may reflect more general attentional processes, further discussion of the P300 will not be pursued. Rather, I will focus discussion on the LPP, where differences in the size of responses have been linked with emotion reactivity and regulation processes (Hajcak et al., 2010). The LPP is manifested as a sustained positivity that, similar to the P300, is greater for emotional relative to neutral stimuli. In adults, the LPP generally begins between 300 and 500 ms post-stimulus onset (potentially an extension of the P300) and can extend for several seconds post-stimulus onset (Hajcak et al., 2010). As opposed to the P300, the LPP is believed to reflect sustained increased attention toward intrinsically motivating stimuli (Hajcak et al., 2010). The size of the LPP is larger for emotional versus neutral stimuli and is relatively stable over time and within individuals, in adults (Codispoti, Ferrari, & Bradley, 2006). Responses in the LPP may represent amygdala activity via modulation of visual responses (Bradley, Sabatinelli, Lang, Fitzsimmons, King, & Desai, 2003). Notably, similar ERP components are sensitive to both emotion and memory processes, as will become evident below.

As earlier introduced, adults demonstrate better and more enduring memory for emotional, positive and negative, relative to neutral events (e.g., LaBar & Cabeza, 2006). The "emotion effect" on memory has been tied to emotional arousal at encoding, and in fMRI research, located to amygdala activity, as well as other areas of the limbic system that are well-connected to the amygdala, particularly the hippocampus (Cahill et al., 1996; Hamann, Ely, Grafton, & Kilts, 1999). Differences in memory performance are also reflected in electrophysiological measures, such as ERPs. Specifically, larger (more positive-going) ERP responses during encoding and subsequent recognition of emotional stimuli are associated with better subsequent recall and recognition of the stimuli (Dolcos & Cabeza, 2002; Maratos & Rugg, 2001; Weymar, Löw, Melzig, & Hamm, 2009). The old-new memory effect (larger ERP response to old, familiar stimuli relative to new stimuli) has been commonly observed across a number of paradigms with participants from infancy to adulthood (e.g., Rugg, 1995). It appears to be larger and stronger when the stimuli are emotional in nature (e.g., Weymar et al., 2009).

There are individual differences in emotional memory. For example, depressed individuals show better memory for negative stimuli relative to non-depressed controls (e.g., Bradley, Mogg, & Williams, 1995). Moreover, in an fMRI paradigm, Hamilton and Gotlib (2008) observed that depressed individuals exhibited more right amygdala activation than healthy controls during the successful encoding of negative, but not neutral or positive stimuli, suggesting that depressed individuals may differentially encode negative stimuli, and thus show differential retrieval of negative experiences.

Children's emotional memory has yet to be examined as thoroughly as adults'. Much of the research on children's emotional memory is in the autobiographical memory literature specifically, thus the events are personal experiences and typically unique or stressful events (e.g. a trip to Disney World, Hammond & Fivush, 1991, or a painful medical procedure (e.g., Goodman, Hirschman, Hepps, & Rudy, 1991). From this body of work we know that children as young as 3 remember emotional events, and further, that emotional events may be remembered in greater detail than neutral events (e.g., Ackil, Van Abbema, & Bauer, 2003). Such studies have been richly informative of children's memory, yet leave several questions about children's memory for emotional events. Firstly, examination of personally experienced emotional events may implicate a network of neural and neurochemical responses that may be specific to the stress response, and may not provide as clean a picture of non-stressful emotional memory. Secondly, focus on personal experiences as emotional memory stimuli is less-controlled than a lab design, and holds several limitations including: little to no control of the encoded material, reliance on self- or parent-report to describe the encoded material (after encoding has occurred), and no opportunity to examine the encoding processes as they relate to subsequent memory. The use of lab-controlled stimuli offers the opportunity to include a rich diversity of emotional stimuli that can be varied on dimensions of valence and arousal, and further, to examine encoding and memory for the same exact controlled events across contexts and individuals.

The first part of this question, namely controlling the content of to-be encoding emotional stimuli, has begun to be tested. Behavioral examinations of children's memory for experimentally-controlled emotion stimuli have yielded partial evidence of an emotion effect on memory. For example, 7-11-year-olds recalled the actions in emotional stories better than in non-emotional stories after an immediate and 24-hour delay (Davidson, Luo, & Burden, 2001). Further, findings from Cordon and colleagues (2013) suggest that 8-12-year-olds recognize negative scenes better than neutral scenes (qualitative differences only, the two conditions were never compared within the child sample, but the emotion effect was significant when collapsed with an adult sample; Cordon, Melinder, Goodman, & Edelstein, 2013). Thus the limited data available to date suggests that school-age children may remember emotional stimuli better than neutral stimuli, adding to the findings that children may recall emotional events in greater detail than neutral events. Combining behavioral methods with ERP techniques may offer a fruitful opportunity to further examine children's emotional memory.

Only limited work has begun to emerge whereby children's encoding of emotional stimuli has been measured (Hajcak & Dennis, 2009; Solomon, DeCicco, & Dennis, 2011). Encoding processes seem similar to those of adults, namely, in ERP paradigms, children demonstrate larger positive-going responses to emotional relative to neutral stimuli. Further, the effects are apparent as soon as 300 milliseconds following stimulus onset, and endure for as long as 2000 milliseconds, and are apparent across both posterior and anterior scalp sites. Yet it remains unclear how emotion effects at encoding relate to subsequent retrieval processes, behaviorally or neurobiologically. Examining children's emotional memory is critical to understand the healthy development of emotion processing, and specifically healthy emotional memory in development.

Thus the first aim of the current research was to **examine the status of emotional memory in school-age children.** In both behavioral and ERP measures, adults demonstrate more robust memory for emotional relative to neutral experience. These effects are largely attributed to the experience of higher arousal during the encoding of emotional versus neutral events. Children also experience higher arousal during emotional events (as demonstrated by ERP and self-report measures in Hajcak & Dennis, 2009, and physiological and self-report measures in McManis, Bradley, Berg, Cuthbert, & Lang, 2001); therefore if arousal drives memory performance, it is predicted that children will demonstrate stronger memory performance for high-arousal emotional events versus low-arousal neutral events. However, it is possible that emotion and memory processes are less tightly connected in children, and arousal at the time of experience does not affect encoding and subsequent memory processes; memory performance would be unrelated to arousal. That is, arousal may be limited to the initial experience of emotion, and remain separate from subsequent memory processes. It may be the case that the developmental status of emotion and memory systems in school-age children, for example, does not support the robust integration of emotion and memory processes that is observed in adults, due to maturation of the neural networks, socialization, emotion regulation, and so forth. Thus, as a group, children's recognition memory was examined by emotion condition (negative, positive, neutral) to reveal the status of the development of emotional memory. This research is the first step in examining the development of emotional memory. This aim was tested in Study 1.

A further question tested in the present research is the role of individual differences in emotional memory. In adults, it has been observed that individuals with atypical emotional processing have differentiated patterns of emotional memory as well. For example, depressed adults show better memory for negative stimuli relative to non-depressed controls (Leppanen, 2006). To date, there are no ERP studies of emotional memory in depressed individuals, however during the encoding of emotional stimuli, depressed adults show reduced emotion effects in their ERPs to positive stimuli compared to non-depressed controls (e.g., Shestyuk, Deldin, Brand, & Deveney, 2005). The findings suggest that emotion processing and memory may be a fundamental component of healthy and unhealthy emotional well-being. We examined such relations in the present research by examining general patterns in temperament and depressive symptomatology as it relates to children's emotional memory.

Temperament is composed of reactivity and regulation (Rothbart, Ahadi, & Evans, 2000), and may be a foundational component of mood disorders (e.g., Clark, Watson, & Mineka, 1994). Individual differences in emotion regulation can have profound effects on emotional well-being. Maladaptive strategies used to regulate emotions are associated with emotional difficulties such as aggressive behavior, or, in contrast, withdrawn behavior associated with anxious-depressive symptoms (Calkins & Dedmon, 2000; Calkins & Fox, 2002; Davidson, 1998, 2002; Posner & Rothbart, 2000). Specifically, longitudinal measures (mostly parent and teacher report) of children's reactive responses and children's control of reactive responses reveal specific patterns of under- and over-control of reactivity that are components as well as precursors of internalizing and externalizing disorders (Fox & Calkins, 2003; Woltering & Lewis, 2009). Poor or under-controlled style of reactivity is associated with the development of aggressive behavior problems. In contrast, over-control is characterized by the excessive inhibition of emotional response tendencies, and is associated with anxiety-related symptoms. Importantly, over- and under-control are two ends of a continuum of regulation, and there is a range of patterns that fall in between. Healthy emotion regulation is key for successful navigation of the social environment.

Thus the second aim of the current research was to **examine the relative role of individual differences in emotion processing on memory for emotional stimuli in development.** In adults, particular patterns of emotion regulation and memory for emotional stimuli are typical of particular psychopathologies, and thus it is important to examine these processes in children as possible indicators or precursors of psychopathology. The measures of negative affectivity and surgency as sub-factors of temperament were selected from the Child Behavior Questionnaire (Putnam & Rothbart, 2006), and anxious/depressed and withdrawn/depressed behaviors were selected from the Child Behavior Checklist (Achenbach, 1991) as a proxy for depressed symptomatology. I predicted that the factors associated with depression (high negative affectivity, low surgency, more anxious/depressed and withdrawn depressed behaviors) would predict better memory for negative stimuli. This aim was tested in Study 1.

Also of interest in the current research is the LPP as a measure of emotional arousal and regulation. Emotion regulation strategies employed during the encoding of a stimulus, through reappraisal, for example, also affects the size of the LPP. Reappraisal is a cognitive emotion regulation strategy that involves changing the interpretation or meaning of a stimulus (Lazarus, 1991). In emotion processing studies, reappraisal often involves interpreting negative stimuli in a more neutral or less threatening way (e.g., Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006). Effective reappraisal of negative stimuli has dampening effects on the size of the LPP for the reappraised stimuli (Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; Hajcak, Dunning, & Foti, 2009). Interestingly, reappraisal can also work in the opposite direction, with negative reinterpretations of neutral stimuli increasing the size of the LPP (MacNamara, Foti, & Hajcak, 2009).

To date, only two studies have examined the effects of reappraisal on school-age children’s processing of emotional stimuli via ERPs (DeCicco, Solomon, & Dennis, 2012; Dennis & Hajcak, 2009). Only reappraisal of negative stimuli was examined, and successful down-regulation of emotional responses (reduced LPP) was observed in only one of the two studies. In each study, reappraisal was examined using the same paradigm (i.e., pairing negative stimuli with stories that either reappraised the emotional content or matched in emotional content). Reappraisal effects were not observed in the sample of 5- to 7-year-olds (DeCicco et al., 2012), but were observed in children between 7- to 10-years-old (Dennis & Hajcak, 2009), suggesting that perhaps children under age 8 are less capable of reappraisal (as tested in this paradigm), or that their ERPs are not sensitive to reappraisal. Thus further examination of reappraisal in children is necessary to determine the efficacy of such a manipulation on reducing ERP indices of emotion responses.

A curious pattern of predicted effects emerges in the context of reappraising emotional experience during encoding. Successful reappraisal, or down-regulation of emotion and arousal, shifts the positive-going ERP response downward across anterior and posterior sites (e.g., Moser, Hajcak, Bukay, & Simons, 2006), which in turn should predict poorer memory performance. Yet, in behavioral paradigms, reappraisal has no negative effects on subsequent memory performance (e.g., Gross, 2002). Thus, it seems that arousal and the positive ERP response are not the only factors that are related to successful memory performance. To date, the emotion and memory literatures remain largely separate, perhaps partly because emotion processes, for example, reactivity and regulation, are often examined as individual differences, whereas emotional memory is typically examined at the group level; emotional experience (unregulated vs. regulated) has yet to be systematically examined in relation to ongoing and subsequent memory processes. It is critical to examine these processes to qualify the role of emotional arousal on subsequent memory.

Thus the third goal of the current research was to **examine emotional memory as a factor of directed emotion regulation during the encoding of emotional stimuli.** A directed emotion regulation task was used to examine the influence of emotion regulation on latent memory processes. A sub goal of this aim was to examine the efficacy of an emotion regulation manipulation on reducing the LPP in children. The emotion regulation task implemented reappraisal strategies (neutral interpretation of emotional stimuli) to down-regulate emotional reactivity. This was expected to reduce the reactive response in the ERP signal, but not expected to affect memory performance based on behavioral work (e.g., Gross, 2002). However, as introduced in a previous aim, larger reactive ERP responses should predict better memory, and smaller reactive (or down-regulated) ERP responses should predict poorer memory. Thus, one of the aims of this proposal was to further investigate the ERP responses to better understand how it reflects emotional reactivity, regulation, and memory processes. This aim was tested in Study 2. A further aim of Study 2 was to explore the use of ERPs to measure reappraisal of positive stimuli, which has yet to be examined in the literature. The limited examination of reappraisal of negative stimuli leaves room for the possibility that reappraisal effects are valence-specific. One possible explanation for valence-specific effects relates to motivational congruence. It is desirable to reduce negative affect, but less so for positive affect, and it may be more effortful to reduce positive affect. Thus we extended the examination of reappraisal to include both negative and positive stimuli in order to examine the use of ERPs to measure reappraisal, and to explore possible valence differences in ERP measures of reappraisal.

In sum, I examined the developmental status of emotional memory in school-age children, and the role of emotional reactivity and regulation in neural and behavioral measures of memory performance. The research examines the interaction of emotion and memory processes, and will elucidate the role of emotional experience at the time of encoding, on the subsequent memory process. Electrophysiological, behavioral, and questionnaire measures were used together to reveal a more comprehensive picture of the latent processes of emotional memory. The findings inform our understanding and interpretation of ERPs to examine emotion processes (i.e., reactivity and regulation) and memory processes, and further our understanding of the status of emotional memory in school-age children.

In Study 1, I used ERP and behavioral measures to examine emotional memory in 5- to 8-year-old children. This age range was selected as a period of developing emotion and memory skills, where children could complete the task demands of an ERP and recognition memory paradigm. Also explored in Study 1 was the role of individual differences, specific to depressive symptomatology and temperament, on emotional memory. Report of subsequent memory analysis of encoding is not reported in the manuscript proper due to insufficient trial counts for “missed” recognition responses, but is included as an appendix in this dissertation (following Study 2, before the general discussion). In Study 2, I used a reappraisal manipulation to examine the role of emotional arousal at encoding on subsequent memory. The sample was of 8-year-old girls given the findings that ERPs might not be sensitive to reappraisal in children under 8. Further, findings from Study 1 suggested that emotion effects on memory might not emerge until age 7 to 8. Because Study 2 was an examination of arousal as an explaining factor of emotion effects on memory, it was important to focus on a period of development where we might expect the emotion effects without the arousal manipulation. Due to gender differences in the socialization of emotion that warrants larger samples of each gender in examination of emotion processes, and the fact that Study 2 was part of a larger on-going study that involved a prolonged data collection process, we limited the current investigation to one gender. The decision to first test girls over boys was largely arbitrary, but due in part to findings suggesting that girls use reappraisal more than boys (Gullone, Hughes, King, & Tonge, 2010), thus it may be more likely to observe ERP effects of reappraisal in girls versus boys.

Study 1: Emotion processing and memory in school-age children

Emotion pervades our everyday lives from birth to adulthood. As adults, we demonstrate better memory for emotional relative to neutral events, words, stories, and scenes (“emotion effect,” LaBar & Cabeza, 2006). The effect is attributed to emotional arousal during the initial encoding of a memory, which grants the memory privileged status over the course of the memory process, and permits an advantage in consolidation and storage processes over less arousing and neutral events (Dolcos , LaBar, & Cabeza, 2005; McGaugh, 2004). Further, distinct variations on the emotion effect are observed in adults with disturbed mental health (e.g., depression: Lappanen, 2006; anxiety: Foa, Gilboa-Schechtman, Amri, & Freshman, 2000; PTSD: Rauch, Shin, & Phelps, 2006). Examining developmental status of emotional memory is a necessary foundation to further understanding the ontogeny of emotional well-being. Children experience emotion and remember personal emotional experiences, but the processes of experiencing, encoding, and subsequently remembering emotional events have not been well examined in development, and it remains unclear if emotion and memory processes are as integrated in children as in adults. Further, connections between children’s emotional memory and emotional well-being have not been established. In the present study, we examined children’s encoding and subsequent memory of emotional stimuli (IAPS) as a group and as a factor of individual differences in emotion related behavior (temperament and depressive symptomatology). The work informs the status of emotion and memory processes in school-age children who are in a period of developing emotion and memory skills.

Children’s emotion processing has been examined in a variety of contexts, using a range of measures including visual attention, behavioral ratings, and neural and physiological responses. In their looking behavior, infants as young as 4 months can distinguish different emotions in facial expressions (e.g., happy vs. angry expressions, LaBarbera, Izard, Vietze, & Parisi, 1976). Preschoolers can sort and identify facial expressions depicting specific emotion categories (e.g., fearful, happy, etc., Widen & Russell, 2008), as well as correctly label specific emotion categories for emotion-inducing stories (e.g., Camras & Allison, 1985). When asked to rate emotional scenes on the dimensions of valence arousal, school-age children rate emotional scenes as more emotional and arousing than neutral scenes, similar to adults’ ratings (Lang, Bradley, & Cuthbert, 2008).

Evidence of emotion processing in children also comes from neurological and physiological investigations. fMRI work indicates that emotional stimuli (specifically, fearful faces) activate similar emotion networks in 12-year-olds as adults (Baird et al., 1999). Physiological indices indicate that children as young as 7 years demonstrate somatic markers of emotional responses, including heart rate deceleration to negative stimuli, and greater skin conductance to negative stimuli (effect greater for girls), similar to adults (McManis, Bradley, Berg, Cuthbert, & Lang, 2001). An excellent tool for measuring neural indices of emotion processing is event-related potentials (ERPs), which are sensitive to real-time emotional arousal during the encoding of an event. A prominent emotion effect in ERP signal is the late-positive potential (LPP). The LPP is a sustained positive-going ERP waveform that begins around 300 milliseconds post-stimulus onset, maximal over posterior sites, and is larger for emotional and arousing stimuli versus neutral stimuli (Hajcak, Weinberg, MacNamara, & Foti, 2012). Emotion effects to word and picture stimuli have been reported in children as young as 5 years (e.g., Hajcak & Dennis, 2009; Perez-Edgar & Fox, 2007). Thus a diverse set of evidence indicates that emotion processes emerge early in development, with further evidence suggesting that children in the early school-age years show similar emotion effects as adults. However, it remains unclear how emotion is integrated into memory processes in development. Specifically, do children with adult-like emotion processing display adult-like emotion effects on memory performance?

Children’s memory for emotional events has been tested in a different approach, often focusing on children’s recall of personally experienced events (autobiographical memories). Further, the focus is often on stressful or unique events, such as a painful medical procedure (e.g., Goodman, Hirschman, Hepps, & Rudy, 1991), a natural disaster (e.g., Ackil Van Abbema, & Bauer, 2003; Bahrick, Parker, Fivush, & Levitt, 1998), or a trip to Disney World (Hammond & Fivush, 1991). Children as young as 3 years recall accurate details of such experiences, however it has yet to be formally examined how children remember everyday emotional events, such as the disgust from spotting a gross bug or the joy from watching the cat chase her tail. Further, unique experiences feature elements that may differ from everyday emotional experience (e.g., more personally relevant, significant, stressful, etc.), and may involve more than just emotion processes during encoding and subsequent retrieval (e.g., self-concept, meaning making, stress responses, etc.). Experimental stimuli that depict commonplace emotional events and vary on dimensions of valence and arousal offer an experimentally cleaner approach to examine the encoding and subsequent retrieval of emotional experience. Behavioral examinations of children’s memory for experimentally-controlled emotion stimuli have yielded partial evidence of an emotion effect on memory. For example, 7- to 11-year-olds recalled the actions in emotional stories better than in non-emotional stories after an immediate and 24-hour delay (Davidson, Luo, & Burden, 2001). Further, findings from Cordon and colleagues (2012) suggest that 8-12-year-olds recognize negative scenes better than neutral scenes (qualitative differences only, the two conditions were never compared within the child sample, but the emotion effect was significant when collapsed with an adult sample; Cordon, Melinder, Goodman, & Edelstein, 2012). Thus the limited data available to date suggests that school-age children may remember emotional stimuli better than neutral stimuli. Combining behavioral methods with ERP techniques may offer a fruitful opportunity to further examine children’s emotional memory. In the current research, we examined how children’s emotion effects in ERPs at the time of encoding related to their subsequent recognition of emotional stimuli.

To date, ERP methodology has demonstrated that children as young as 5 years show emotion effects similar to that of adults (e.g., Hajcak & Dennis, 2009). ERPs are an ideal platform to examine emotional memory in children because they represent the real-time underlying processing of a discrete event, providing complementary information to an explicit behavior response alone. In the current research, we used ERPs to examine children’s encoding and recognition of emotional scenes, and had children participate in a behavioral recognition task. We hypothesized that children would show emotion effects at encoding, such that negative and positive stimuli would generate a larger ERP response than neutral stimuli. Specifically, we predicted that emotion effects would be strongest at posterior sites where the effect in adults is most robust (Hajcak et al., 2012). Predictions regarding memory effects came in two forms. Firstly, if emotional arousal at encoding enhances subsequent memory, as in adults, then we predicted that greater arousal at encoding (via larger ERP responses) would positively predict subsequent recognition performance. Further, recognition responses in the ERP signal would be larger for emotional stimuli, and behavioral recognition performance would be higher for emotional versus neutral stimuli. Alternatively, emotional arousal at encoding may be unrelated to subsequent memory performance. Emotions are transient feelings that may remain a passing experience that does not get encoded into the memory process. In this case, ERP measures of arousal at encoding would not be related to subsequent memory performance, and ERP and behavioral measures of recognition would not differ between emotional and neutral stimuli.

A further question tested in the present research was the role of individual differences in emotional memory. In adults, it has been observed that individuals with atypical emotional processing have differentiated patterns of emotional memory as well. For example, depressed individuals show better memory for negative stimuli relative to non-depressed controls (Leppanen, 2006). The finding suggests that emotion processing and memory may be a fundamental component of healthy and unhealthy emotional well-being. Measurable and stable individual differences in emotion processing (e.g., in temperament) are observed in non-clinical samples (e.g., Rothbart, Ahadi, & Evans, 2000). Further, individual differences in temperament may be a foundational component of mood disorders whereby high negative affectivity is associated with anxiety and depression and low surgency is associated with depression (e.g., Clark, Watson, & Mineka, 1994). In the present research, we examined the relations of temperament and depressive symptomatology to emotional memory in a community sample. Temperament was measured by parent-report using the Child Behavior Questionnaire (CBQ, Putnam & Rothbart, 2006) summing to the factors of negative affectivity, surgency, and effortful control. Depressive symptomatology was sampled from the Child Behavior Checklist (CBCL, Achenbach, 1991), by the measures of anxious/depressed and withdrawn/depressed behaviors. We predicted that greater negative affectivity, low surgency, and greater depressive symptomatology would predict enhanced memory for negative stimuli. We did not predict any relations with effortful control because it remains unclear how this factor of temperament relates to emotion processing. However, because the research questions were tested in a community sample, it is possible that the necessary variance might not be available to reveal such relations.

We tested the hypotheses in 5- to 8-year-old children to examine emotion processing and emotional memory during a developmental period during which children could successfully complete a recognition memory task in an ERP paradigm, a diverse set of child-appropriate emotional images could be tested, and where there is sufficient range in the sample to assess age-related differences. Based on the literature, we predicted that all children would experience the stimuli as emotional and would evidence memory for them, but perhaps only older children would show an emotion effect in their memory performance. Because memory of lab-controlled emotional stimuli has yet to be examined in children under 7, and the tenuous evidence for emotion effects on memory in older children suggesting less robust emotion effects in children versus adults, we predicted that the younger children in our sample might not show emotion effects in their memory performance. Thus the current research addresses the relations between emotional experience, encoding, and subsequent retrieval, and informs the relative integration of emotion and memory processes and emergence of the emotion effect in the school-age years.

Method

Participants

Forty-six school-age children participated in two laboratory sessions, separated by 24 hours (24 girls; M_{age} = 7.13 years, *range* = 5.42-8.92 years). Children were divided into two age groups: younger (*n* = 24, 11 girls; M_{age} = 6.23 years, 5.42-7.50 years) and older (*n* = 22, 13 girls; M_{age} = 8.08 years, 7.58-8.92 years). Participants were recruited from a list of families who had previously expressed interest in participating in child development research. Six children were parent-identified as Hispanic, 39 as non-Hispanic, and one did not self-report. Forty children were parent-identified as Caucasian, 3 as African American, and 3 as mixed race. Children were given a small toy at the end of each session, and families were given a gift certificate to a local merchant at the end of the second session, as a token of appreciation for their time and effort. Prior to testing, the researchers received written informed consent from the guardian and verbal assent from the participating child. A university IRB approved all of the methods and materials included in the study.

Materials

A set of 164 child-appropriate images (55 positive; 53 neutral; 56 negative) was selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), as well as a lab-collected set of supplemental stimuli of similar content. Approximately half of the stimuli came from each source, and children’s ratings of images between the two sets did not differ.[1] Images from the IAPS containing weapons, mutilated bodies, or sexual content were excluded from this child-appropriate set. To control for previously reported biases in affective processing of stimuli with humans (Proverbio, Adorni, Zani, & Trestianu, 2009), within each emotion condition, half of the image set included humans and half did not include humans. Of the 164 images, 150 were used as the experimental stimuli (50 in each emotion condition). An additional five positive images were available for the end of the EEG recording, three neutral images for practice trials, and six negative images as a source of replacement stimuli for images deemed objectionable by parents. All images were presented in full color.

Before the families came to the lab, thumbnails of all 164 images were sent via email to the guardian to approve presentation of the images (procedure approved by Lang, personal communication). For nine participants the guardians expressed concern about some of the negative images (*M* = 5.22 images, range = 1-8); all guardians approved of all positive and neutral images. Objectionable images were replaced with approved images from the supplemental set. In the three cases in which the number of objectionable images exceeded the number of supplemental images available, the participants' trial counts were reduced accordingly.

For the EEG recording at Session 1, two sets of 90 images (30 positive, 30 neutral, 30 negative) were selected from the set of 150 experimental stimuli. Within each set, images were presented in a pseudo-randomized order such that no more than two images of the same valence preceded one another. Two pseudo-randomized orders were created for each set, for a total of four sets. The image set was counterbalanced across participants. Five additional positive images were added to the end of each presentation so that the session ended on a positive note. Data analysis did not include the final five positive trials. The pictures were 30.5 cm (h) x 23 cm (w) in size, providing a visual angle of 15.59° (h) x 20.58° (w).

For the EEG recording at Session 2, two sets of 120 images were selected from the set of 150 experimental stimuli. Sixty of the 120 images were presented during session 1 (“old” pictures: 20 positive, 20 neutral, 20 negative), and 60 images were novel and were not presented at Session 1 (“new” pictures: 20 positive, 20 neutral, 20 negative). Within each set, images were presented in a pseudo-randomized order such that no more than four images of the same valence and no more than eight images of the same old/new condition preceded one another. Two pseudo-randomized orders were created for each set, for a total of four sets. The image set was counterbalanced across participants. Three additional positive images were added to the end of each presentation so that the session ended on a positive note (three of the five that were presented at the end of the Session 1 recording). Data analysis did not include the final three positive trials.

For the valence and arousal ratings at Session 2, the set of 150 experimental stimuli was divided into five sets of thirty images (10 positive, 10 neutral, 10 negative; presented in a pseudo-randomized order within each set such that there was no more than two consecutive images in one condition; final image was either positive or neutral so that session ended on a positive note). Participants were randomly assigned to one of the five ratings sets. The pictures were 17.5 cm (h) x 31 cm (w) in size, providing a visual angle of 13.49° (h) x 23.66° (w).

Parents completed two questionnaires: the Child Behavior Questionnaire (CBQ, Putnam & Rothbart, 2006) and the Child Behavior Checklist (CBCL, Achenbach, 1992). From the CBQ, the factors of negative affectivity, effortful control, and surgency were used to examine individual differences in temperament. From the CBCL, the measures of depression/withdrawal and anxiety/depression were selected to examine individual differences in behaviors associated with depressive symptomatology. Temperament and depressive symptomology was examined as an individual differences factor in children's emotional memory.

Procedure

The study consisted of two sessions separated by 24 hours. During Session 1, electrophysiological (EEG) and psychophysiological (respiration rate, cardiac activity, galvanic skin response) data were collected as participants viewed the set of 90 positive, negative, and neutral images and participated in a simple behavioral task to ensure that they were attending to the trials (psychophysiological responses are beyond the scope of this dissertation and are not reported here). Session 1 lasted approximately 90 minutes. Twenty-four hours later, the participants returned to the lab for Session 2, where EEG and behavioral data were collected as participants viewed the set of 120 positive, negative, and neutral images and participated in a behavioral recognition memory task. Immediately after the EEG recording children provided subjective ratings of valence and arousal using the Self Assessment Manikin (SAM; Bradley & Lang, 1994). Session 2 was approximately one hour.

Session 1. Participants were seated approximately 84 centimeters from the screen where the images were presented. They were fitted with the EEG electrode cap. EEG data were collected using an Advanced Neuro Technology (A.N.T.) Waveguard EEG cap with 32-shielded Ag/AgCl electrodes (A.N.T. Software B.V., Enschede, The Netherlands) (see Figure 1). Electrode placement followed the 10/5 system, an adaptation of the International 10/20 system (Jasper, 1958). Impedances were kept under 10 kΩ, and were generally under 5 kΩ. The sampling rate was set at 256 Hz. Data were amplified 20,000 times using an A.N.T. amplifier and values that exceeded A/D thresholds were excluded. Data were referenced online to mathematically-linked mastoids (sites M1 and M2; see Figure 1).

To verify attention to the picture stimuli, participants were asked to use a video game controller to indicate whether each image depicted a human, or any part of the human body. Images were presented for a total of 6000 milliseconds. For the first 3000 ms, images were framed with a thick blue border and then a bright green border for the last 3000 ms. Participants were instructed to attend to the stimuli and to wait until the blue border turned bright green (3000ms post-stimulus onset) before choosing one of two buttons to indicate their response (counterbalanced across participants). The researchers presented three practice trials to the child to establish that she or he understood how to complete the task and the practice period was repeated as necessary until children demonstrated that they understood the task instructions. The practice trials consisted of three neutral images that were not presented during the testing phase. Once the participants affirmed they understood the task instructions, image presentation and data recording began.

Participants viewed 95 images as ERPs were recorded (see Materials for more details). Each image of the presentation encompassed the entire monitor and was presented in color. Images were presented for a total of 6000 milliseconds (3000 ms with a blue border, then 3000 ms with a green border to signal the button press), with a 3500-4500 millisecond inter-stimulus interval (ISI) where the screen was blank. The image presentation lasted approximately 15 minutes. Stimulus presentation was controlled using ASA computer software (A.N.T. Software B.V., Enschede, The Netherlands).

Analysis of children's button presses indicated that the participants understood the task and were attentive during the image presentation. Children made a button press on 90.54% of trials and of these, were correct on 90.24% of trials. Because of the low incidence of missed trials, all trials were included in analysis.

Participants completed a 5-point mood questionnaire (1 = unhappy, 3 = neutral, 5 = happy) immediately before and after the EEG/psychophysiological recording. This measure was utilized to verify that the children's mood did not change as a result of the presentation of the emotional stimuli. Across age groups, children self-rated their mood similarly before and after the image presentation (Pre: $M = 4.47$, $SD = 0.79$; Post: $M = 4.38$, $SD = 0.91$; $t(38) = 0.52$, $p > .60$)[2], indicating that children's mood did not significantly change from before to after the image presentation.

Session 2. Participants were seated approximately 84 centimeters from the screen where the images were presented, and were fitted with the EEG electrode cap with the same specifications as described for Session 1.

Participants completed a behavioral recognition memory task during the image presentation. During the task, participants indicated if they thought each picture was old or new, and then rated their confidence in their old/new response (very sure/maybe sure/unsure). After each image, an old/new decision screen appeared (see Figure 2 for depiction of old/new screen). The screen depicted a check mark and an ‘X’ which corresponded to two vertically-oriented buttons on a video game controller (position of check and ‘X’ counterbalanced across participants). Participants were instructed that the check mark meant that the image was old and presented at Session 1 and that the ‘X’ meant that the image is new and was not presented at Session 1. After the old/new screen, a confidence rating screen appeared (see Figure 3 for depiction of confidence screen). The screen displayed three levels of confidence (very sure, maybe sure, unsure), which corresponded to 3 vertically-oriented buttons on the game controller. It was explained to the participant that the three choices referred to their old/new response. Participants were instructed to wait for the old/new screen to make an old/new response, and to wait for the confidence screen to make a confidence rating. The researchers presented three practice trials to the child to establish that she or he understood how to complete the task and the practice period was repeated as necessary until children demonstrated that they understood the task instructions. The practice trials consisted of three neutral images that were not presented during the testing phase (same as Session 1). Once the participants affirmed they understood the task instructions, image presentation and data recording began.

Participants viewed 123 images as ERPs were recorded (see Materials for more details). Each image of the presentation encompassed the entire monitor and was presented in color. Each trial consisted of the following sequence: the image was presented for 2000 milliseconds, then the old/new decision screen for 2000 milliseconds, then the confidence rating screen for 3000 milliseconds. Each trial was separated by a 450-650 millisecond ISI where the screen was blank. Children under 7 years of age did not complete the confidence rating part of the memory task because pilot testing indicated that the full task was too burdensome for younger participants. For children under 7, the old/new decision screen appeared for 5000 milliseconds, then the ISI (confidence screen did not appear at all). For all participants, the image presentation lasted approximately 17 minutes.

Participants' button presses were scored as follows. On trials that were presented at encoding and recognition (old trials), 'old' responses were scored as hits and 'new' responses were scored as misses. On trials that were presented at recognition only (new trials), 'old' responses were scored as false alarms and 'new' responses were scored as correct rejections.

Participants completed the 5-point mood questionnaire immediately before and after the EEG recording. Across groups, children's mood did not significantly change from before to after the image presentation (Pre: $M = 4.59$, $SD = 0.89$; Post: $M = 4.46$, $SD = 1.05$; $t(34) = 0.88$, $p > .35$).[3]

The ERP cap then was removed and participants were asked to sit at a table within the same testing room to complete the ratings task. On a laptop, they were shown a self-paced presentation of 30 images from the experiment. Participants then provided subjective valence and arousal ratings using a modified Self-Assessment Manikin (SAM; Bradley & Lang, 1994; see Figure 4, panels a and b). The SAM was abbreviated from the 9-point version of the scale to reduce participant burden on children who had just completed a relatively lengthy task during EEG recording, and the modified version consisted of two 5-point scales: one for valence (1 = very unpleasant, 3 = neutral, and 5 = very pleasant), and one for arousal (1 = very low arousal, 5 = very high arousal).

ERP data reduction

EEG data were filtered offline using a bandpass filter between 0.1 to 30 Hz with a 24dB/octave roll-off using Advanced Source Analysis software (A.N.T. Software B.V., Enschede, The Netherlands). All subsequent data processing was completed using EEGLAB 6.03b (Delorme & Makeig, 2004) and ERPLAB 1.0.0.3 (www.erplab.org) operating in Matlab 7.7.0 (MathWorks, Natick, MA, USA). Independent component analysis (ICA) was applied after filtering to identify and remove eye-blink artifact from the data. EEG data was segmented into 2200ms epochs beginning 200 ms before stimulus onset and ending 2000 ms after stimulus onset. A 200 ms pre-stimulus window was used to correct for baseline activity in each epoch. Trials that were contaminated by deflections that exceeded ± 200 μV were excluded from analysis.

Artifact-free epochs were averaged by condition. For the analysis of emotion effects at encoding, there were 3 conditions: positive, neutral, and negative. To be included in analysis, participants were required to have a minimum of 10 trials in at least two of three conditions. Two children in the younger group did not meet these criteria and were excluded from analysis. Thus in each the older and younger groups, 22 participants were included in analysis. Trial counts by condition are reported for each age group in Table 1.

For the analysis of recognition memory, there were 6 conditions: positive old, positive new, neutral old, neutral new, negative old, and negative new. Only trials on which participants made correct button presses were included, since these represent the cleanest measure of memory responses (i.e., correct responses were 'hit' responses on old trials, and 'correct rejection' responses on new trials). In the older group, seven participants were excluded from analyses due to experimental error (*n* = 6), or attrition after Session 1 (*n* = 1), thus a total of 15 participants were included in analysis. In the younger group, six participants were excluded from analysis due to experimental error (*n* = 3), excessive noise in EEG data (*n* = 1), incompletion of the session (*n* = 1), or attrition after Session 1 (*n* = 1), thus a total of 18 participants were included in analysis. Trial counts by condition are reported for each age group in Table 2.

ERP Data Analysis

Examination of the data was guided by similar investigations (Dawson, Webb, Carver, Panagiotides, & McPartland, 2004; Dolcos & Cabeza, 2002; Hajcak & Dennis, 2009; Maratos & Rugg, 2001; Solomon, DeCicco, & Dennis, 2012). Based on the previous research and visual inspection of the ERP waveforms, we identified a sustained positive slow-wave consistent with the late positive potential (LPP) over all scalp sites. For all analyses, effects were examined at posterior clusters primarily, as well as central and frontal clusters (posterior: P7/8, O1/2; central: T7/8, C3/4, CP5/6, CP1/2; frontal: F7/8, F3/4, FC5/6, FC1/2; Clusters are depicted in Figure 1). For the analysis of emotion effects at encoding, mean amplitude of the LPP was examined over three time windows (early: 800-1200ms, middle: 1200-1600ms, and late: 1600-2000ms) to investigate the duration and timing of emotion effects. For the analyses of memory effects at recognition, mean amplitude of the LPP was examined over the same three time windows. For the analyses of encoding by subsequent memory, mean amplitude of the LPP was examined over four time windows (300-800ms, 800-1200ms, 1200-1600ms, and 1600-2000ms). In the analysis of subsequent memory at encoding, in some cases participants did not have any subsequent miss trials in some conditions.[4] In these cases the values were replaced with the mean of the series for all group-level analyses. Because preliminary analysis did not indicate effects of site, data were collapsed by hemisphere within each cluster. The LPP is interpreted for deflections toward positive amplitude regardless of value. That is, effects at frontal sites may be negative, but it is the positive deflection that is interpreted. This is consistent with the approach taken in Solomon et al. (2012).

Results

Results are divided into four major sections: analysis of emotion effects, analysis of recognition memory, and examination of individual differences in emotional memory. Analysis of emotion effects includes ERP data at encoding (examined by emotion condition), and analysis of SAM ratings collected at the end of the recognition session. Analysis of recognition memory includes ERP data at recognition (correct responses on old and new trials) and behavioral recognition responses. Analysis of subsequent memory includes ERP data at encoding examined by subsequent memory performance (trials that were subsequent hits or misses at recognition). And examination of individual differences in emotional memory consisted of correlation analysis of measures of temperament and parent-reported depressed symptomatology and emotional memory in ERP and behavior. As will become apparent, age effects emerged for all ERP effects.

For all analyses where a mixed analysis of variance (ANOVA) was calculated, emotion was treated as a within-subjects factor and age as a between-subjects factor. For all ERP analyses, hemisphere was a within-subjects factor, and for analyses of recognition and subsequent memory, memory was a within-subjects factor. Greenhouse-Geisser corrections were applied in cases of violation of sphericity. Unless noted otherwise, for all post-hoc analyses with multiple comparisons, Bonferroni corrections were applied to the *t*-values.

Emotion effects

Subjective ratings. Valence and arousal ratings were available for 29 participants (n = 16 in the older group).[5] Mean ratings by emotion condition are plotted in Figure 5. To examine emotion effects in children's ratings, we calculated a 3 (Emotion: negative, neutral, positive) x 2 (Age: younger, older) mixed ANOVA, for valence and arousal ratings separately. For valence ratings, a main effect of emotion was observed, $F(1.38, 37.35) = 43.56$, $p < .001$, $p\eta^2 = .617$, with negative stimuli rated as more negative than neutral and positive stimuli, and positive stimuli rated as more positive than neutral and negative stimuli (all *p*s < .001). A main effect of emotion also was observed for arousal ratings, $F(2, 54) = 12.14$, $p < .001$, $p\eta^2 = .310$. Positive and negative stimuli were rated as more arousing than neutral stimuli ($p < .001$ and $p = .041$, respectively; ratings of positive and negative stimuli did not differ. For both valence and arousal ratings, no main effects of or interactions with age were observed. The results indicate that children experienced the emotional stimuli as emotional and more arousing than the neutral stimuli.

ERP responses. To examine effects of emotion in children's ERPs over the course of the LPP we calculated a 3 (Window: early, middle, late) x 3 (Emotion: negative, neutral, positive) x 2 (Hemisphere: left, right) x 2 (Age: younger, older) mixed ANOVA, for mean amplitude in each of the three clusters (posterior, central, and frontal). Because they do not inform the research question, main effects or interactions that do not include emotion are not reported. Post-hoc comparisons by condition were examined at the more stringent level of $p = .025$ following the Sidak-Bonferroni-Keppel correction (Keppel & Wickens, 2004). Waveforms for each cluster are plotted in Figures 6 and 7 (for younger and older children, respectively), Panels a, b, and c (for posterior, central, and frontal clusters, respectively). Descriptive statistics for each cluster are reported in Table 3.

Posterior cluster. A main effect of emotion was observed across all windows, $F(2, 84) = 3.60$, $p = .032$, $p\eta^2 = .079$, with responses larger to negative versus neutral stimuli, $t(43) = 2.38$, $p = .022$. Responses to positive stimuli fell in between the two other conditions, and did not significantly differ from them (*p*s > .05). Further, the interaction of window, emotion, and age was significant, $F(2.56, 107.60) = 2.91$, $p = .046$, $p\eta^2 = .065$. Two-way 3 (Window) x 3 (Emotion) repeated measures ANOVAs were calculated for each age group to further examine the interaction. Among the older children, a main effect of emotion was observed across all windows, $F(2, 42) = 4.04$, $p = .025$, $p\eta^2 = .161$, whereby responses to negative stimuli were larger than to neutral stimuli, $p = .023$. Responses to negative stimuli also were larger than those to positive, although the effect did not reach significance with the correction, $p = .039$. Responses to positive and neutral stimuli did not differ ($p > .10$). Among the younger children, the interaction of window and emotion was significant, $F(2.29, 48.14) = 3.31$, $p = .039$, $p\eta^2 = .136$. Follow up analysis indicated a main effect of emotion in the late window, $F(2, 42) = 3.21$, $p = .050$, $p\eta^2 = .133$, with no significant differences between emotion conditions (*p*s > .05). Effects of emotion were not observed in the early and middle windows.

Central cluster. A main effect of emotion was observed across all windows, $F(2, 84) = 3.78$, $p = .027$, $p\eta^2 = .082$, with significantly larger responses to positive versus neutral stimuli, $t(43) = 2.91$, $p = .006$. Responses to negative stimuli fell in between the two other conditions, and did not significantly differ from them (ps > .05). Emotion did not interact with window, hemisphere, or age group.

Frontal cluster. A main effect of emotion was observed across all windows, $F(2, 84) = 3.11$, $p < .05$, $p\eta^2 = .069$, with larger responses to positive versus neutral stimuli, $t(43) = 2.45$, $p = .019$. Responses to negative stimuli fell in between the two other conditions, and did not significantly differ from them (ps > .05). Emotion did not interact with window, hemisphere, or age group.

Summary of emotion effects. Children's ratings of the stimuli indicated that they experienced the emotional stimuli as more emotional and arousing than the neutral stimuli. ERP findings differed by age group in the posterior cluster, where condition older children showed strong emotion effects across windows to negative stimuli specifically, and younger children showed relatively late emotion effects that were not strongly differentiated by condition. Across groups, emotion effects emerged at the central and frontal clusters whereby responses were larger to positive versus neutral stimuli.

Recognition memory

Behavioral recognition. Corrected recognition scores were used to examine children's recognition memory, and were calculated by subtracting the proportion of false alarms from the proportion of hits within each emotion condition for each participant (proportion scores for false alarms and hits were relative to the total number of new and old trials presented, respectively). Two-way mixed ANOVAs were calculated on the corrected recognition scores to examine children's recognition memory performance as a factor of age and emotion. Descriptive statistics are plotted in Figure 8, separate for younger and older children in Panels a and b, respectively.

Overall recognition performance was strong, with significantly higher performance than chance, $t(34) = 14.36$, $p < .001$. An age effect that approached statistical significance was observed, $F(1, 33) = 3.26$, $p = .080$, $p\eta^2 = .090$, with stronger performance by older versus younger children. Effects of emotion did not reach statistical significance.

ERP recognition. To examine recognition memory effects in children's ERPs we calculated a 2 (Memory: old, new) x 3 (Emotion: positive, neutral, negative) x 2 (Hemisphere: left, right) x 2 (Age: younger, older) mixed ANOVA for mean amplitude in each of the three clusters (posterior, central, and frontal) in each of the three windows (early, middle, late). Because they do not inform the research question, main effects or interactions that do not include memory are not reported. Waveforms for each cluster are plotted in Figures 9 and 10 (for younger and older children, respectively), Panels a, b, and c (for posterior, central, and frontal clusters, respectively).

Posterior cluster. In the early window, there was a main effect of memory, $F(1, 31) = 5.10$, $p = .031$, $p\eta^2 = .141$, whereby responses were larger to old versus new stimuli (old: $M = 12.30$ µV, $SD = 8.51$; new: $M = 10.47$ µV, $SD = 9.66$). The effect was qualified by the interaction of memory, emotion, and age, $F(2, 62) = 4.302$, $p = .018$, $p\eta^2 = .122$. Follow-up analysis by age group revealed a main effect of memory in the older group, $F(1, 14) = 6.19$, $p = .026$, $p\eta^2 = .307$, whereby responses were larger to old versus new stimuli (old: $M = 13.08$ µV, $SD = 7.68$; new: $M = 9.57$ µV, $SD = 10.07$). The effect was qualified by the interaction of memory and emotion, $F(2, 28) = 4.43$, $p = .021$, $p\eta^2 = .240$.

Follow-up analysis revealed that the interaction was driven by memory effects in the negative condition, $t(14) = 4.13$, $p = .001$, with larger responses to old versus new negative stimuli (old: $M = 16.11$ µV, $SD = 8.11$; new: $M = 7.62$ µV, $SD = 10.14$). Memory effects were not observed in the other emotion conditions. No memory effects were observed in the younger group.

In the middle window, the interaction of memory, emotion, hemisphere, and age was observed, $F(2, 62) = 3.25$, $p = .046$, $p\eta^2 = .095$, however memory effects were not observed in follow-up analysis. No memory effects were observed in the late window.

Central cluster. There were no statistically significant effects of memory in the early and middle windows. In the late window, a main effect of memory was observed, $F(1, 31) = 6.16$, $p = .019$, $p\eta^2 = .166$, with larger responses to old versus new stimuli (old: $M = 5.63$ µV, $SD = 7.84$; new: $M = 3.49$ µV, $SD = 6.03$). The effect was qualified by the interaction of memory, emotion, hemisphere, and age, $F(2, 62) = 3.87$, $p = .026$, $p\eta^2 = .111$. Follow-up analysis by age revealed a main effect of memory in the older group, $F(1, 14) = 5.83$, $p = .030$, $p\eta^2 = .294$, whereby responses were larger to old versus new stimuli (old: $M = 5.71$ µV, $SD = 7.64$; new: $M = 2.95$ µV, $SD = 5.68$). In the younger group, follow-up analysis did not reveal any significant effects involving memory.

Frontal cluster. The interaction of memory and hemisphere was observed in the early window, $F(1, 31) = 5.83$, $p = .022$, $p\eta^2 = .158$. However, follow-up analysis by hemisphere did not reveal memory effects. No memory effects were observed in the middle window. In the late window, the interaction of memory, emotion, hemisphere, and age was observed, $F(2, 62) = 5.18$, $p = .008$, $p\eta^2 = .143$. Follow-up analysis by age revealed the interaction of memory, emotion, and hemisphere in the younger group, $F(2,$

34) = 3.78, p = .033, $p\eta^2$ = .182, but further examination by hemisphere did not reveal any memory effects. No memory effects were observed in the older group in the late window.

Summary of recognition memory effects. In their behavioral responses, older children showed an emotion effect on memory (better memory for negative vs. positive stimuli), whereas younger children did not. Overall, children remembered the stimuli, with stronger performance by older versus younger children.

In ERP responses, evidence for an emotion effect on memory came in the early window of the posterior cluster, for older children only. Specifically, there was a significant recognition effect within the negative condition only. The only other memory effect that emerged was observed across conditions in the late window of the central cluster, and for older children only.

Individual differences

Individual differences in emotional memory (measured in behavior and ERPs) was examined by parent-reported temperament and depressive symptomatology. To limit the number of correlations calculated, depressive symptomatology was defined by the measures of anxious/depressed and withdrawn/depressed behaviors from the CBCL and temperament was summed by the 3 major factor loadings from the CBQ (negative affectivity, surgency, and effortful control). Descriptive statistics for parent-reported depressed symptomatology and temperament are reported in Table 4. Corrected recognition scores were used as the measure of behavioral recognition memory. For ERP data at recognition, difference scores were used to measure recognition memory. Specifically, difference scores were calculated as old minus new responses within each emotion condition, for each window and cluster, collapse over hemisphere. Thus larger recognition scores indicate a more positive ERP response to old versus new stimuli, and a stronger memory effect.

Behavioral recognition. Behavioral recognition data and temperament data were available for 35 participants, and behavioral recognition data and depressive symptomatology data were available for 26 participants. No relations between children's temperament or depressive symptomatology and recognition performance were observed (all *r*s < ± .15, *p*s > .05).

ERP recognition. ERP recognition data and depressive symptomatology data were available for 25 participants, and ERP recognition data and temperament data were available for 33 participants. Correlations for the posterior, central, and frontal clusters are reported in Tables 5, 6, and 7, respectively.

Depressive symptomatology, specifically withdrawn/depressed behaviors, was related to recognition in different directions within the negative and positive conditions. In the posterior cluster, more withdrawn/depressed symptoms was associated with larger recognition scores in the positive condition across all windows, and smaller recognition scores in the negative condition in the middle window. The pattern in the negative condition continued in the early and middle windows in the central cluster (i.e., more withdrawn/depressed symptoms and smaller recognition scores). More anxious/depressed symptoms was related to larger recognition scores in the neutral condition in the early windows in the central and frontal clusters.

Temperament generally did not relate to recognition memory except for the surgency measure, where greater surgency was related to smaller recognition scores in the negative and neutral conditions, and larger recognition scores in the positive condition (the pattern was more apparent in the central and frontal clusters, and more often in the later windows). Effortful control generally did not relate to recognition memory, and negative affectivity did not relate to recognition memory.

Summary of individual differences. Parent-report of children's temperament and depressive symptomatology was not related to children's recognition behavior.

Relations between temperament and depressive symptomatology and ERP measures of memory were observed. The most robust and consistent relations were with the measure of withdrawn/depressed behaviors. Specifically, more withdrawn/depressed behaviors was related to better recognition of positive stimuli and lower recognition of negative stimuli in the posterior and central clusters (pattern for positive stronger in posterior cluster, and pattern for negative stronger in central cluster). Although other relations were observed, the large number of correlations calculated leaves the other relations less powerful. The pattern with withdrawn/depressed behaviors was the most evident.

Discussion

We examined school-age children's memory for emotional stimuli, and patterns therein as a factor of individual differences in temperament and depressive symptomatology. First, we evaluated children's experience of the emotional stimuli. Children rated the stimuli as emotional, with no differences between age groups, and the ratings were similar to those of adults in other studies. Further, across the sampled ages (5-8 years), children showed emotion effects in their ERP responses at encoding (i.e., larger positive response to negative and positive stimuli versus neutral). At posterior sites, where emotion effects are largest (Hajcak et al., 2012), the emotion effects were more robust for older than younger children (effects were sustained from 800-2000ms, and only emerged late in the window, from 1600-2000ms in younger children). Children demonstrated successful recognition memory in their ERP and behavioral responses. Emotion effects on memory emerged only in the older group. Specifically, ERP recognition effects specific to the negative condition were observed at posterior sites (among general memory effects across conditions). Thus there appeared to be a developmental emergence of emotion effects on recognition memory, with children under age 7.5 showing no emotion effects on memory, and children older than 7.5 beginning to show adult-like patterns of emotional memory.

The findings indicate that children as young as 5 years rate IAPS stimuli as emotional and similarly to adults. Further, ERP indices of children's emotion processing demonstrate that children as young as 5 show ERP correlates of emotion effects observed in older children and adults. The pattern, however, was less robust in children younger than 7.5, and though there were no age effects in children's valence and arousal ratings of the stimuli, the differential ERP effects may be indicative of a different functional experience of emotion between the two age groups. Specifically, the pattern of emotion effects in the posterior LPP (where emotion effects are strongest, e.g. Hajcak et al., 2012), is consistent with Davidson's affective chronometry argument whereby different windows within the emotion response may represent different functional components of emotion processing (Davidson, 1998). Davidson identified four components of the emotion response that may be indicative of underlying emotion processes: threshold for reactivity, peak amplitude of response, rise time to peak, and recovery time. The differences observed in the present findings seem particular to the third element, rise time to peak, and suggest that emotion response systems are slower in younger versus older school-age children. In this period of development, children are still learning about the causes of emotion and how to change emotional experience, thus perhaps it is these maturing emotion systems that delays the onset of emotion effects in younger children, and older children have already become more knowledgeable and efficient emotion processors.

Although main effects of emotion on children's behavioral recognition responses did not emerge, the pattern of performance is suggestive of emerging emotion effects. Qualitatively, older children demonstrated better memory for negative versus positive stimuli, adding to the ERP finding of enhanced recognition of negative stimuli in older children (younger children showed no evidence of emotion effects on memory in behavior or ERP). The pattern does not parallel exactly what is observed in adults. Adults often demonstrate better memory for emotional versus neutral stimuli, and if valence effects occur, memory is stronger for negative versus neutral stimuli. Older children's memory for neutral stimuli was very similar to memory for negative stimuli, and it was the difference between negative and positive that generated the emotion effect. Thus the data suggest that there are continued changes in emotional memory between the school-age years and adulthood, by which time specific differences in the patterns of emotional memory have evolved. Further, the absence of any emotion effects on memory among younger children suggests that emotion and memory processes are less strongly integrated in the early school-age years.

The data highlight the importance of using multiple methods to assess memory. We did not observe an emotion effect on behavioral indices of children's memory; however, the ERP data provided a richer picture of the underlying processes supporting recognition memory. In the ERP data, we detected an emotion effect specific to negative stimuli in the older group of children.

Examination of individual differences in emotion memory focused on temperament and depressive symptomatology. The findings indicated that withdrawn/depressed behavior, as measured by parent-report on the CBCL, was related to ERP indices of recognition memory for negative stimuli specifically. That is, children with more reported withdrawn/depressed behavior showed a smaller recognition effect for negative stimuli. The pattern is opposite that of behavioral findings between depression and memory, where depressed adults demonstrate enhanced memory for negative stimuli. We did not observe relations with behavioral recognition, but the ERP data suggest a distinct pattern of underlying neural indices of recognition for those with more depressive behaviors. Temperament factors generally did not relate to recognition, suggesting that the effects were specific to depressive symptomatology, rather than broader temperamental characteristics that may be foundational components of mood disorders such as depression.

In light of the relations between depression symptoms and ERP indices of recognition memory, it is important that investigation of emotional memory continues beyond laboratory stimuli that represent emotion externally and include more personal stimuli that represent emotion internally. One way to do this is to invite participants to think about personal emotional experiences and record ERPs during this task. In a study that featured such an approach, differential ERP effects by emotion condition were observed in 7- to 10-year-old children (Bauer, Stevens, Jackson, & San Souci, 2012). Examining the processing of external and internal sources of emotion could be a fruitful approach in understanding healthy emotion processing.

Unfortunately we did not have the opportunity to examine subsequent memory due to the low incidence of ‘miss’ trials at recognition. Thus we could not observe how arousal at encoding related to subsequent memory among school-aged children. Future research should modify the paradigm employed in the current research to increase the incidence of miss trials to permit examination of this question.

The findings from the present study inform our understanding of children’s memory for emotional stimuli, adding to the body of work on children’s memory for *personally experienced* emotional events (i.e., autobiographical memories). Specifically, the findings confirm that children remember emotional experiences, and add the emergence of an emotion effect on school-age children’s memory at 7 to 8 years of age. The findings are suggestive that in the early school-age years, emotional experience is less-well integrated with subsequent memory processes, whereby children demonstrate emotion effects that do not significantly affect memory processes. Further work should examine the behavioral and neurophysiological patterns of children’s and adolescents’ emotional memory to chart the developmental trajectory of the emotion effect.

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Footnotes

[1] Within the negative set, 28 came from the IAPS and 28 from the supplemental set. Within the neutral set, 18 came from the IAPS and 35 from the supplemental set. Within the positive set, 21 pictures came from the IAPS and 34 came from the supplemental set. *T*-tests were used to compare valence and arousal ratings on negative, neutral, and positive stimuli from the IAPS versus the supplemental set and did not reveal any significant differences on how the two sets were rated (all *p*s > .10).

[2] Mood ratings were available for a total of 39 participants.

[3] Mood ratings were available for a total of 35 participants.

[4] In the older group, 6 children had zero subsequent miss trials in at least one of the three conditions (negative: $n = 5$; neutral: $n = 3$; positive: $n = 4$). In the younger group, 3 children had zero subsequent miss trials in at least one of the three conditions (negative: $n = 1$; neutral: $n = 1$; positive: $n = 3$).

[5] Ratings were not collected for 15 participants due to burdensome session length. Ratings from an additional 2 participants were excluded due to apparent confusion on the part of the participants regarding how to use the scales.

Table 1. *Trial counts per condition for each age group at encoding.*

	Older		Younger	
Condition	*M*	*SD*	*M*	*SD*
Negative	23.00	6.44	18.18	6.64
Neutral	23.68	5.71	17.95	7.77
Positve	22.36	6.77	17.73	6.45

Table 2. *Trial counts per condition for each age group at recognition.*

	Older		Younger	
Condition	*M*	*SD*	*M*	*SD*
Negative old	14.47	3.50	10.78	3.26
Negative new	14.13	4.41	12.17	3.78
Neutral old	14.13	3.40	10.56	3.50
Neutral new	14.20	4.41	12.78	3.44
Positive old	14.13	3.60	10.56	4.10
Positive new	13.13	4.73	12.50	3.59

Table 3. *Descriptive statistics for mean amplitude responses at encoding across and within windows in the posterior, central, and frontal clusters (panels a, b, and c, respectively). Data within the posterior cluster are separated by age group: younger (< 7.5 years) and older participants (> 7.5 years).*

a) Posterior	Older		Younger	
	M	*SD*	*M*	*SD*
All				
Negative	13.14	2.77	10.48	2.29
Neutral	9.59	2.07	8.82	4.02
Positive	10.32	1.80	10.17	1.95
Early				
Negative	16.46	10.11	13.19	10.97
Neutral	11.91	7.93	13.66	11.46
Positive	12.08	8.55	12.48	9.45
Middle				
Negative	12.75	7.35	9.65	10.10
Neutral	9.25	6.23	8.25	9.45
Positive	9.95	8.19	9.37	8.26
Late				
Negative	10.20	6.78	8.55	10.22
Neutral	7.59	6.54	4.49	9.43
Positive	8.87	8.51	8.73	9.08

b) Central	*M*	*SD*
All		
Negative	-0.44	4.64
Neutral	-2.43	3.24
Positive	0.43	3.93
Early		
Negative	-5.47	9.23
Neutral	-6.33	7.72
Positive	-4.02	6.03
Middle		
Negative	0.50	8.56
Neutral	-1.28	6.82
Positive	1.60	6.91
Late		
Negative	3.70	8.96
Neutral	0.36	6.66
Positive	3.73	6.28

c) Frontal	*M*	*SD*
All		
Negative	-4.89	5.37
Neutral	-6.42	3.92
Positive	-3.36	4.27

Early		
Negative	-11.02	9.13
Neutral	-10.89	8.71
Positive	-8.42	6.39
Middle		
Negative	-3.64	9.55
Neutral	-5.21	9.19
Positive	-2.06	8.17
Late		
Negative	0.02	9.43
Neutral	-3.15	8.45
Positive	0.49	7.58

Table 4. *Descriptive statistics for parent-reported depressed symptomatology (from the CBCL) and temperament (from the CBQ).*

	M	*SD*
Depressed symptomatology		
Anxious/Depressed	2.70	2.71
Withdrawn/Depressed	0.59	1.28
Temperament		
Negative affectivity	3.91	0.83
Surgency	4.69	0.83
Effortful control	5.45	0.69

Table 5. *Correlation statistics for ERP recognition in the posterior cluster and parent-reported temperament and depressive symptomatology.*

Depressed symptomatology	Negative	Neutral	Positive
Early window			
Anxious/Depressed	.246	.079	.060
Withdrawn/Depressed	-.246	.126	.359^
Middle window			
Anxious/Depressed	.040	.102	.017
Withdrawn/Depressed	-.421*	.034	.394^
Late window			
Anxious/Depressed	.183	.049	-.071
Withdrawn/Depressed	-.199	.039	.430*
Temperament			
Early window			
Negative affectivity	.092	-.108	-.037
Surgency	-.081	-.028	.283
Effortful control	.062	.013	-.203
Middle window			
Negative affectivity	-.009	-.007	.177
Surgency	-.135	-.154	.197
Effortful control	.099	.018	-.327^
Late window			
Negative affectivity	.008	.036	.180

Surgency	-.187	-.225	.298^
Effortful control	.077	-.022	-.380*

Note. ^$p < .10$, *$p < .05$.

Table 6. *Correlation statistics for ERP recognition in the central cluster and parent-reported temperament and depressive symptomatology.*

Depressed symptomatology	Negative	Neutral	Positive
Early window			
Anxious/Depressed	.083	.579**	.041
Withdrawn/Depressed	-.392^	.137	.244
Middle window			
Anxious/Depressed	.052	.206	.001
Withdrawn/Depressed	-.400*	-.066	.281
Late window			
Anxious/Depressed	.079	.060	-.243
Withdrawn/Depressed	-.280	.025	.150
Temperament			
Early window			
Negative affectivity	.062	.276	-.136
Surgency	-.227	-.074	.357*
Effortful control	.281	-.195	-.169
Middle window			
Negative affectivity	-.084	.033	.120
Surgency	-.333^	-.322^	-.024
Effortful control	.244	.139	-.116
Late window			
Negative affectivity	.031	.091	-.034

Surgency	-.281	-.358*	.271
Effortful control	.135	.206	-.126

Note. ^*p* < .10, **p* < .05, ***p* < .01.

Table 7. *Correlation statistics for ERP recognition in the frontal cluster and parent-reported temperament and depressive symptomatology.*

Depressed symptomatology	Negative	Neutral	Positive
Early window			
Anxious/Depressed	.150	.378^	.055
Withdrawn/Depressed	-.186	.183	.284
Middle window			
Anxious/Depressed	.160	.104	.222
Withdrawn/Depressed	-.105	.081	.333
Late window			
Anxious/Depressed	.113	-.011	-.100
Withdrawn/Depressed	-.077	.155	.261
Temperament			
Early window			
Negative affectivity	.094	.233	-.055
Surgency	-.219	-.073	.344*
Effortful control	.074	-.150	-.263
Middle window			
Negative affectivity	-.073	.020	.266
Surgency	-.357*	-.181	-.056
Effortful control	.083	.120	-.170
Late window			
Negative affectivity	.068	.029	.050

Surgency	-.298^	-.160	.170
Effortful control	.062	.169	-.123

Note. ^$p < .10$, *$p < .05$.

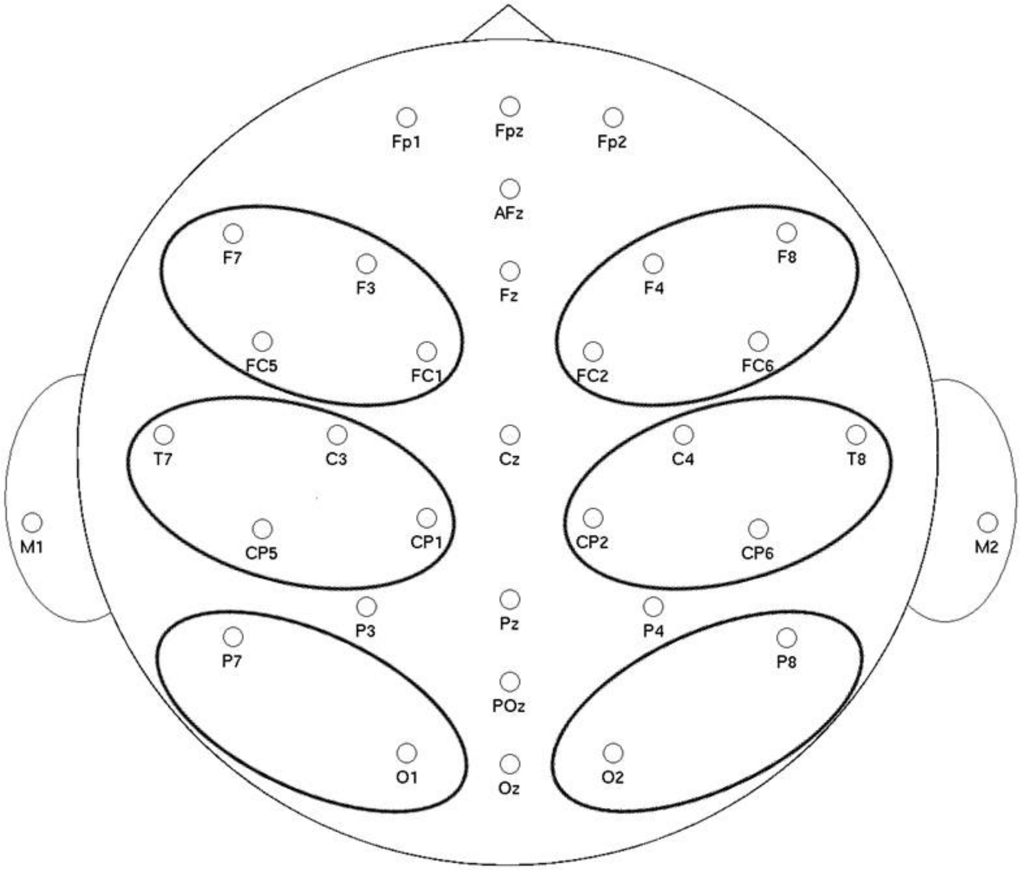
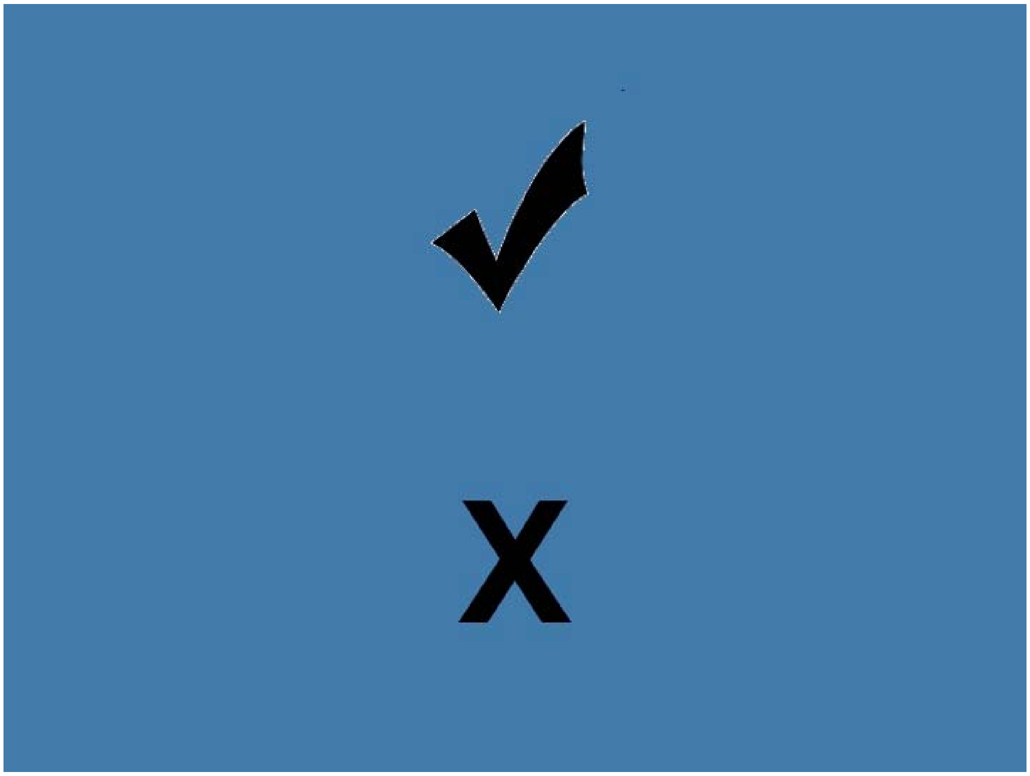


Figure 1. Depiction of electrode layout following the 10-5 system with marked clusters used in analysis.



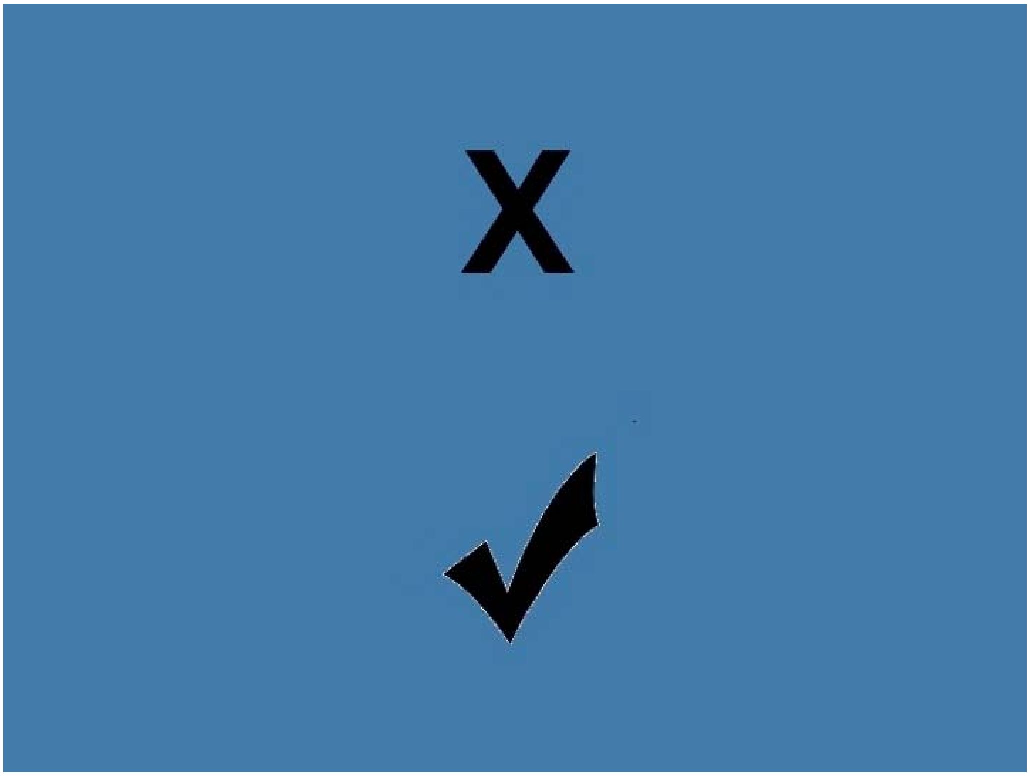
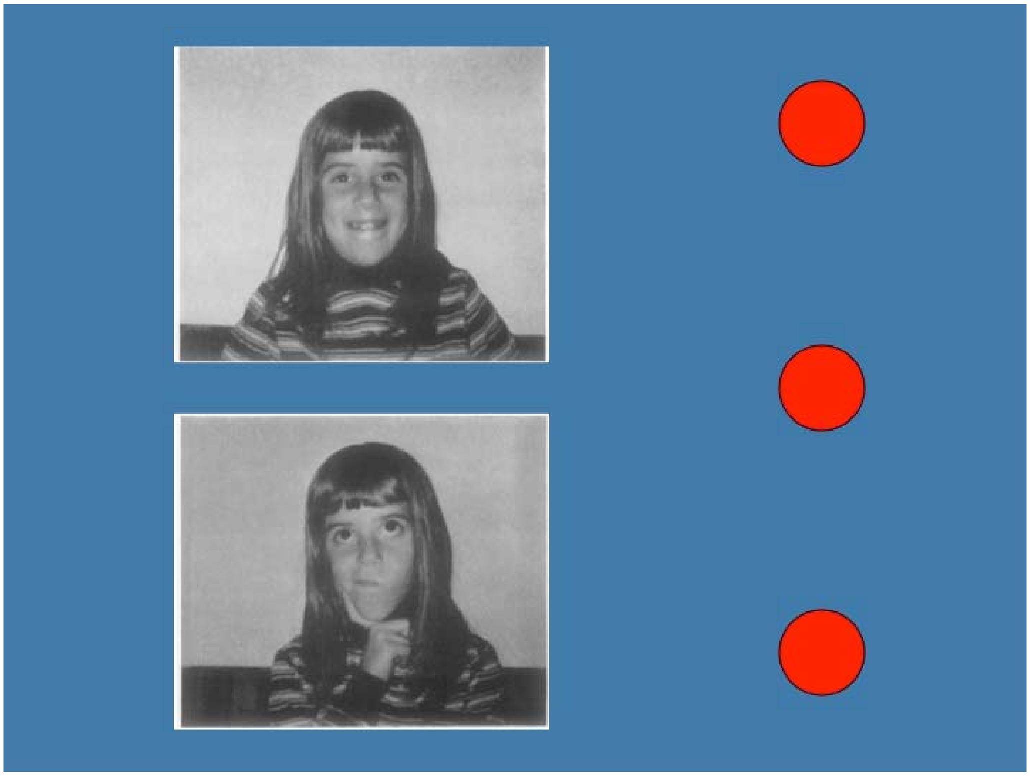


Figure 2. Depiction of old/new decision screens (position counterbalanced across participants).

a) Girls



b) Boys

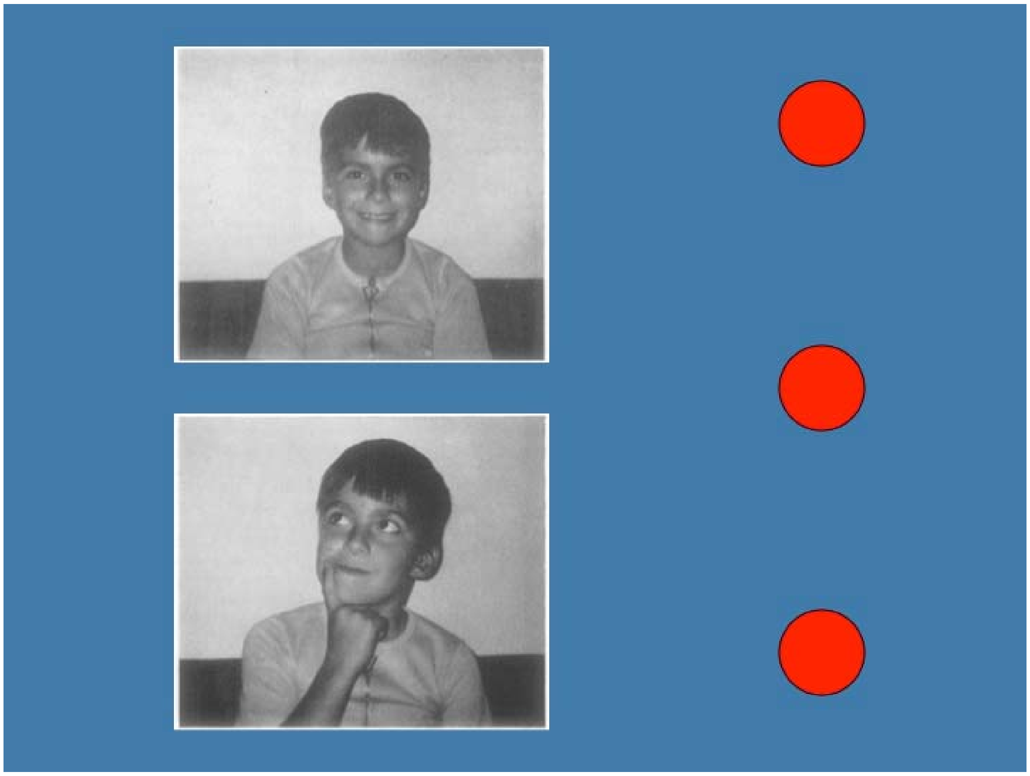
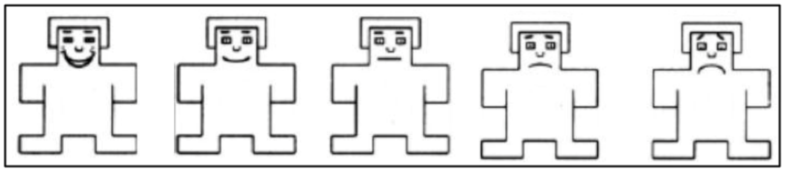


Figure 3. Depiction of confidence ratings screens for a) girls and b) boys.

a) Valence



b) Arousal

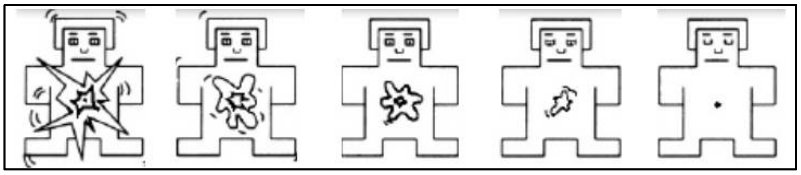


Figure 4. Depiction of Self-Assessment Manikin for rating a) valence and b) arousal.

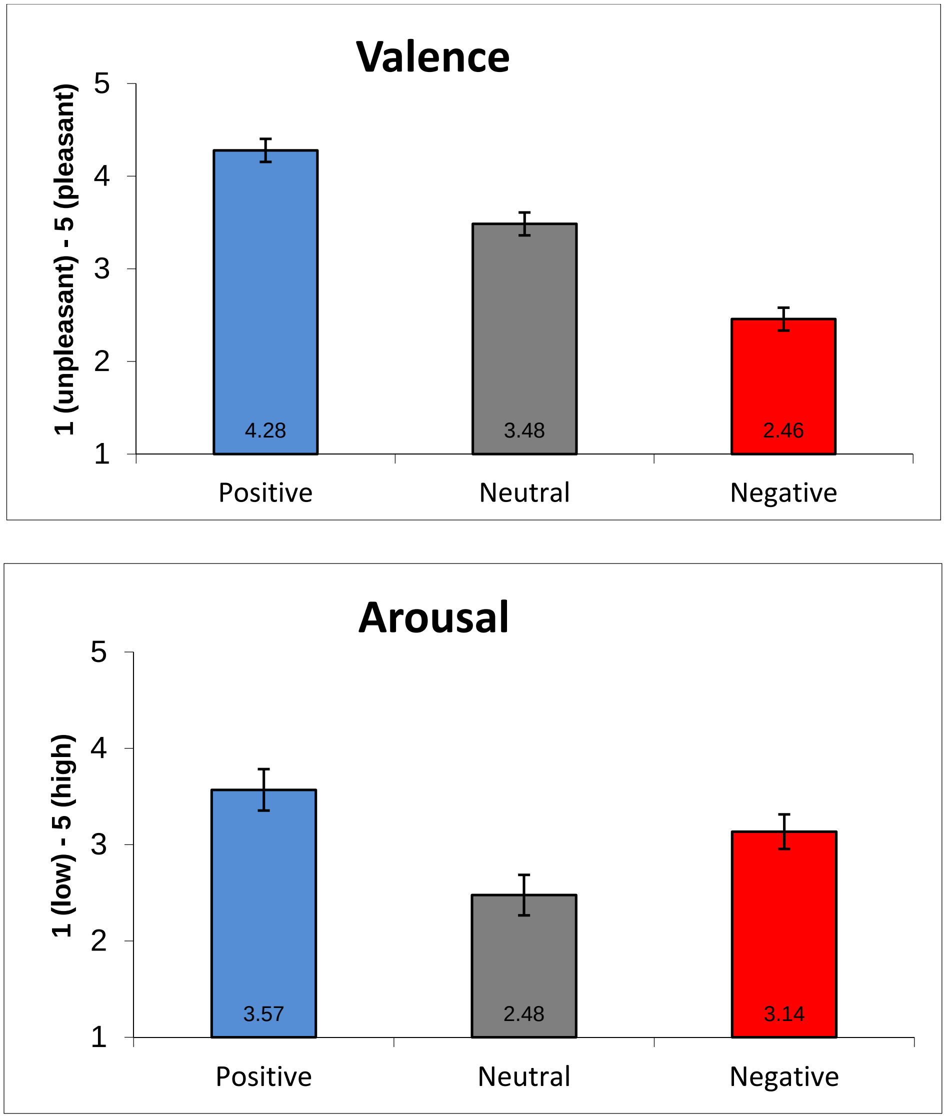
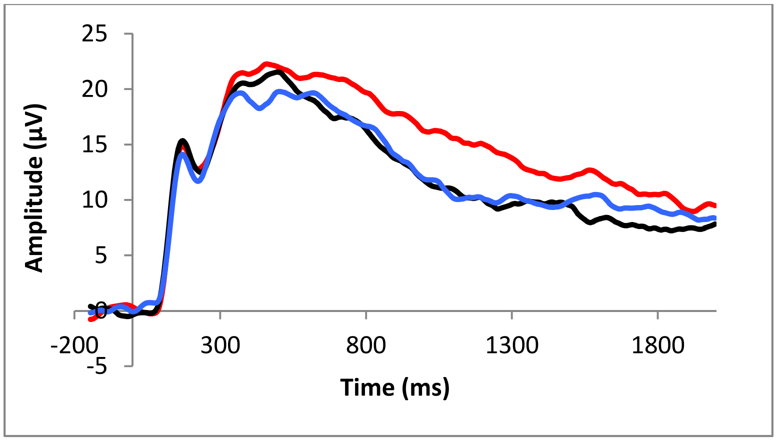
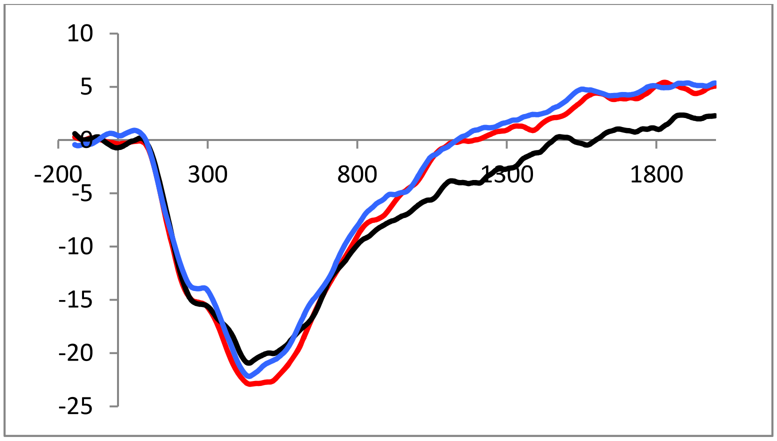


Figure 5. Valence and arousal ratings from the SAM. Error bars represent ± 1 *SEM*.

a) Posterior



b) Central



c) Frontal

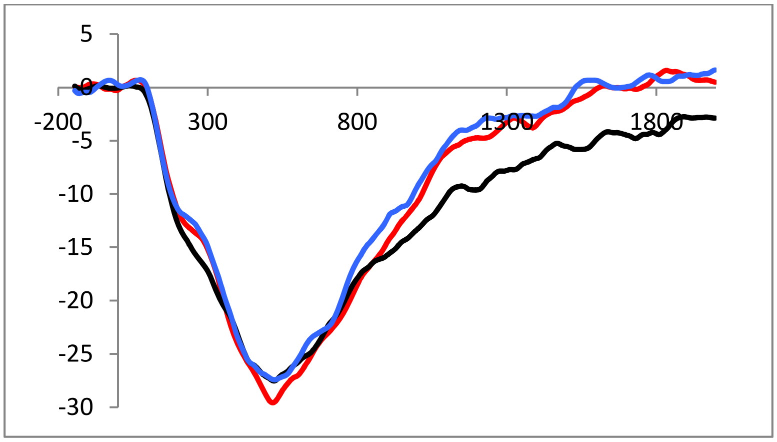
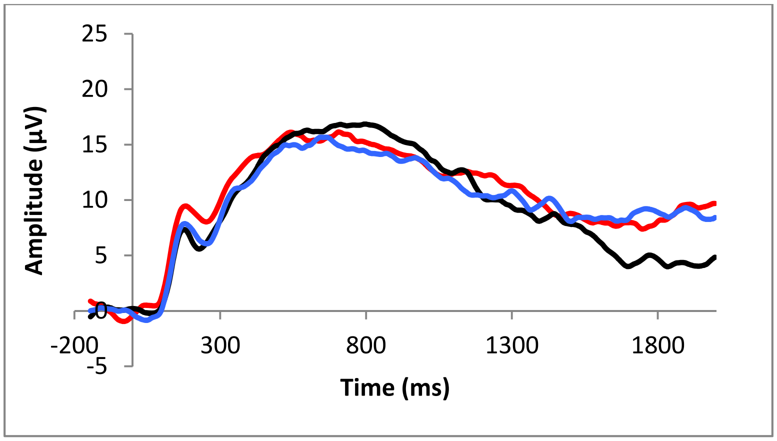
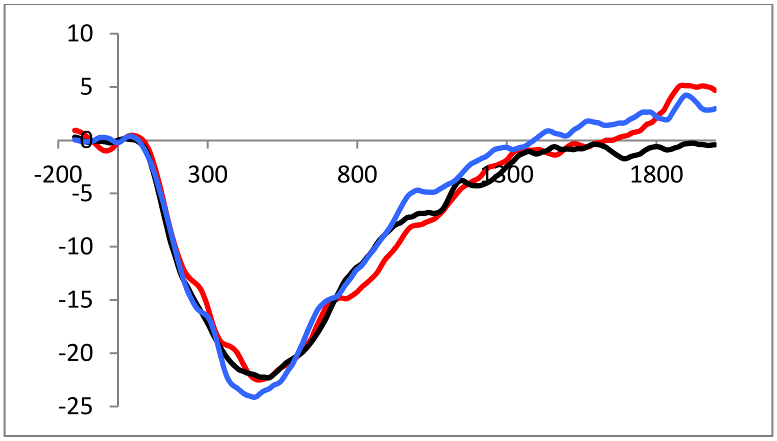


Figure 6. Grand averaged waveforms at encoding from older participants at posterior, central, and frontal clusters, panels a, b, and c, respectively (positive is plotted in blue, neutral in black, and negative in red).

a) Posterior



b) Central



c) Frontal

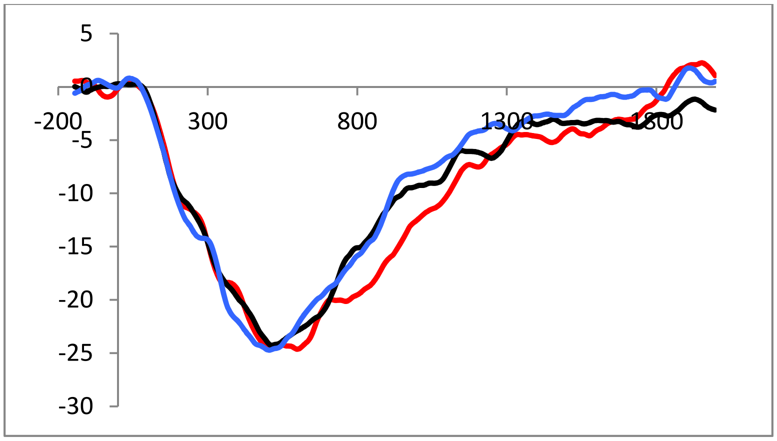
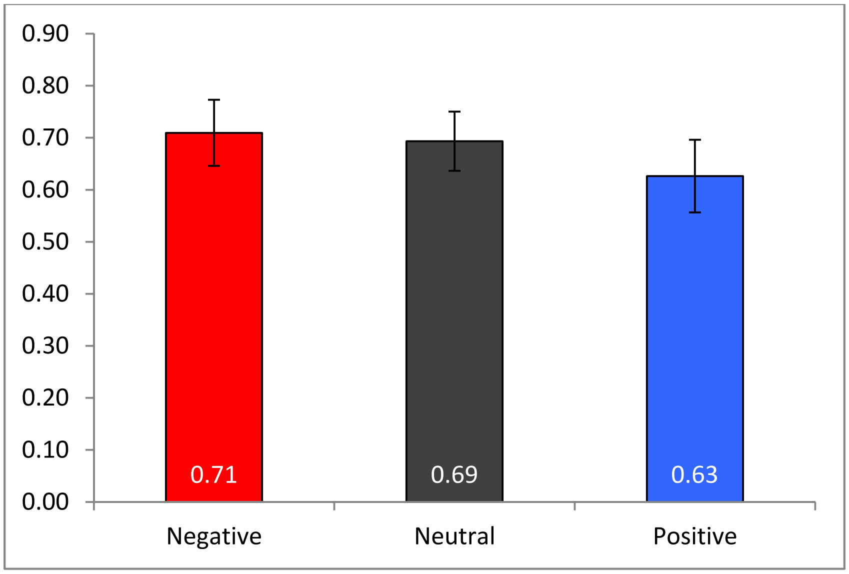


Figure 7. Grand averaged waveforms at encoding from younger participants at posterior, central, and frontal clusters, panels a, b, and c, respectively (positive is plotted in blue, neutral in black, and negative in red).

a) Older children



b) Younger children

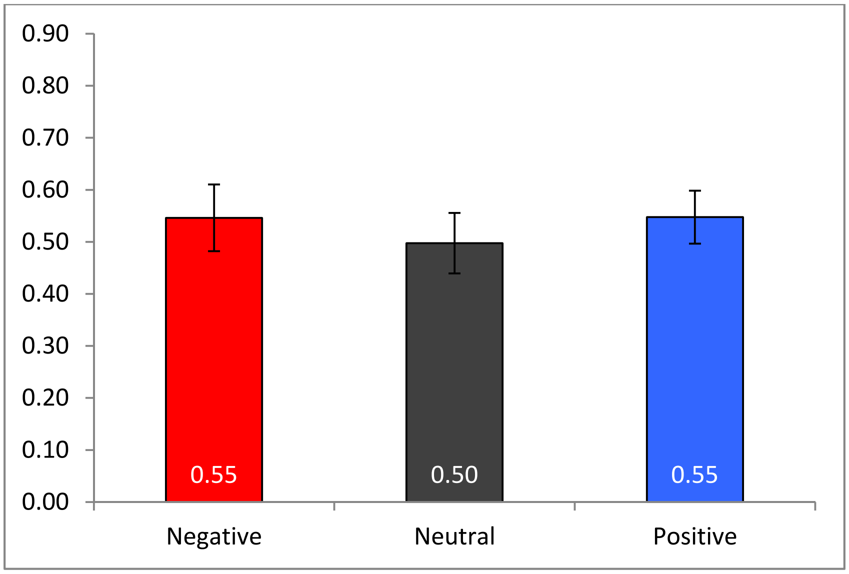
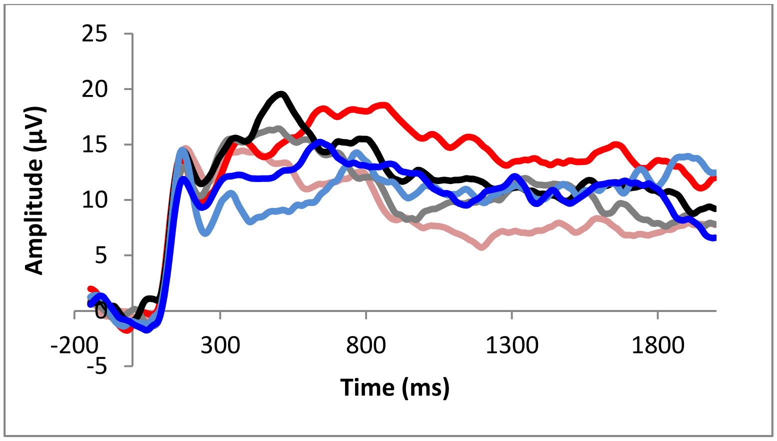
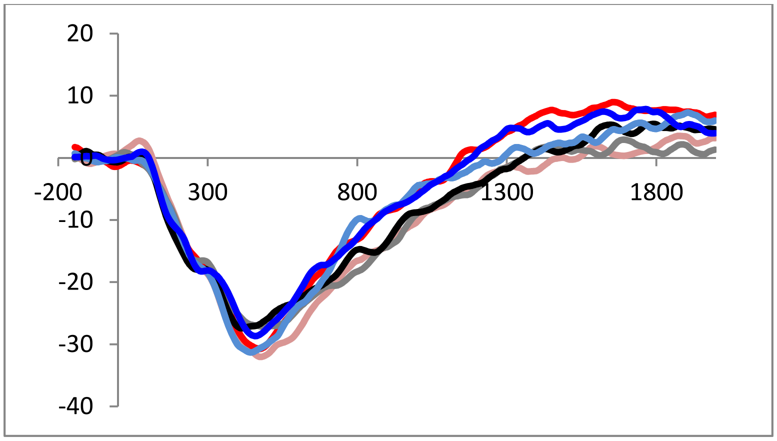


Figure 8. Corrected recognition scores plotted by emotion condition for a) older and b) younger children. Error bars represent ± 1 *SEM*.

a) Posterior



b) Central



c) Frontal

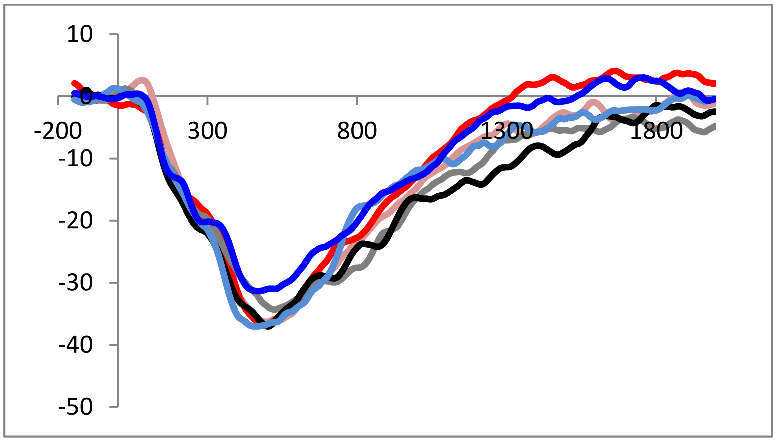
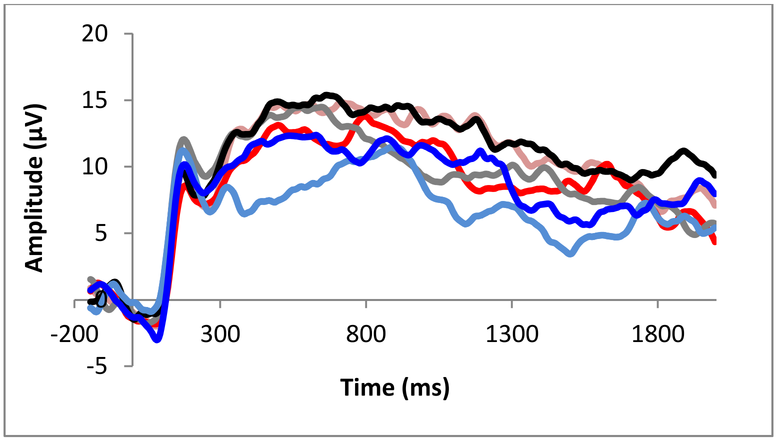
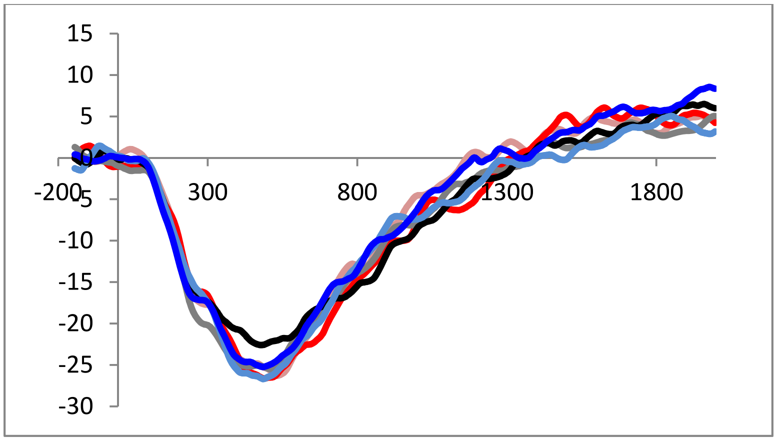


Figure 9. Grand averaged waveforms at recognition from older participants at posterior, central, and frontal clusters, panels a, b, and c, respectively (positive is plotted in blue, neutral in black, and negative in red; ‘old’ is in darker shades, ‘new’ in lighter shades).

a) Posterior



b) Central



c) Frontal

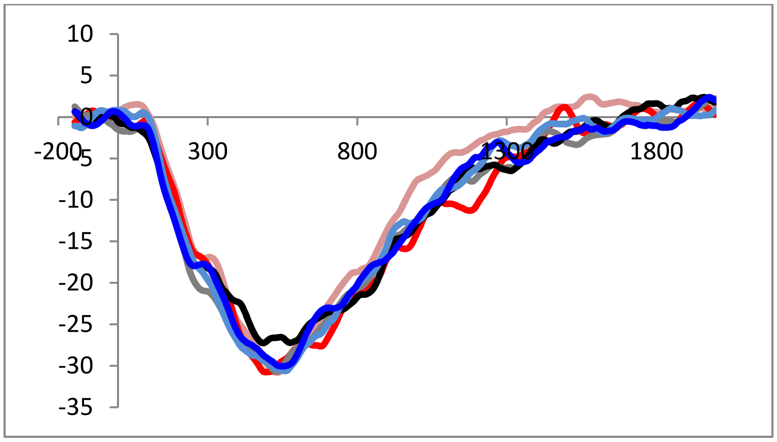


Figure 10. Grand averaged waveforms at recognition from younger participants at posterior, central, and frontal clusters, panels a, b, and c, respectively (positive is plotted in blue, neutral in black, and negative in red; ‘old’ is in darker shades, ‘new’ in lighter shades).

Study 2: Emotion regulation during the encoding of emotional stimuli: Effects on subsequent memory

Emotion permeates our everyday lives from birth to adulthood. As adults, we demonstrate better memory for emotional relative to neutral events, words, stories, and scenes ("emotion effect," LaBar & Cabeza, 2006). Children also experience emotion and remember personal emotional experiences, but the processes of experiencing, encoding, and subsequently remembering emotional events have not been well examined in development, and it remains unclear if emotion and memory processes are as integrated in children as in adults. The enhancing effect of emotion on memory is argued to be due to emotional arousal at the time of encoding. Manipulating arousal at the time of encoding offers the opportunity to examine functional links between emotional experience and subsequent memory, and thus the relative integration of emotion and memory processes in development. If arousal at encoding is reduced (down-regulated), does this impair the enhancing effects of emotion on subsequent memory? Mixed evidence from the adult literature suggests that down-regulation, specifically reappraisal, does not impair memory, bringing question to the role of arousal on subsequent memory. In a study of the developmental status of emotional memory in school-age children, we implemented an emotion regulation manipulation (reappraisal) at encoding to examine the explanatory role of arousal on subsequent memory.

Because distinct variations of emotion processing and emotional memory are observed in adults with disturbed mental health (e.g., depression: Lappanen, 2006; anxiety: Foa, Gilboa-Schechtman, Amri, & Freshman, 2000; PTSD: Rauch, Shin, & Phelps, 2006), examination of the developmental status of emotional memory is a necessary foundation to further understanding the ontogeny of emotional well-being. An excellent tool for measuring emotion processing is event-related potentials (ERPs), which are sensitive to real-time emotional arousal during the encoding of an event. A prominent emotion effect in ERP signal is the late-positive potential (LPP). The LPP is a sustained positive-going ERP waveform that begins around 300 milliseconds post-stimulus onset, maximal over posterior sites, and is larger for emotional and arousing stimuli versus neutral stimuli (Hajcak, Weinberg, MacNamara, & Foti, 2012). Emotion effects to word and picture stimuli have been reported in children as young as 5 years (e.g., Study 1; Hajcak & Dennis, 2009; Perez-Edgar & Fox, 2007). Thus ERPs are sensitive to emotional experience at encoding in both children and adults. In adults, emotion effects at encoding are predictive of subsequent recall performance (e.g., Dolcos & Cabeza, 2002), and ERP recognition effects are larger for emotional versus neutral stimuli (e.g., Weymar, Löw, Melzig, & Hamm, 2009). Subsequent memory effects at encoding have yet to be examined in children, however ERP recognition effects as measured in Study 1 suggest that emotion effects specific to negative stimuli are emerging by 7 to 8 years of age. Further from Study 1, the absence of emotion effects on memory in children under 7.5 years (in ERP and behavioral measures), coupled with emerging effects in children over 7.5 years, is suggestive of emotion and memory processes becoming more integrated in the school-age years, but perhaps not quite adult-like.

One potentially powerful tool for examining the integration of emotion and memory processes is to manipulate the encoding of emotional experience in a way that would affect subsequent memory. As mentioned earlier, the enhancing effect of emotion on memory is argued to be due to emotional arousal at the time of encoding. If arousal at encoding is reduced by an emotion regulation strategy such as reappraisal, and subsequent memory is reduced, this would suggest an integration of emotion and memory processes.

Reappraisal is a cognitive emotion regulation strategy that involves changing the meaning of an emotional experience (Gross, 2002). Typically, it involves changing from an emotionally arousing meaning to a more neutral, less-arousing meaning and *down*-regulates emotional experience (however, *up*-regulation is also possible, but not how reappraisal is used in the current research). Reappraisal is adaptive for healthy emotion processing, and can be measured neurophysiologically, by event-related potentials (ERPs). When emotional arousal is down-regulated, by a reappraisal instruction for example, the emotion effect in the LPP is reduced. Several studies including adult samples have confirmed the effect of reappraisal on the LPP (e.g., Foti & Hajcak, 2008; Hajcak, Moser, & Simons, 2006; Hajcak & Nieuwenhuis, 2006).

In adults, two literatures make opposite predictions on the effect of reappraisal on emotional memory. Behavioral evidence is mixed, with some research suggesting that reappraisal does not alter memory performance (Gross, 2002; Richards & Gross, 2000), and in some cases reappraisal enhances recall (e.g., Dillon, Ritchey, Johnson, & LaBar, 2007). Although it remains to be tested in the ERP literature, studies of emotional memory and reappraisal separately predict the opposite effect. Specifically, indices of emotional arousal at encoding are predictive of successful memory performance (e.g., Dolcos & Cabeza, 2002), and down-regulation of arousal would subsequently predict impaired memory performance (that is, if arousal is the explanatory factor in the enhancing effect of emotion on memory). Thus the relation of arousal, specifically down-regulation of arousal, and memory remains unclear, and is the primary focus of the current research.

Reappraisal is an emotion regulation skill that emerges in the early school-age years, with 5- and 6-year-olds understanding that feeling states can be changed by thinking about a different feeling (e.g. thinking about something positive to improve a negative state), and around age 7 to 8 the skill develops toward an understanding that a different perspective can be taken on the same event (Stegge & Meerum Terwogt, 2007). Thus by age 8 years, children understand how reappraisal works. However it is an emerging skill, and it remains to be seen if reappraisal can be observed in children's ERPs. Two ERP studies of reappraisal have included child samples, and have produced mixed findings. One study demonstrated successful down-regulation effects in 7- to 10-year-olds (Dennis & Hajcak, 2009), and the other study showed no effects of reappraisal in 5- to 7-year-olds (DeCicco, Solomon, & Dennis, 2012). Together, the studies suggest that reappraisal might not be measurable by ERPs until about 8 years of age, and that further examination of the use of ERPs to measure reappraisal in development is needed.

The status of emotional memory in school-age children is such that emotion effects on memory are emerging, but not yet adult-like. Testing a reappraisal manipulation at the time of encoding will inform how emotional experience at encoding connects to subsequent memory processes, and will inform theory on the effects of emotion on memory, and how emotion and memory processes are related. We examined the relation of arousal and memory by employing a reappraisal manipulation at the time of encoding of emotional stimuli, and collecting ERPs during encoding and at subsequent retrieval in a recognition paradigm. Although reappraisal might not be immediately observable in children’s ERPs, we can still examine how the manipulation affects memory performance, which will clarify our understanding of emotion and memory processes in development

We predicted that evidence for successful reappraisal would be demonstrated by reduced LPPs for reappraised stimuli (compared to non-reappraised stimuli). However, given the limited and mixed status of the child literature on ERPs revealing reappraisal effects, it is possible that the effects might not be immediately substantiated at the time of encoding (i.e., immediately following the reappraisal instruction). Thus we examined the effect of the reappraisal manipulation at two time points: once immediately after the reappraisal instruction, and again after a delay. We hypothesized that it might take time for the reappraisal instruction to effectively change the meaning of an emotional stimulus, and speculated that reappraisal effects may not emerge immediately but after a delay.

Notably, reappraisal of positive experiences has yet to be formally examined, and it remains unclear if the dynamics of the LPP response are specific to the reappraisal of negative stimuli (compared to emotional stimuli more broadly). Thus we included both negative and positive stimuli as the emotional stimuli, and examined the effects of reappraisal on each valence, as well as memory for reappraised negative and positive stimuli. If reappraisal operates on all emotional stimuli similarly, across valences, then we predicted that reappraisal effects would not differ between negative and positive stimuli. Alternatively, reappraisal may operate differently on negative versus positive stimuli, for reasons including motivation to reduce negative feelings and maintain positive feelings for healthy emotional well-being, which may make reappraisal of positive stimuli more effortful and something one might want to avoid. In this case, we made no predictions regarding the expression of reappraisal effects for positive stimuli.

Given the status of the literature regarding the effects of reappraisal on subsequent memory, we made two competing predictions. Based on the ERP literature alone, we might observe weaker memory for reappraised stimuli, due to down-regulated arousal at encoding. This would be expressed as smaller recognition effects in the ERP signal and reduced behavioral recognition for reappraised versus non-reappraised stimuli. However, based on the behavioral literature in adults, we might observe that down-regulated arousal at encoding is not related to subsequent memory performance, suggesting that arousal may not be the explanatory variable in the enhancing effect of emotion on memory. Further, as demonstrated in young school-age children, emotional experience may be unrelated to subsequent memory, due to less-integrated emotion and memory systems. In this case, memory performance would not differ as a function of the reappraisal manipulation.

We examined these questions in 8-year-old girls who were part of a larger study of emotion and memory. Because the focus of this research is examination of the developmental status of emotional memory in school-age children using reappraisal as a tool to examine the role of emotional arousal at encoding, we selected 8-year-olds as a starting point for this research since children of this age are capable of reappraisal, may produce ERPs that are sensitive to reappraisal, and begin to show emotion effects on memory. Further, due to gender differences in the socialization of emotion that warrants larger samples of each gender in examination of emotion processes, and the fact that the present research was part of a larger on-going study that involved a prolonged data collection process, we limited the current investigation to one gender. We began the investigation with girls due in part to findings suggesting that girls use reappraisal more than boys (Gullone, Hughes, King, & Tonge, 2010), thus it may be more likely to observe ERP effects of reappraisal in girls versus boys. We first measured if we could detect reappraisal via ERPs in 8-year-old children, followed by our primary investigation of the role of arousal at encoding on subsequent memory: how does reappraisal affect emotional memory?

Method

Participants

Twenty-eight 8-year-old girls participated in two laboratory sessions (M_{age} = 8.48 years, *range* = 8.09-8.84 years). The participants were part of a larger study that involved 3 laboratory sessions (data from Sessions 2 and 3 are reported here and are described as Session 1 and 2, respectively; data from Session 1 are not reported). Participants were recruited from a list of families who had previously expressed interest in participating in child development research. Three children were parent-identified as Hispanic, and 25 as non-Hispanic. Seventeen children were parent-identified as Caucasian, 6 as African American, 3 as mixed race, and the parents of 2 children did not disclose the child’s race. Children were given a small toy at the end of each session, and families were given a gift certificate to a local merchant at the end of the second session, as a token of appreciation for their time and effort. Prior to testing, the researchers received written informed consent from the guardian and verbal assent from the participating child. A university IRB approved all of the methods and materials included in the study.

Materials

A set of 174 child-appropriate images (57 positive; 55 neutral; 62 negative) was selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), as well as a lab-collected set of supplemental stimuli of similar content. Approximately half of the stimuli came from each source, and children's ratings of images between the two sets did not differ.[1] Images from the IAPS containing weapons, mutilated bodies, or sexual content were excluded from this child-appropriate set. To control for previously reported biases in affective processing of stimuli with humans (Proverbio, Adorni, Zani, & Trestianu, 2009), within each emotion condition, half of the image set included humans and half did not include humans. Of the 174 images, 156 were used as the experimental stimuli (52 in each emotion condition). An additional five positive images were available for the end of the EEG recording, three neutral images for practice trials, and ten supplemental negative images as a source of replacement stimuli for images deemed objectionable by parents. All images were presented in full color.

Before the families came to the lab, thumbnails of all 174 images were sent via email to the guardian to approve their use as stimuli (procedure approved by Lang, personal communication). For three participants the guardians expressed concern about some of the negative images (*M* = 5.67 images, range = 1-10); all guardians approved of all positive and neutral images. Objectionable images were replaced with approved images from the supplemental set.

Audio recordings of brief narratives were created for each of the images (range: 8-17 words, 4.5-7.0 seconds). Images were paired with a corresponding narrative during the image presentation at Session 1 only. For each of the 52 primary negative, 10 supplemental negative, and 52 positive images, two kinds of narratives were recorded. In one kind, the narratives described the scene in a way that matched the emotional content of the picture (matching condition), and in the other, the narratives described the scene in a way that reappraised the positive or negative scene in a neutral way (reappraisal condition). An example of a negative scene is the image of a car wreck. This negative scene was accompanied by a negative story in the matching condition (“This was a very bad car accident; they're checking if the driver is ok”), and a neutral story in the reappraisal condition (“This car was destroyed for a movie set; no one was inside”). All neutral images were paired with neutral stories. The narratives were recorded as .wav files and played to the participants through speakers attached to the computer that was used to present the visual experimental stimuli. A full list of narratives is available in the Appendix.

For the EEG recording at Session 1, two sets of 96 images (32 positive, 32 neutral, 32 negative) were selected from the set of 156 experimental stimuli. Within the positive and negative conditions, 16 images were assigned to the matching condition and 16 images were assigned to the reappraisal condition. The 32 experimental neutral images were always assigned to the matching condition. Within each set, images were presented in a pseudo-randomized order such that no more than two images of the same valence preceded one another. Two pseudo-randomized orders were created for each set, for a total of four sets. The image set was counterbalanced across participants. Five additional positive images were added to the end of each presentation so that the session ended on a positive note. Data analysis did not include the final five positive trials. The pictures were 30.5 cm (h) x 23 cm (w) in size, providing a visual angle of 15.59° (h) x 20.58° (w).

For the EEG recording at Session 2, two sets of 120 images were selected from the set of 156 experimental stimuli. Sixty of the 120 images were presented during session 1 (“old” pictures; 20 positive (10 matching, 10 reappraisal), 20 neutral, 20 negative (10 matching, 10 reappraisal), and 60 images were novel and were not presented at Session 1 (“new” pictures; 20 positive, 20 neutral, 20 negative). Within each set, images were presented in a pseudo-randomized order such that no more than four images of the same valence and no more than eight images of the same old/new condition preceded one another. Two randomized orders were created for each set, creating a total of four sets. The image set was counterbalanced across participants. Three additional positive images were added to the end of each presentation so that the session ended on a positive note (three of the five that were presented at the end of the Session 1 recording). Data analysis did not include the three final positive trials.

For the valence and arousal ratings at Session 2, the set of 156 experimental stimuli was divided into eight sets of 24 images that were presented at Session 1 (8 positive (4 matching, 4 reappraisal), 8 neutral, 8 negative (4 matching, 4 reappraisal); presented in a pseudo-randomized order within each set such that there was no more than two consecutive images in one condition; the final image was either positive or neutral so that session ended on a positive note). Participants were randomly assigned to one of the eight ratings sets. The pictures were 17.5 cm (h) x 31 cm (w) in size, providing a visual angle of 13.49° (h) x 23.66° (w).

Procedure

The study consisted of two sessions separated by 1-5 days (*M* = 2.96 days, *SD* = 1.09). During Session 1, electrophysiological (EEG) data were collected as participants viewed the set of 96 positive, negative, and neutral images and listened to the audio narratives that corresponded to each picture. Session 1 lasted approximately 90 minutes. During Session 2, we collected EEG and behavioral data as participants viewed the set of 120 positive, negative, and neutral images and participated in a behavioral recognition memory task. Immediately after the EEG recording children provided subjective ratings of valence and arousal using the Self Assessment Manikin (SAM; Bradley & Lang, 1994). Session 2 was approximately 60 minutes.

Session 1. Participants were seated approximately 84 centimeters from the screen where the images were presented. Participants were fitted with the EEG electrode cap. EEG data were collected using an Advanced Neuro Technology (A.N.T.) Waveguard EEG cap with 32-shielded Ag/AgCl electrodes (A.N.T. Software B.V., Enschede, The Netherlands) (see Figure 1). Electrode placement followed the 10/5 system, an adaptation of the International 10/20 system (Jasper, 1958). Impedances were kept under 10 kΩ, and were generally under 5 kΩ. The sampling rate was set at 256 Hz. Data were amplified 20,000 times using an A.N.T. amplifier and values that exceeded A/D thresholds were excluded. Data were referenced online to mathematically-linked mastoids (sites M1 and M2; see Figure 1).

Three practice trials were presented to the child to demonstrate how the trials would appear. Participants were informed that a picture would appear on the screen for 2 seconds, then a story would be played that described the picture, and then the picture would appear again for 2 seconds. Participants were instructed to think about how the story described the picture, and to try to match the story to the picture during the second presentation of the picture. The practice trials consisted of three neutral images that were not presented during the testing phase. Once the participants affirmed they understood the task instructions, image presentation and data recording began.

Participants viewed 101 images as ERPs were recorded (see Materials). Each trial consisted of the following sequence: the image was presented for 2000 milliseconds, then a fixation cross was presented while the corresponding audio narrative was played (4500-7000 milliseconds), then the image was presented again for 2000 milliseconds. Each trial was separated by an 800-1200 millisecond inter-stimulus interval (ISI) where the screen was blank. The image presentation lasted approximately 18 minutes. Stimulus presentation was controlled using ASA computer software (A.N.T. Software B.V., Enschede, The Netherlands).

Participants completed a 5-point mood questionnaire (1 = unhappy, 3 = neutral, 5 = happy) immediately before and after the EEG recording. The children self-rated their mood similarly before and after the image presentation (Pre: *M* = 4.59, *SD* = 0.97; Post: *M* = 4.40, *SD* = 1.05; *t*(25) = 1.200, *p* > .20)^2, indicating that children's mood did not significantly change from before to after the image presentation.

Session 2. Participants were seated approximately 84 centimeters from the screen where the images were presented, and were fitted with the EEG electrode cap with the same specifications as described for Session 1.

Participants completed a behavioral recognition memory task during the image presentation. During the task, participants indicated if they thought each picture was old or new, and then rated their confidence in their old/new response (very sure/maybe sure/unsure). After each image, an old/new decision screen appeared (see Figure 2 for depiction of old/new screen). The screen depicted a check mark and an 'X' which corresponded to two vertically-oriented buttons on a video game controller. Participants were instructed that the check mark meant that the image was old and presented at Session 1 and that the ‘X’ meant that the image is new and was not presented at Session 1. After the old/new screen, a confidence rating screen appeared (see Figure 3 for depiction of confidence screen). The screen depicted three levels of confidence (very sure, maybe sure, unsure), which corresponded to 3 vertically-oriented buttons on the game controller. It was explained to the participant that the three choices referred to their old/new response. Participants were instructed to wait for the old/new screen to make an old/new response, and to wait for the confidence screen to make a confidence rating. The researchers presented three practice trials to the child to establish that she understood how to complete the task and the practice period was repeated as necessary until children demonstrated that they understood the task instructions. The practice trials consisted of three neutral images that were not presented during the testing phase (same as Session 1). Once the participants affirmed they understood the task instructions, image presentation and data recording began.

Participants viewed 123 images as ERPs were recorded (see Materials). Each trial consisted of the following sequence: the image was presented for 2000 milliseconds, then the old/new decision screen for 2000 milliseconds, then the confidence rating screen for 3000 milliseconds. Each trial was separated by a 400-600 millisecond ISI where the screen was blank. The image presentation lasted approximately 17 minutes.

Participants’ button presses were scored as follows. On trials that were presented at encoding and recognition (old trials), ‘old’ responses were scored as hits and ‘new’ responses were scored as misses. On trials that were presented at recognition only (new trials), ‘old’ responses were scored as false alarms and ‘new’ responses were scored as correct rejections. Recognition data were available for 25 participants [3 participants were excluded from analysis due to experimental error (*n* = 1), attrition from study (*n* = 1), or insufficient trial counts (< 25% of total possible, *n* = 1)].

Participants completed the 5-point mood questionnaire immediately before and after the EEG recording (same procedure as Session 1). Children’s mood did not significantly change from before to after the image presentation (Pre: $M = 4.44$, $SD = 1.13$; Post: $M = 4.22$, $SD = 1.12$; $t(23) = 0.849$, $p > .40$)[3].

The ERP cap then was removed and participants were asked to sit at a table within the same testing room to complete the ratings task. On a laptop, they were shown a self-paced presentation of 24 images from the experiment. Participants provided subjective valence and arousal ratings using a modified Self-Assessment Manikin (SAM; Bradley & Lang, 1994; see Figure 4, panels a and b). The SAM was abbreviated from the 9-point version of the scale to reduce participant burden on children who had just completed a relatively lengthy task during EEG recording, and the modified version consisted of two 5-point scales: one for valence (1 = very unpleasant, 3 = neutral, and 5 = very pleasant), and one for arousal (1 = very low arousal, 5 = very high arousal).

ERP data reduction

EEG data were filtered offline using a bandpass filter between 0.1 to 30 Hz with a 24dB/octave roll-off using Advanced Source Analysis software (A.N.T. Software B.V., Enschede, The Netherlands). All subsequent data processing was completed using EEGLAB 6.03b (Delorme & Makeig, 2004) and ERPLAB 1.0.0.3 (www.erplab.org) operating in Matlab 7.7.0 (MathWorks, Natick, MA, USA). Independent component analysis (ICA) was applied after filtering to identify and remove eye-blink artifact from the data. EEG data was segmented into 2200ms epochs beginning 200 ms before stimulus onset and ending 2000 ms after stimulus onset. A 200 ms pre-stimulus window was used to correct for baseline activity in each epoch. Trials that were contaminated by deflections that exceeded ± 200 μV were excluded from analysis.

ERP data from encoding were available for a total of 27 participants (1 participant was excluded due to experimental error), and recognition ERP data were available for 21 participants [7 participants were excluded from analyses because they did not return for the session (*n* = 1), EEG data was not recorded (*n* = 1), or due to excessive noise in EEG data (*n* = 5)].

To examine emotion effects, artifact-free epochs were averaged by emotion condition (pre-manipulation: negative, neutral, and positive; post-manipulation: negative matching, negative reappraisal, neutral, positive matching, and positive reappraisal). Pre-manipulation, post-manipulation-immediate, and post-manipulation-delayed trial counts are reported in Table 1.

To examine recognition effects, artifact-free epochs were averaged by condition for trials on which participants made a correct button press since these trials represent the cleanest memory response (i.e., correct responses were ‘hit’ responses on old trials: negative matching, negative reappraisal, neutral old, positive matching, and positive reappraisal, and ‘correct rejection’ responses on new trials: negative new, neutral new, and positive new). Trial counts for each condition are reported in Table 2. For one participant, channels C3/4 were removed due to off-scale measurements; missing values were replaced with the mean of the series for group-level analyses. Further, for one participant, zero trials were available for the negative reappraisal condition, and missing values were replaced with the mean of the series for group-level analyses.

Encoding as a factor of subsequent memory was not examined due to the low incidence of ‘subsequent miss’ trials.[4]

ERP Data Analysis

Examination of the data was guided by similar investigations (Dennis & Hajcak, 2009; Maratos & Rugg, 2001; Solomon, DeCicco, & Dennis, 2012). Based on the previous research and visual inspection of the ERP waveforms, we identified a sustained positive slow-wave consistent with the late positive potential (LPP) over all scalp sites. Mean amplitude of the LPP was examined over four time windows (400-800ms, 800-1200ms, 1200-1600ms, and 1600-2000ms) to investigate the duration and timing of emotion effects at frontal, central and posterior clusters (posterior: P7/8, P3/4, O1/2; central: T7/8, C3/4, CP5/6, CP1/2; frontal: F7/8, F3/4, FC5/6, FC1/2; all clusters marked on Figure 1). Because preliminary analysis did not indicate effects of site, data were collapsed by hemisphere within each cluster. The LPP is interpreted for deflections toward positive amplitude regardless of value. That is, effects at frontal sites may be negative, but it is the positive deflection that is interpreted. This is consistent with the approach taken in Solomon, DeCicco, & Dennis (2012).

Emotion effects were examined at three time points: pre-manipulation and post-manipulation (immediate), and post-manipulation (delayed). Pre-manipulation trials came from the encoding session during the first presentation of the images (before the reappraisal story). Immediate post-manipulation trials came from the encoding session during the second presentation of the images (immediately after the reappraisal story) and delayed post-manipulation trials came from the recognition session ('old' trials that were presented at encoding).

Recognition memory effects were first examined for the negative conditions, and then the positive conditions, both in relation to the neutral conditions. This approach was taken for two reasons. Firstly, reappraisal of emotional stimuli has been examined only in regard to negative stimuli, and this is the first examination of memory for reappraised stimuli. Thus the first step is to examine recognition memory for negative stimuli that have been reappraised. Secondly, because there are a total of eight levels of condition (across negative, positive, and neutral trials), effects of condition would be hazardous to interpret in a coherent manner. For each analysis, there were 5 conditions: reappraisal (old), matching (old), negative/positive new, neutral old, and neutral new. Only trials on which participants made correct button presses were included, since these represent the cleanest measure of memory responses (i.e., correct responses were 'hit' responses on old trials, and 'correct rejection' responses on new trials).

Results

Examination of the emotion manipulation is presented first (SAM ratings, ERP pre- and post-reappraisal manipulation), followed by recognition data (behavior, then ERP). In cases of violation of sphericity, Greenhouse-Geisser corrections were applied. Unless noted otherwise, Bonferroni adjustments were made for post hoc analysis with multiple comparisons.

Emotion manipulation

SAM ratings. Children's valence and arousal ratings of the stimuli were examined separately in a one-way repeated measures analysis of variance (RM ANOVA) with five levels of condition: negative matching, negative reappraisal, neutral, positive matching, and positive reappraisal. Descriptive statistics are plotted in Figure 5, Panels a and b. Valence ratings differed significantly by condition, $F(1.86, 42.70) = 72.83$, $p < .001$, $p\eta^2 = .760$, with significant differences between every condition at $p < .001$ except the comparison of matching and reappraisal in the negative ($p = .082$) and positive conditions ($p = 1.000$). Negative stimuli were rated as more negative than neutral, which were rated as more negative than positive stimuli. Arousal ratings also differed significantly by condition, $F(2.20, 50.50) = 6.12$, $p = .003$, $p\eta^2 = .210$, with higher arousal ratings on both positive conditions versus the neutral condition (ps $< .002$). Arousal ratings did not significantly differ between any of the other conditions.

ERP effects. Emotion effects were examined at three stages. First, emotion effects due to picture content alone, prior to the reappraisal manipulation, were examined. Then emotion effects immediately after the manipulation were examined. And emotion effects at recognition were examined (1-5 days post-manipulation). For each of the three approaches, a 3-way RM ANOVA was calculated on the measure of mean amplitude in the posterior, central, and frontal clusters (on the factors of window, emotion, and hemisphere). There were four levels of window: first (400-800ms), second (800-1200ms), third (1200-1600ms), and fourth (1600-2000ms), to examine emotion effects over the course of the LPP. For the pre-manipulation analysis, there were 3 levels of emotion: negative, neutral, and positive. For the two post-manipulation analysis, there were 5 levels of emotion: negative matching, negative reappraisal, neutral, positive matching, and positive reappraisal. Effects that do not involve the emotion factor are not reported since it is not relevant to the research question.

Emotion effects pre-manipulation. Descriptive statistics are reported in Table 3, and waveforms are plotted in Figure 6. A main effect of emotion was observed in every cluster, Fs(2, 52) > 4.18, ps < .025, $p\eta^2$s > .138, and was qualified by the interaction of window and emotion in each cluster, Fs > 3.81, ps < .010, $p\eta^2$s > .128.

Follow-up analysis of the interaction in the posterior cluster revealed significant emotion effects in the second, third, and fourth windows, ps < .003. ERPs were larger to negative versus neutral stimuli in the second, third, and fourth windows (ps < .003), and to positive versus neutral stimuli in the third and fourth windows (ps < .008). Responses to negative and positive stimuli never differed from each other in any window, and positive did not differ from neutral in the second window. No emotion effects were observed in the first window.

Follow-up analysis of the interaction in the central cluster revealed significant emotion effects in the third and fourth windows, ps < .001, $p\eta^2$s > .259. ERPs to negative and positive stimuli were larger than to neutral stimuli in both windows, ps < .006, and negative and positive did not differ from each other. No emotion effects were observed in the first window, and only approached statistical significance in the second window, $F(2, 52) = 2.84$, $p = .067$, $p\eta^2 = .099$.

Follow-up analysis of the interaction in the frontal cluster revealed significant emotion effects in the third and fourth windows (ps < .007). ERPs were larger to positive versus neutral stimuli in the third and fourth windows (ps < .012), and to negative versus neutral stimuli in the fourth window only ($p = .044$). Responses to negative and positive stimuli did not differ in any window, and emotion effects were not observed in the first and second windows.

Emotion effects post-manipulation (immediate). Waveforms are plotted in Figure 7.

No main effects or interactions involving emotion were observed in the posterior cluster.

A main effect of emotion was observed in the central cluster, $F(3.23, 84.01) = 4.02$, $p = .008$, $p\eta^2 = .134$, with larger ERPs to positive reappraisal than neutral stimuli ($p = .016$). No other significant differences between conditions were observed. The effect was qualified by the interaction of window, emotion, and hemisphere, $F(7.45, 193.56) = 2.57$, $p = .013$, $p\eta^2 = .090$. Further examination of the interaction was pursued by window (descriptive statistics are reported in Table 4). A main effect of emotion was observed in the first window, $F(4, 104) = 3.07$, $p = .019$, $p\eta^2 = .106$, with more positive responses to positive reappraisal than neutral stimuli ($p = .009$); no other significant differences between conditions were observed. A main effect of emotion also was observed in the second window, $F(4, 104) = 4.83$, $p = .001$, $p\eta^2 = .157$, with more positive responses to negative matching versus neutral stimuli ($p = .021$), and to positive reappraisal versus neutral stimuli ($p = .014$). No other significant differences between conditions were observed. No effects of emotion were observed in the third window. In the fourth window, the interaction of emotion and hemisphere was significant, $F(4, 104) = 2.69$, $p = .035$, $p\eta^2 = .094$. Follow-up analysis by hemisphere revealed a main effect of emotion in the left hemisphere only, $F(4, 104) = 4.47$, $p = .002$, $p\eta^2 = .147$, where responses to positive reappraisal were more positive than to neutral and negative reappraisal stimuli (ps = .029 and .037, respectively). No other significant differences between conditions were observed. Descriptive statistics are reported in Table 4.

In the frontal cluster, there was a main effect of emotion, $F(4, 104) = 3.84$, $p = .006$, $p\eta^2 = .129$, where responses were more positive to positive reappraisal than neutral stimuli ($p = .022$). No other significant differences between conditions were observed. Descriptive statistics are reported in Table 5.

Emotion effects post-manipulation (delayed). Waveforms are plotted in Figure 8, and descriptive statistics are reported in Table 6.

A main effect of emotion was observed in each cluster, Fs$(4, 84) > 2.85$, ps $< .029$, $p\eta^2$s $> .119$. Follow-up analysis in the posterior cluster revealed more positive responses to negative matching versus neutral stimuli ($p = .019$); all other conditions fell in between and did not differ from each other. In the central cluster, responses were more positive to negative matching, negative reappraisal, and positive reappraisal than neutral stimuli (ps $< .036$); no other significant differences between conditions were observed. And in the frontal cluster, responses were more positive to negative matching versus neutral stimuli ($p = .029$); all other conditions fell in between and did not differ from each other.

Summary of emotion effects. Children's ratings of the stimuli differed by emotion condition, but were largely unaffected by the manipulation. Negative stimuli were rated as more negative than neutral, which were rated as more negative than positive stimuli Positive stimuli were rated as more arousing than neutral and negative stimuli, which were not rated differently from each other.

In the ERP signal, emotion effects in the pre-manipulation analysis were present across all clusters, and were consistent with predicted emotion effects (negative and positive stimuli elicited larger responses than neutral stimuli). Post-manipulation effects differed between the two time points at which it was measured (immediate vs. delay). Immediately after the manipulation, emotion effects were specific to the positive reappraisal condition (with one exception), and measured in the central and frontal clusters only (no emotion effects in the posterior cluster). At the delay, emotion effects were present for the negative matching condition across all windows in the posterior and frontal clusters (no other conditions differed). In the central cluster, emotion effects were present across all conditions but positive matching.

Recognition

For the behavioral and ERP analyses, recognition in the negative and positive conditions was examined separately in relation to the neutral condition. Preliminary analysis indicated that delay (range: 1-5 days) did not affect recognition (in either behavior and ERP responses), thus delay was not included as a factor in the analyses.

Behavioral Recognition. Corrected recognition scores were used to examine children's behavioral recognition performance (calculated as the proportion of hits minus the proportion of false alarms from the total number of presented trials). That is, a one-way RM ANOVA was calculated on corrected recognition examining 3 levels of condition: matching, reappraisal, and neutral. Descriptive statistics are plotted in Figure 9.

Negative condition. Recognition performance differed significantly by condition, $F(2, 48) = 5.61$, $p = .006$, $p\eta^2 = .189$. Recognition was significantly higher in the matching versus neutral condition, $p = .005$. No other significant differences between conditions were observed.

Positive condition. Recognition performance did not differ by condition.

ERP Recognition. Due to the unbalanced design of emotion and memory conditions (i.e., two levels of 'old' trials for the negative and positive conditions, and one level of 'new' trials), the factors of emotion and memory were collapsed into one factor of condition with five levels (e.g., for the negative condition: negative matching- old, negative reappraisal- old, negative new, neutral old, neutral new). Since recognition memory effects are the focus of this research question, follow-up comparisons will focus only on only old-new effects (i.e., differences between old and new conditions).

For all ERP analyses, a 4 [Window: First (400-800ms), Second (800-1200ms), Third (1200-1600ms), Fourth (1600-2000ms)] x 5 (Condition) x 2 (Hemisphere: Left, Right) RM ANOVA was computed on the measure of mean amplitude, for each cluster separately (posterior, central, frontal). Separate RM ANOVAs were calculated to examine recognition effects in the negative and positive conditions, relative to the neutral condition (waveforms are plotted by cluster in Figures 10 and 11, for the negative and positive analysis, respectively). Thus the five levels of condition within the negative condition were: Negative Matching (old), Negative Reappraisal (old), Negative new, Neutral old, and Neutral new; and within the positive condition: Positive Matching (old), Positive Reappraisal (old), Positive new, Neutral old, and Neutral new. Main effects and interactions that do not include condition are not reported since they are not relevant to the question of interest.

Negative condition. Descriptive statistics are reported in Table 7 (effects did not differ by window, thus values are reported across windows). A main effect of condition was observed in the posterior cluster, $F(4, 80) = 4.05$, $p = .005$, $p\eta^2 = .168$. Follow-up analysis indicated that responses were more positive to matching (old) than to neutral new stimuli ($p = .035$). All other conditions fell in between, and no other significant differences between conditions were observed. No interactions with condition were observed.

A main effect of condition also was observed in the central cluster, $F(4, 80) = 6.56$, $p < .001$, $p\eta^2 = .247$. Follow-up analysis indicated that responses were more positive to matching (old) stimuli than neutral new stimuli ($p < .001$). Further, responses were larger to reappraisal (old) versus neutral new stimuli, although the effect only approached statistical significance, $p = .052$. No other significant differences between conditions were observed, and no interactions with condition were observed.

Lastly, a main effect of condition was observed in the frontal cluster, $F(4, 80) = 3.58$, $p = .010$, $p\eta^2 = .152$. Follow-up analysis indicated that responses were more positive to matching (old) stimuli than neutral new stimuli ($p = .007$). All other conditions fell in between, and no other significant differences between conditions were observed. No interactions with condition were observed.

Thus recognition effects were observed in the matching condition across all clusters and windows, and also in the reappraisal condition across windows in the central cluster. Recognition effects were relative to the neutral new condition, and were not observed within emotion conditions.

Positive condition. Descriptive statistics are provided in Table 8. In the posterior cluster, a main effect of condition was observed that approached statistical significance, $F(3.32, 66.45) = 2.41$, $p = .056$, $p\eta^2 = .108$. The effect was qualified by the interaction of window, condition, and hemisphere, $F(5.62, 112.42) = 2.63$, $p = .022$, $p\eta^2 = .116$. Analysis of the interaction revealed only one statistically significant effect, a main effect of condition in the second window, *F*(4, 80) = 4.25, $p = .004$, $p\eta^2 = .175$, with larger responses to the matching and reappraisal (old) stimuli versus neutral new stimuli (*p*s = .0005 and .048, respectively). No other main effects of or interactions with condition were observed in any of the windows.

In the central cluster, a main effect of condition was observed, *F*(4, 80)= 5.32, $p = .001$, $p\eta^2 = .210$. Responses were larger to matching (old) stimuli than neutral new stimuli, $p = .022$. Further, responses to reappraisal (old) stimuli were larger than neutral new stimuli ($p = .017$). No other significant differences between conditions were observed, and no interactions with condition were observed.

In the frontal cluster, analysis did not reveal any memory effects. A main effect of condition was observed, *F*(4, 80) = 3.62, $p = .009$, $p\eta^2 = .153$. No significant differences between conditions emerged in follow-up analysis. No other main effects of or interactions with condition were observed in any of the windows.

Thus recognition effects emerged for the matching condition specific to the second window in the posterior cluster, and for the reappraisal condition across all windows in the central cluster (recognition effects were relative to the neutral new condition, and were not observed within emotion conditions).

Discussion

We examined school-age children's memory for emotional stimuli as a factor of manipulated arousal at the time of encoding. First, we evaluated the effect of the manipulation on children's experience of the emotional stimuli. Children's ERPs before the manipulation indicated main effects of emotion that replicates previous findings (e.g., Study 1, Hajcak & Dennis, 2009). Thus prior to the manipulation, the stimuli were experienced as emotional. ERP measures of the manipulation differed at the two time points tested, immediate and delayed. Immediately after the manipulation, ERPs largely differed for reappraised positive stimuli only (i.e., larger LPPs for reappraised positive stimuli versus neutral). After the delay, ERPs indicated emotion effects for matching negative stimuli at posterior and frontal clusters (i.e., larger LPPs for matching negative versus neutral stimuli), whereas ERPs to reappraised negative stimuli were reduced and did not elicit an emotion effect. Responses to positive stimuli did not differ by reappraisal condition, and general emotion effects, across manipulation conditions, were observed at the central cluster (i.e., larger LPPs to emotional stimuli). Children's ratings of the stimuli after the manipulation were unaffected by the reappraisal manipulation, but indicated general emotion effects.

Children demonstrated successful recognition memory in their ERP and behavioral responses. Behavioral performance differed within valence conditions such that for negative stimuli, recognition was significantly higher for matching than neutral stimuli, with recognition of reappraised stimuli falling in between. No differences by emotion or reappraisal were observed for positive stimuli. ERP measures of recognition indicated memory effects for matching negative stimuli across all clusters and windows, and for reappraised negative stimuli in the central cluster. For positive stimuli, recognition effects were observed for both matching and reappraised stimuli in the second window of the posterior cluster, and across all windows in the central cluster.

The findings demonstrate that reappraisal effects can be measured in children's ERPs. Specifically, we observed reduced emotion effects (i.e., smaller LPPs) for reappraised stimuli in the negative condition only, and only after a delay. The effect was not observed for positive stimuli at either time point tested. Rather, an unexpected effect of reappraisal was observed for positive stimuli, at the immediate test only, whereby LPPs were largest to reappraised positive stimuli and no other emotion effects were observed. The finding is not fully consistent with findings in the adult ERP emotion literature, and suggests that reappraisal may be an effortful process, especially for positive experiences (see Nelson & Monk, 2001, for discussion of positive slow-wave activity indicating continued processing). Taken together, the findings from each time point tested suggests that reappraisal is not immediately observable in children's ERPs, and that it is a prolonged cognitive effort. It is notable that the predicted effect of reappraisal was observed at the delay only, when the manipulation was not repeated, but a thing of the past. This suggests that the stimuli were encoded with a changed, reappraised, down-regulated meaning.

The effect of the reappraisal manipulation on the encoding of emotional stimuli was also observed in subsequent memory. Specifically, the enhancing effect of emotion on memory was reduced for reappraised negative stimuli, in both behavioral and ERP measures. Memory effects were not affected by the reappraisal manipulation for positive stimuli, and only in ERPs was enhanced memory for positive versus neutral stimuli observed. Thus the memory findings inform the primary question of the role of arousal on the enhancing effect of emotion on memory. Although we did not observe reduced arousal at encoding, emotion effects at the delay suggest that reappraised negative stimuli were less arousing than non-reappraised negative stimuli. Accordingly, memory for reappraised versus non-reappraised negative stimuli was reduced, in both brain and behavior. Further, we did not observe reducing effects of reappraisal for positive stimuli, and also did not observe reduced recognition of reappraised versus non-reappraised positive stimuli. Together, the findings highlight the role of arousal on the enhancing effects of emotion on memory performance. Reduced arousal via reappraisal decreases memory performance and the enhancing effect of emotion.

The present research elucidates the developmental status of emotional memory. Previous research (e.g., Study 1), indicates emerging emotion effects on memory by age 8, but effects that are not as robust as measured in adults. The finding calls to question the enhancing role of arousal on subsequent memory, since children show robust emotion effects that resemble those of adults. Here, by manipulating arousal, we demonstrate that reduced arousal appears to undermine the enhancing effect of emotion on memory. Thus the findings support the role of arousal in the emotional effect.

To date, the present research is the first to include examination of reappraisal of positive stimuli. Across ERP and behavioral measures, reappraisal did not affect emotion or memory effects, except in the case of the unexpected pattern of larger ERPs to reappraised positive stimuli immediately following the reappraisal manipulation. I speculate that the finding indicates effortful processing in the reappraisal of positive stimuli, and we consider further that it may be unusual and motivationally undesirable to reappraise positive experience. Thus the data suggest that reappraisal functions differently for negative and positive experience. Alternatively, the absence of predicted reappraisal effects for positive stimuli may be a function of the paradigm. Participants were not told to reduce feelings of emotion, but instead to think of a story that contained less emotional content. A more explicit reappraisal task might reveal different effects.

A limitation of the present research is that we did not have the opportunity to examine encoding as a function of subsequent memory performance (due to the low incidence of subsequent ‘miss’ trials). A test of this kind would permit direct examination of the role of arousal, as measured by LPP amplitude, on memory performance. Future research should modify the paradigm to increase the incidence of ‘miss’ trials, perhaps by increasing the delay between encoding and retrieval. A further limitation is that the sample only featured girls. Future research should extend the paradigm to boys to investigate possible gender differences.

The present research highlights the utility of including multiple measures to inform the research question. Specifically, the observation of reappraisal effects in ERPs, but not behavioral ratings, and emotion and reappraisal effects on memory sometimes in ERPs only (i.e. in the case of positive stimuli), emphasizes complementing traditional behavioral methods with neural measures such as ERPs to gain insight on processes such as emotional memory.

In sum, school-age girls demonstrate enhanced memory for emotional versus neutral stimuli. Further, the findings presented here implicate the role of arousal on the enhancing effect of emotion on memory: reduced arousal via reappraisal appears to result in lower levels of memory for negative stimuli. Further work should extend examination of the role of arousal on emotional memory to a broader developmental spectrum and boys to chart the developmental trajectory of the emotion effect.

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Footnotes

[1] Within the positive set, 22 pictures came from the IAPS and 35 came from the supplemental set. Within the neutral set, 20 came from the IAPS and 35 from the supplemental set. Within the negative set, 30 came from the IAPS and 32 from the supplemental set. *T*-tests were used to compare valence and arousal ratings on stimuli from the IAPS versus the supplemental set and did not reveal any significant differences on how the two sets were rated (all *p*s > .05).

[2] Mood ratings at Session 1 were available for 26 participants.

[3] Mood ratings at Session 2 were available for 24 participants.

[4] Mean trial counts (and standard deviations) at encoding by subsequent memory performance are as follows: negative matching hit = 3.87 (1.53), negative matching miss = 0.54 (1.05), negative reappraisal hit = 3.75 (1.77), negative reappraisal miss = 0.65 (1.43), neutral hit = 7.68 (2.23), neutral miss = 1.34 (1.14), positive matching hit = 3.84 (1.22), positive matching miss = 0.68 (0.68), positive reappraisal hit = 3.93 (1.67), and positive reappraisal miss = 0.63 (0.79).

Table 1. *Trial counts by condition for pre-manipulation, post-manipulation (immediate), and post-manipulation (delayed).*

Pre-manipulation	*M*	*SD*
Negative	23.26	4.70
Neutral	24.00	4.05
Positive	22.89	4.76
Post-manipulation (immediate)		
Negative matching	13.56	2.08
Negative reappraisal	13.74	2.40
Neutral	26.33	3.65
Positive matching	13.07	2.53
Positive reappraisal	13.00	2.25
Post-manipulation (delayed)		
Negative matching	7.86	1.96
Negative reappraisal	8.09	1.82
Neutral	16.27	3.68
Positive matching	8.27	1.83
Positive reappraisal	8.18	1.97

Table 2. *Trial counts by condition for recognition.*

Condition	*M*	*SD*
Negative matching	6.19	2.44
Negative reappraisal	6.00	2.83
Negative new	12.10	4.82
Neutral old	12.29	3.57
Neutral new	11.00	5.58
Positive matching	6.14	1.96
Positive reappraisal	6.29	2.67
Positive new	11.57	5.68

Table 3. *Descriptive statistics for pre-manipulation emotion effects in posterior, central, and frontal clusters (mean amplitude measure across and within each window).*

	All windows		First		Second		Third		Fourth	
Posterior	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Negative	1.85	3.16	-2.98	1.47	1.64	0.77	4.19	0.69	4.61	0.36
Neutral	0.49	2.42	-3.19	1.31	0.47	0.69	2.24	0.68	2.47	0.26
Positive	0.88	3.73	-4.80	1.37	0.55	1.14	3.29	0.68	4.53	0.54
Central										
Negative	-15.53	7.46	-26.81	3.31	-16.32	2.04	-10.50	1.25	-8.36	0.44
Neutral	-16.26	6.90	-26.83	3.24	-16.58	2.05	-11.56	1.14	-9.97	0.36
Positive	-15.38	8.11	-27.96	3.25	-15.57	2.55	-9.80	1.00	-8.06	0.56
Frontal										
Negative	-21.24	8.16	-33.23	2.33	-23.09	2.67	-15.94	1.37	-12.59	0.66
Neutral	-21.62	7.71	-33.33	2.39	-22.55	2.89	-16.14	1.06	-14.34	0.49
Positive	-19.88	9.06	-33.84	2.34	-20.74	3.26	-13.24	1.11	-11.54	0.46

Table 4. *Descriptive statistics for emotion effect post-manipulation (immediate) in central cluster (mean amplitude measure at each window, collapsed by hemisphere for first 3 windows, and left hemisphere only for fourth window).*

	First		Second		Third		Fourth (Left only)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Negative matching	-11.43	8.49	-3.14	6.20	-0.62	6.52	3.02	6.75
Negative reappraisal	-12.38	7.50	-4.57	6.48	-1.02	5.84	-0.08	7.33
Neutral	-13.33	7.92	-6.21	5.44	-2.36	5.60	0.37	5.59
Positive matching	-12.40	7.23	-3.95	6.09	-0.79	6.14	0.28	7.87
Positive reappraisal	-9.99	9.02	-1.65	7.31	1.18	7.11	4.32	7.57

Table 5. *Descriptive statistics for emotion effects post-manipulation (immediate) at frontal cluster (mean amplitude across windows and hemispheres).*

	M	*SD*
Negative matching	-5.91	8.47
Negative reappraisal	-6.75	8.02
Neutral	-7.90	7.47
Positive matching	-6.53	8.20
Positive reappraisal	-3.19	9.62

Table 6. *Descriptive statistics for emotion effect post-manipulation (delayed) at all clusters (mean amplitude collapsed over window and hemisphere).*

Posterior	M	SD
Negative matching	6.56	8.55
Negative reappraisal	4.22	7.49
Neutral	1.46	7.01
Positive matching	4.52	8.86
Positive reappraisal	4.60	8.89
Central		
Negative matching	-3.50	7.97
Negative reappraisal	-5.34	8.22
Neutral	-9.30	7.32
Positive matching	-4.10	9.35
Positive reappraisal	-3.99	10.20
Frontal		
Negative matching	-9.15	10.43
Negative reappraisal	-12.36	10.61
Neutral	-13.87	8.87
Positive matching	-9.72	11.33
Positive reappraisal	-9.32	11.41

Table 7. *Descriptive statistics for recognition effects in negative condition (mean amplitude measure by cluster).*

Posterior	*M*	*SD*
Negative matching	6.28	7.47
Negative reappraisal	3.57	6.90
Negative new	4.18	8.37
Neutral old	2.02	6.03
Neutral new	0.03	6.88
Central		
Negative matching	-3.45	5.47
Negative reappraisal	-5.84	7.95
Negative new	-5.13	9.61
Neutral old	2.02	6.03
Neutral new	0.03	6.88
Frontal		
Negative matching	-8.12	8.61
Negative reappraisal	-11.94	9.66
Negative new	-10.58	10.92
Neutral old	-12.96	7.82
Neutral new	-15.21	8.72

Table 8. *Descriptive statistics for mean amplitude measure in positive condition separated by cluster (windows reported separately for posterior cluster, and collapsed over window for central and frontal clusters).*

Posterior	First		Second		Third		Fourth	
	M	SD	M	SD	M	SD	M	SD
Positive matching	-1.15	8.93	5.53	6.60	6.67	6.86	5.94	12.24
Positive reappraisal	-0.35	10.82	6.04	7.99	6.80	8.81	7.65	8.49
Positive new	-2.81	10.36	5.43	9.05	6.21	8.66	4.50	7.79
Neutral old	-3.26	9.56	2.04	7.35	4.64	6.05	2.87	8.65
Neutral new	-4.20	9.60	-0.22	7.63	1.65	7.53	2.87	8.65

Central	All windows	
	M	SD
Positive matching	-4.21	7.84
Positive reappraisal	-2.88	9.93
Positive new	-5.93	8.33
Neutral old	-8.77	6.61

Neutral new	-10.96	8.55
Frontal	All windows	
	M	SD
Positive matching	-9.16	9.39
Positive reappraisal	-7.45	12.42
Positive new	-11.20	7.95
Neutral old	-12.96	7.82
Neutral new	-15.21	8.72

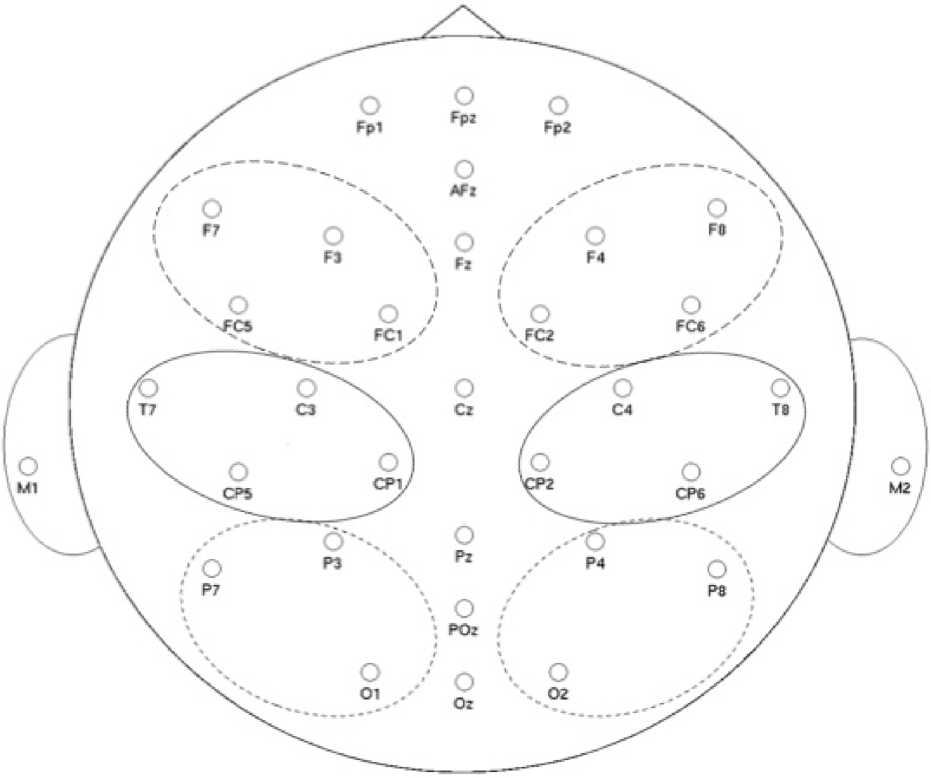


Figure 1. Depiction of electrode layout. Short dashes mark posterior clusters, solid lines mark central clusters, and long dashes mark frontal clusters.

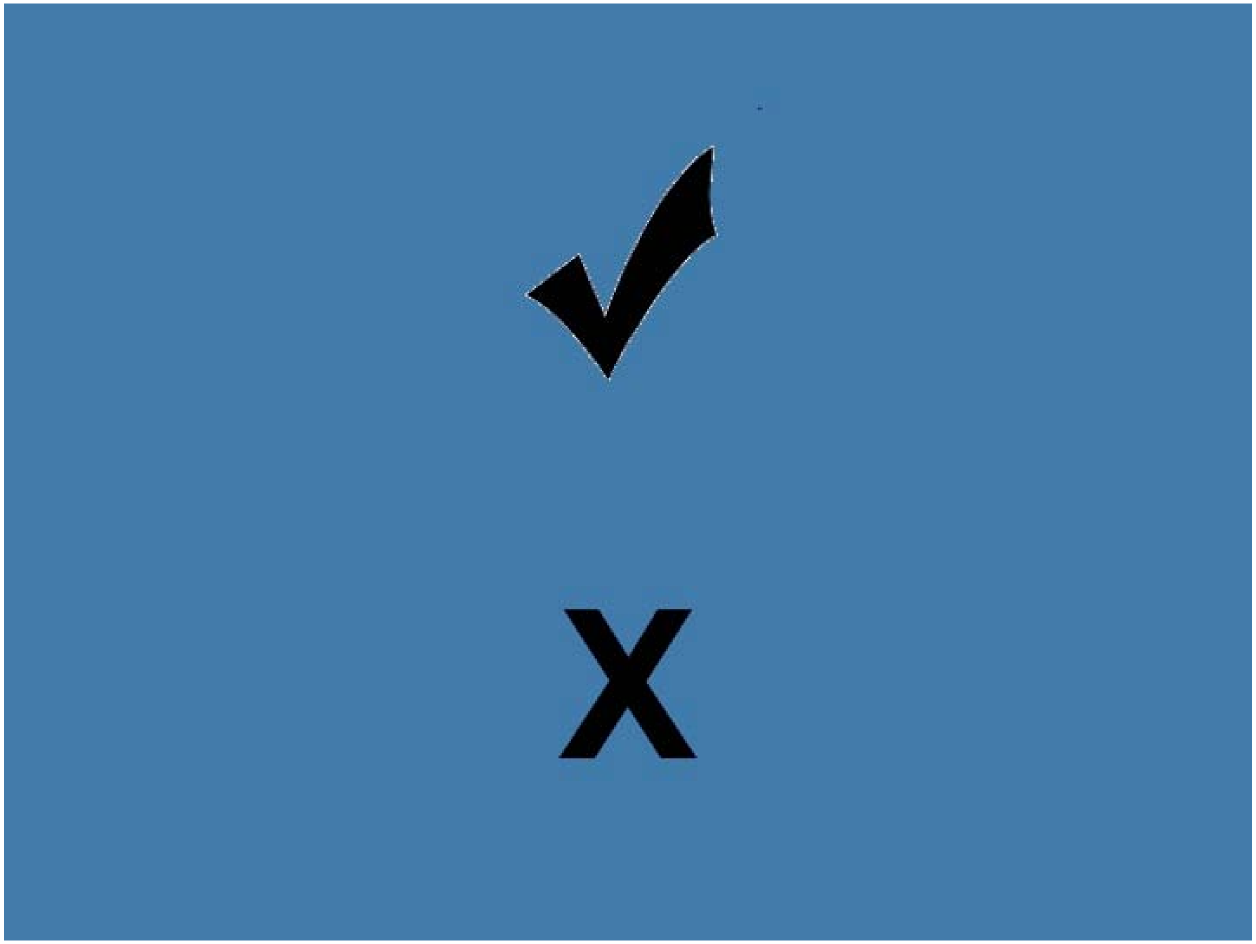


Figure 2. Depiction of old/new decision screen.

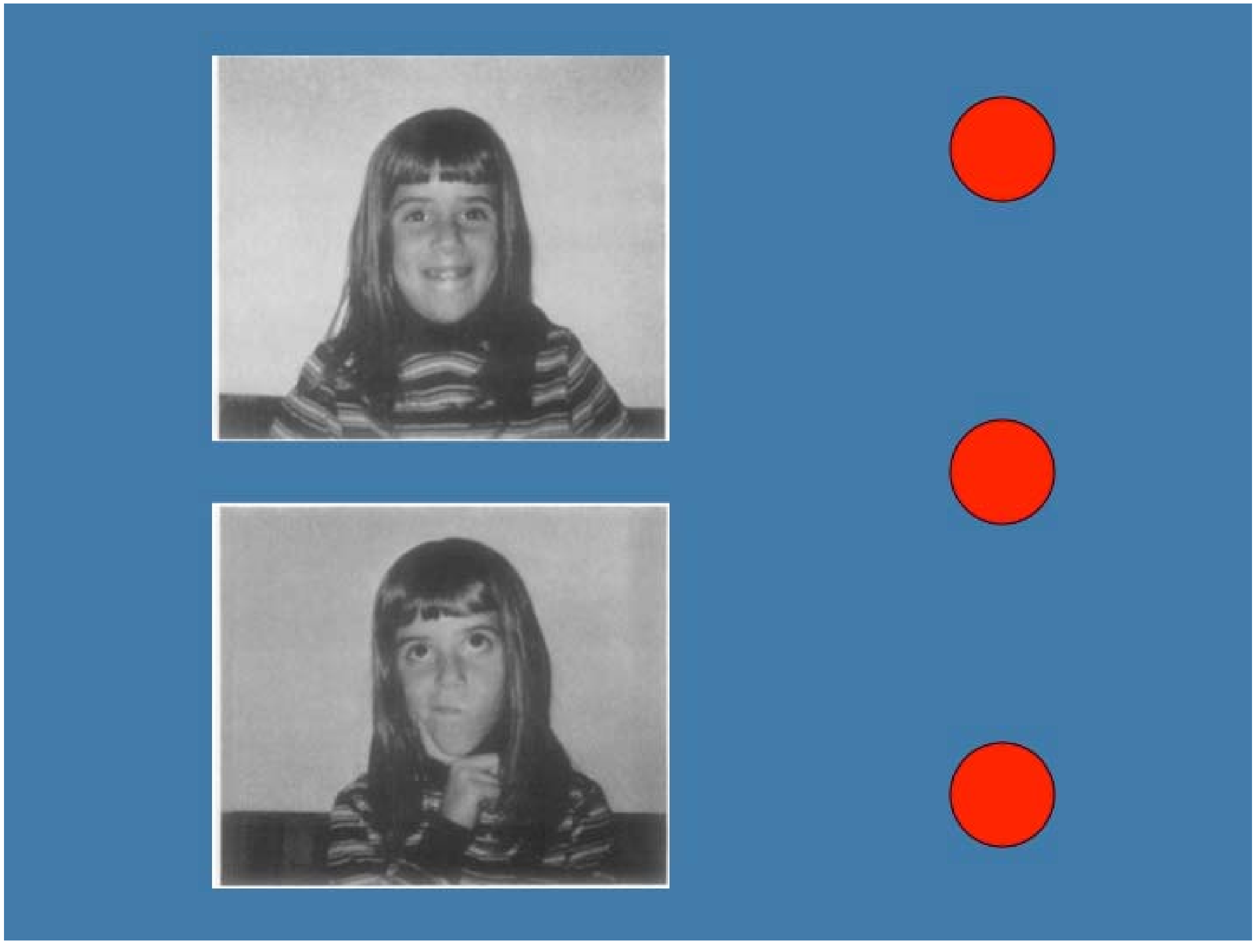
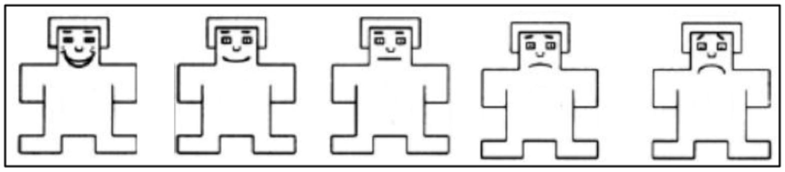


Figure 3. Depiction of confidence ratings screen.

a) Valence



b) Arousal

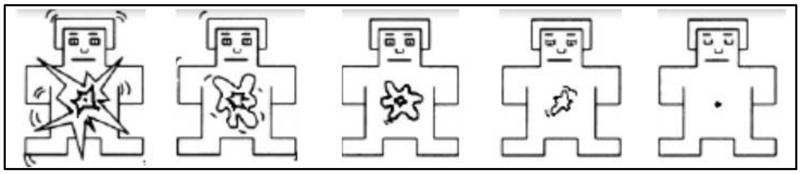
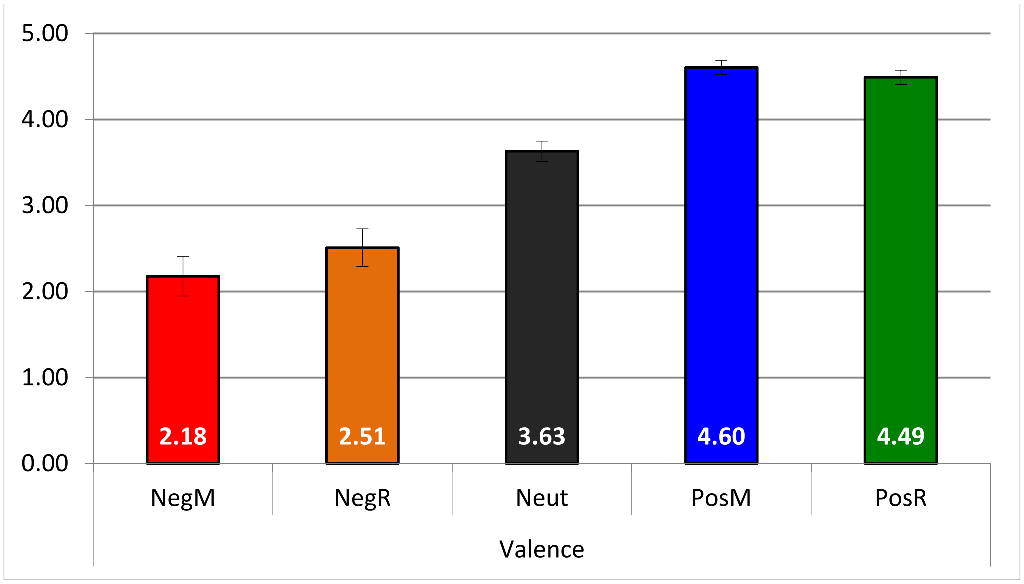


Figure 4. Depiction of Self-Assessment Manikin for rating a) valence and b) arousal.

a) Valence



b) Arousal

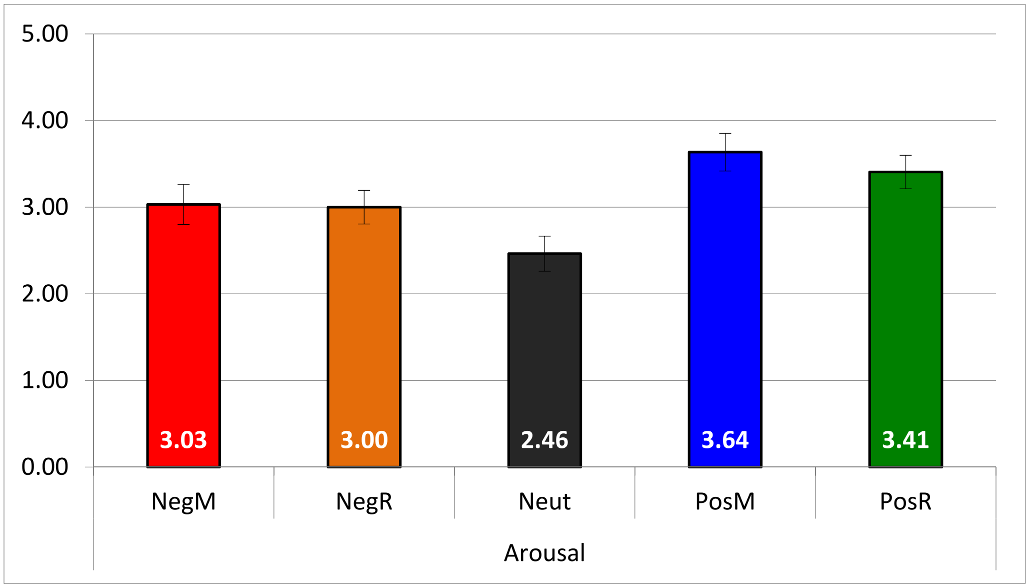
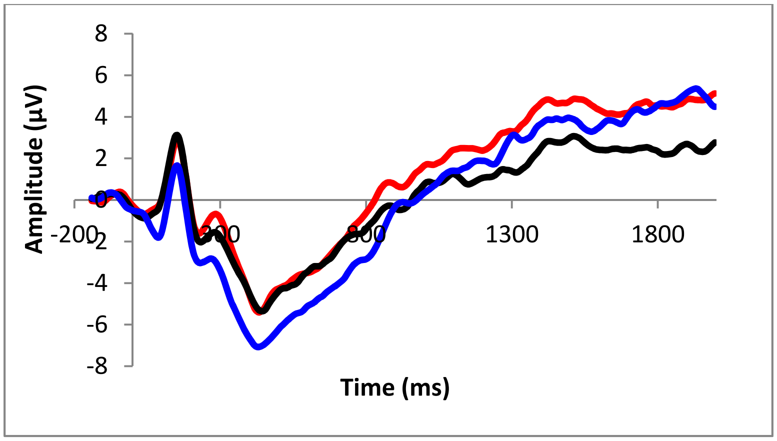
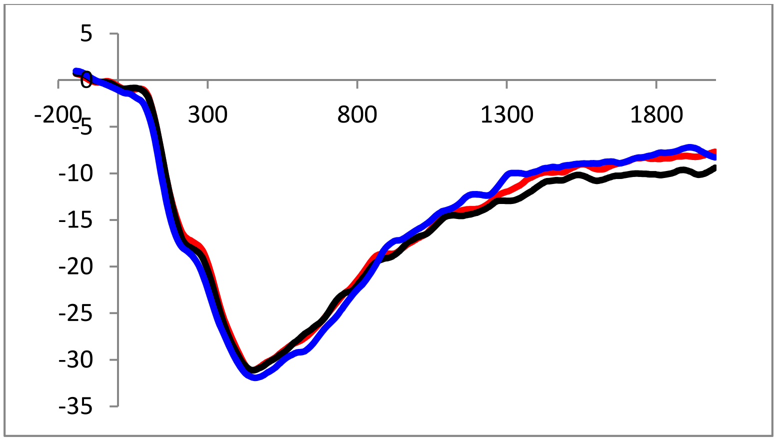


Figure 5. Participants' a) valence and b) arousal ratings from the SAM (error bars represent ± 1 standard error).

a) Posterior



b) Central



c) Frontal

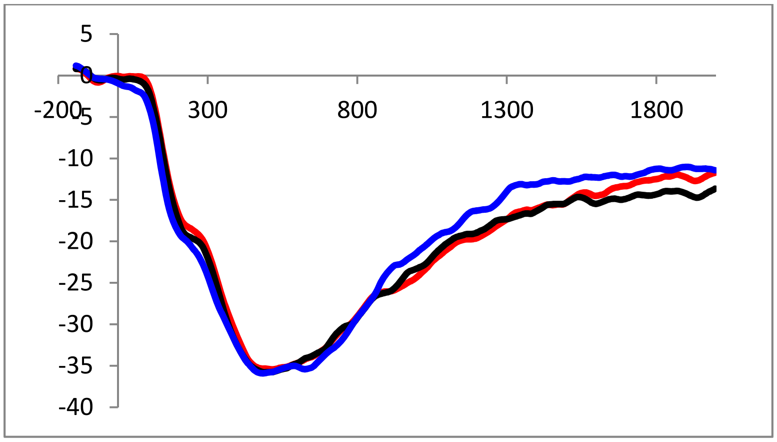
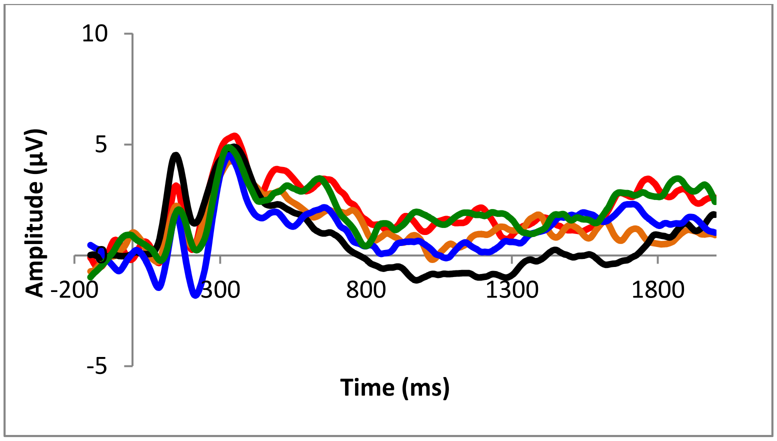
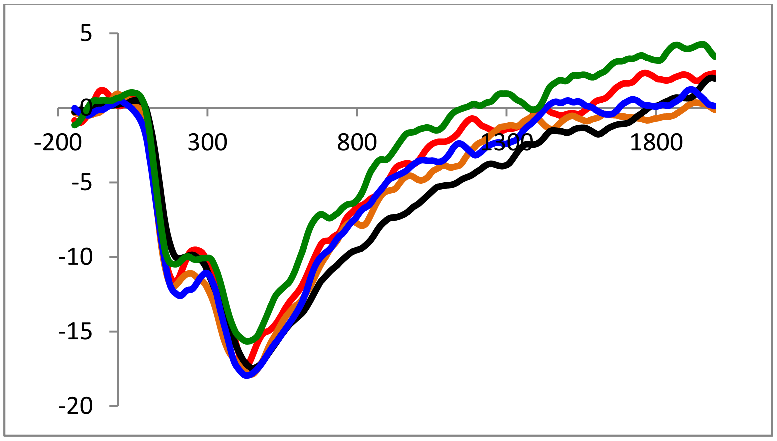


Figure 6. Waveforms plotted by cluster illustrating emotion effects pre-manipulation (posterior, central, frontal, in panels a, b, and c, respectively; red = negative, black = neutral old, blue = positive).

a) Posterior



b) Central



c) Frontal

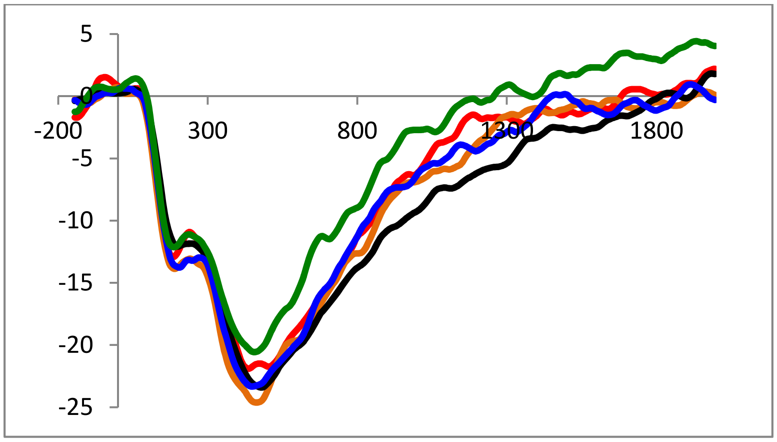
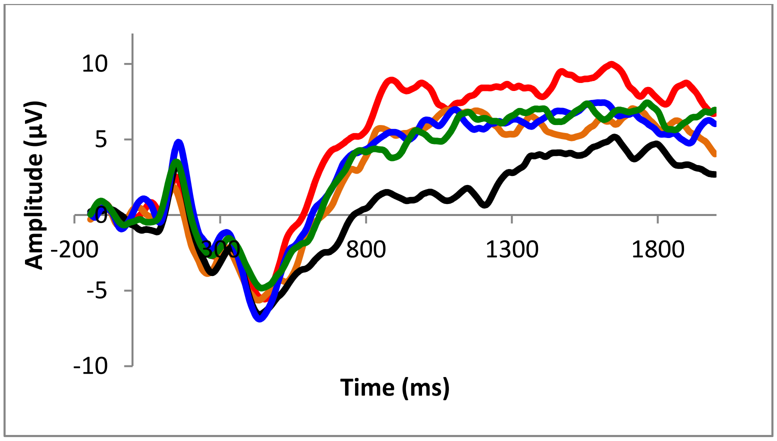
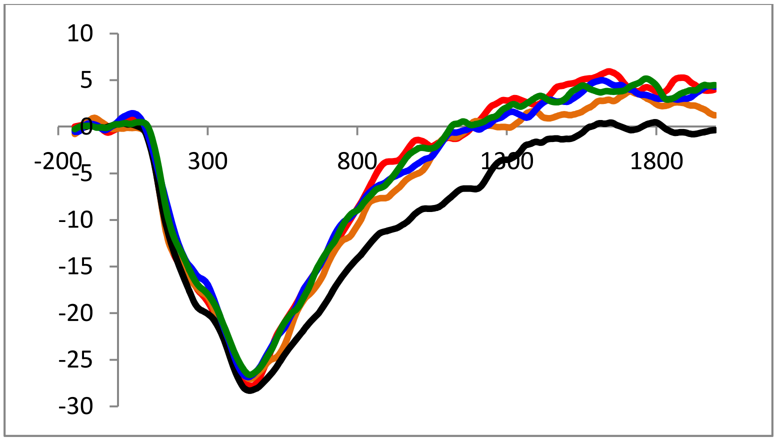


Figure 7. Waveforms plotted by cluster illustrating post-manipulation-immediate emotion effects (posterior, central, frontal, in panels a, b, and c, respectively; red = negative matching, orange = negative reappraisal, black = neutral old, blue = positive matching, green = positive reappraisal).

a) Posterior



b) Central



c) Frontal

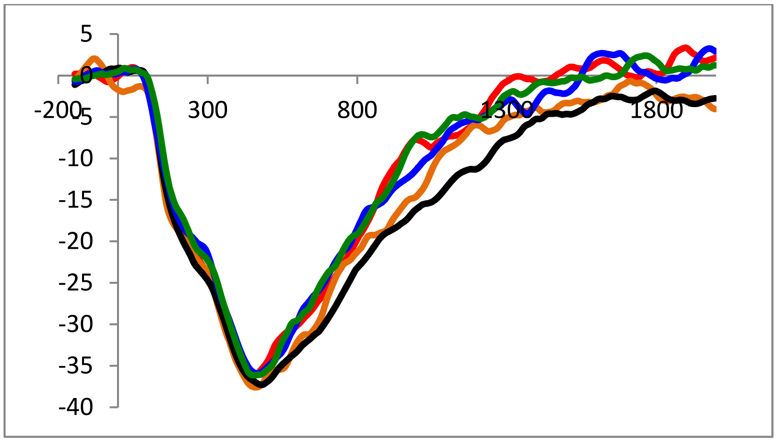


Figure 8. Waveforms plotted by cluster illustrating post-manipulation-delayed emotion effects (posterior, central, frontal, in panels a, b, and c, respectively; red = negative matching, orange = negative reappraisal, black = neutral old, blue = positive matching, green = positive reappraisal).

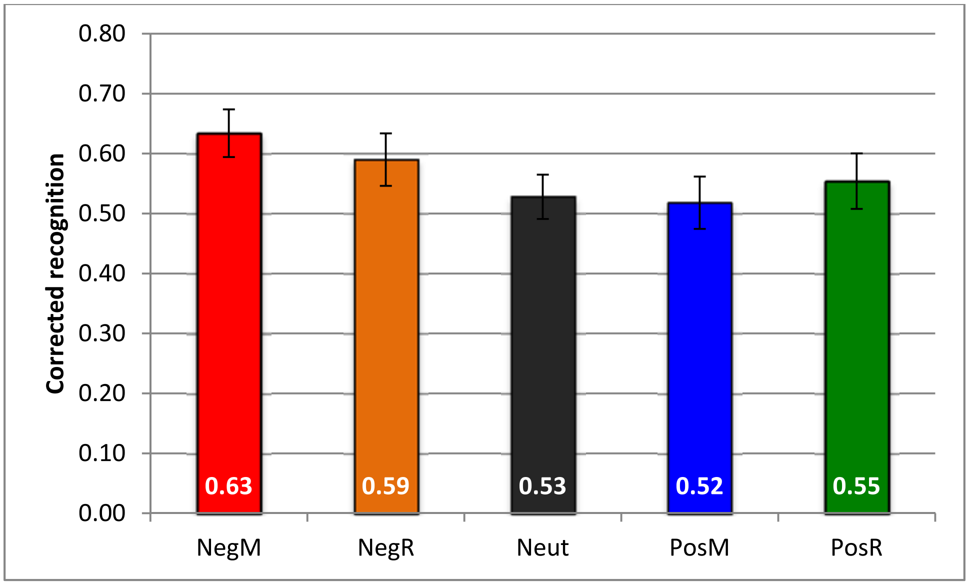
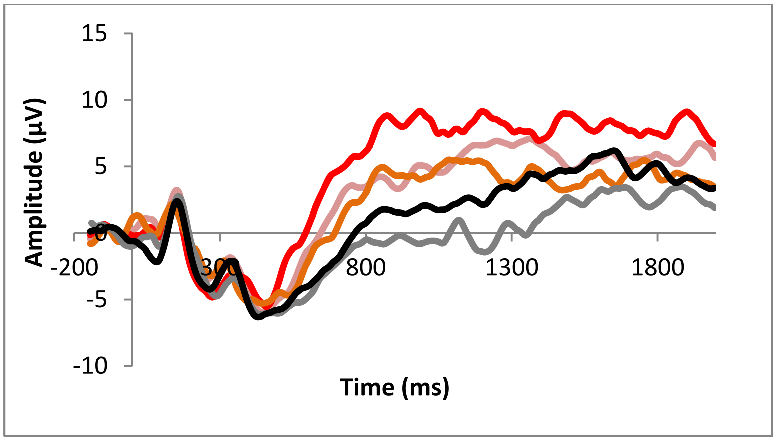
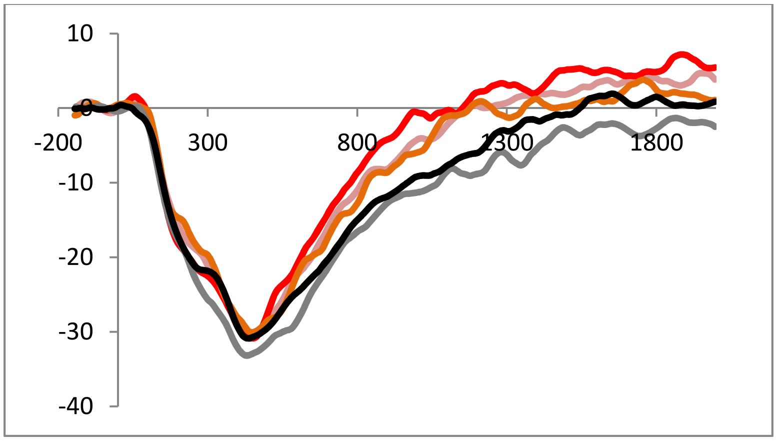


Figure 9. Participants' corrected recognition memory scores across all conditions (error bars represent ± 1 standard error).

a) Posterior



b) Central



c) Frontal

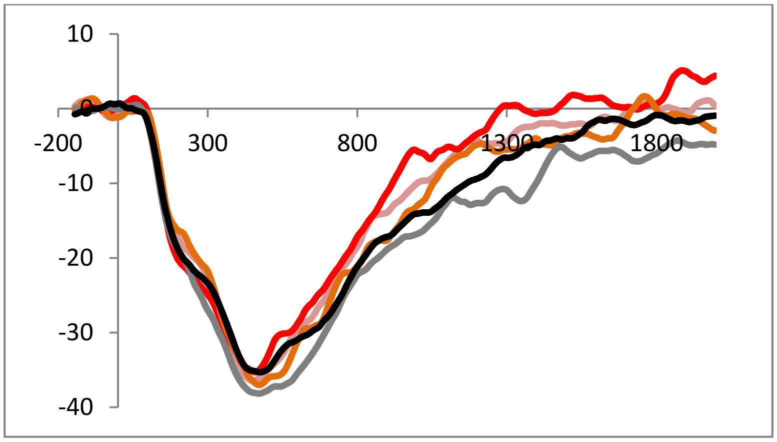
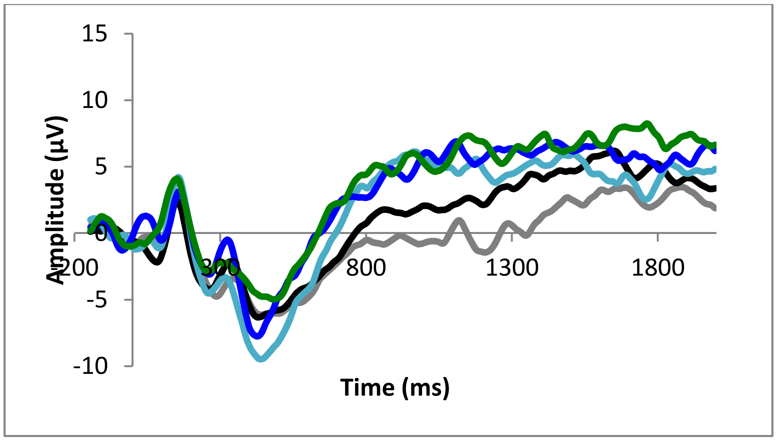
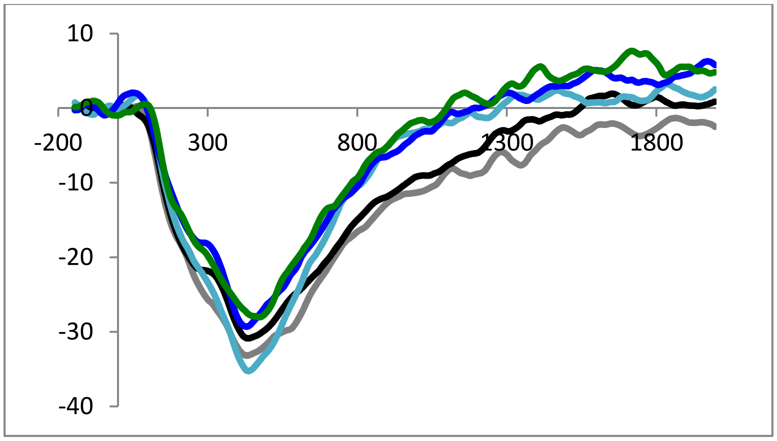


Figure 10. Waveforms plotted by cluster illustrating recognition data in the negative analysis (posterior, central, frontal, in panels a, b, and c, respectively; red = negative matching, orange = negative reappraisal, pink = negative new, black = neutral old, gray = neutral new).

a) Posterior



b) Central



c) Frontal

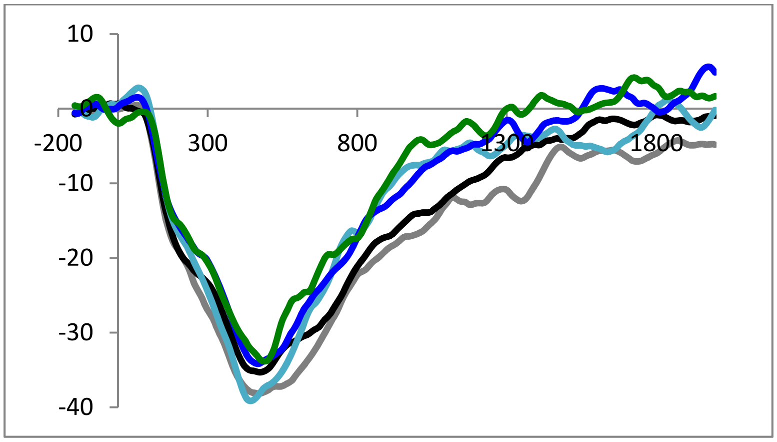


Figure 11. Waveforms plotted by cluster illustrating recognition data in the analysis of the positive condition (posterior, central, frontal, in panels a, b, and c, respectively; dark blue = positive matching, green = positive reappraisal, light blue = positive new, black = neutral old, gray = neutral new).

Appendix A

Narratives accompanying neutral images

Image	Neutral narrative
ZH01	This farmer is checking to see if the soil is dry to check that his plants are growing.
ZH02	This girl is reading a book for class before she has to go to work.
ZH03	These people are having a cup of tea on their work break.
ZH04	These people are leaving the train station to catch their bus.
ZH05	This girl is completing an assignment for her writing class.
ZH06	This man is looking up information about the electronics on display.
ZH07	These students are brainstorming for a school project.
ZH08	These people are looking at the plans for a building.
ZH09	This mailman is using a mail cart to deliver the mail in the city
ZH10	These people are bringing their groceries back to the car.
ZH11	This boy is watching the bike so nobody steals it.
ZH12	This family is waiting for the school bus to come.
ZH13	This man is trying to figure out how to get to the museum.
ZH14	This man is designing a machine on the computer.
ZH15	This woman is checking her mailbox to see if she got any letters.
ZH16	These people each have their own marble to hold.
ZH17	This woman is cooking dinner to serve at her restaurant.
ZH18	This bus gets crowded when people are on their way to work.
ZH19	This woman is reading a magazine while she waits at the doctor's office.

ZH20 These kids are picking out books to read from the bookshelf.

ZH21 These people are looking at the cacti plants in the greenhouse.

ZH22 This woman is picking up grapes from the grocery store.

ZH23 This person is moving their pawn in a game of chess.

ZH24 These people are shopping for supplies at a hardware store.

ZH25 This man is painting the telephone box red.

ZH26 This woman is on the phone taking a message for her boss.

ZN01 These boats are used to go fishing on the lake.

ZN02 These satellite dishes are used to get television signals.

ZN03 This restaurant is open all day and serves many different types of food.

ZN04 This green staircase leads to the bedrooms upstairs.

ZN05 This wooden structure is very strong and holds the roof up.

ZN06 These potatoes are being sold at the farmer's market.

ZN07 This garage has many useful tools for fixing cars and building furniture.

ZN08 This classroom is empty because school just ended.

ZN09 These school supplies belong to someone in middle school.

ZN10 This globe has a lot of the world's cities written on it.

ZN11 This bike rack has a few spots open for more bicycles.

ZN12 These train tracks lead to a very busy train station and sometimes all the tracks are full.

ZN13 These baskets are used to store fruits and vegetables, but they are empty right now.

ZN14 This bridge is being repaired, so no cars can drive on it yet.

ZN15 This sink was just cleaned and has towels, soap, and tissues next to it.

ZN16 This fence is used to keep small animals from leaving.

ZN17 This abacus is used to do math problems.

ZN18 This fax machine is used to send papers to other offices.

ZN19 These laptops are being used to edit photos.

ZN20 This toy plane was made from a kit and now it hangs from the ceiling.

ZN21 These carvings are part of very old ruins.

ZN22 This fence is to keep animals out of the garden where plants are grown.

ZN23 This bird is looking for bugs in the grassy meadow.

ZN24 These shells come in different shapes and sizes.

ZN25 These vases are made out of clay and are very old.

ZN26 This fire hydrant was just painted yellow so it's easier to see.

Narratives accompanying positive images

Image	Matching (positive narratives)	Reappraisal (neutral narratives)
PH01	These football players just won the championship and are celebrating their victory.	These football players just ran out of the locker room to begin warming up for the game.
PH02	These women are on vacation and met some friendly parrots.	There are a lot of parrots at the park and they like to climb on people.
PH03	This couple is going on a bike trip to celebrate their wedding anniversary.	This couple is biking through the park to get to work.

PH04	This skier is jumping to the finish and will win the race.	This skier is practicing for his race and is being careful not to fall.
PH05	This family is having a lot of fun on their rafting adventure.	The rafting trip is over and these people are heading back to the dock.
PH06	This man is dancing and is entertaining a lot of people.	This man has been dancing for a long time and people are starting to leave.
PH07	These students have finally graduated after many years of hard work.	These people are at singing at their weekly choir meeting.
PH08	This boy is amazed after seeing what his friend just learned to do.	These boys are practicing their drills before their dance lesson.
PH09	This baby is excited by the pretty lights flashing on the toy.	This baby is learning how to crawl on top of her blanket.
PH10	This baby is excited to play with a new toy.	This baby is trying to reach for a toy.
PH11	This couple is looking forward to getting married soon.	These people are waiting for their flight at the airport.
PH12	This couple is celebrating their baby girl's birthday with close family.	This couple is talking to their neighbors before going inside.
PH13	This girl just got a Dalmatian as a surprise from her father.	This girl is saying goodbye to her dog before she goes to school.
PH14	These kids are having a great time on their field trip to the beach.	These kids looked up when they heard a helicopter go by.
PH15	These athletes are proud of the medals	These athletes are stretching during

	they just won at the Olympics.	practice at the Olympics.
PH16	This man is enjoying the wind and the waves while windsurfing.	This lifeguard is on patrol in the ocean.
PH17	This boy is celebrating coming in first place in the race.	This boy got a ribbon for participating in the race.
PH18	These girls feel lucky to be so close to the Beluga whales.	These girls are studying the Beluga whales for a school project.
PH19	This person was the lucky winner of a sweepstakes for 400 dollars.	This person is holding fake dollars from a board game.
PH20	This basketball player just won the championship and is very happy.	This basketball player can't wait for the halftime show to end.
PH21	This girl is all dressed up and ready to lead the parade.	This girl is scratching the paint off her face because the parade is over.
PH22	These children are having fun with the puppies they just got at the fair.	These children are waiting to play at the park with their dogs.
PH23	These swimmers are celebrating after winning first place in the competition.	These swimmers are posing for a team photo.
PH24	These girls are having a lot of fun playing in the snow.	These girls want to go inside now after getting snow on their faces.
PH25	These boys are playing a soccer game and their team is winning.	These boys are learning how to play soccer.
PH26	These girls are making delicious lemonade to sell to their neighbors	This girl is making her sister drink the sour lemonade.

PN01	This dog is enjoying the breeze on a nice day.	This dog wishes he could move around outside of the car.
PN02	These beautiful kites are going to fly high in the festival.	These flags tell people where they are allowed to go on the beach.
PN03	These pretty flowers have just bloomed again because its springtime.	This house has many different kinds of trees in the yard.
PN04	This galaxy could be full of many different types of exciting life.	This is what our galaxy looks like from space.
PN05	This place is so pretty that pictures of it are on postcards.	This place is so cold that it is hard for any animals to live here.
PN06	This picture of Earth was taken by one of the very first astronauts on a space mission.	This picture shows the weather patterns on Earth.
PN07	This mother panda learned to feed her child milk from a bottle just like humans.	This mother panda doesn't know how to open the bottle.
PN08	This baby tiger can't wait to go for a ride.	This baby tiger is carefully waiting for food.
PN09	These elephants are helping each other clean one another.	These elephants are touching each other with their trunks.
PN10	This fruit was freshly picked from the farm.	This fruit is made out of plastic and is used to decorate a table.
PN11	This kitten is taking its first few steps.	This kitten can't find anything to eat yet.
PN12	This giraffe is the tallest one at the zoo;	This is the only giraffe at the local zoo.

	everyone likes to watch it.	
PN13	This chocolate tastes really good with the fresh strawberries.	These berries and chocolate were leftover from cooking breakfast.
PN14	This baby polar bear is warm because it is sleeping on its mom.	This baby polar bear is taking a nap.
PN15	This camel is glad that the sun has gone down so it can rest in the cool.	This camel stores water in its hump so it doesn't go thirsty when there's no water outside.
PN16	This koala is happy to be safe with its family.	This koala is looking for food to eat.
PN17	This is a tasty burger that was prepared by the best chef in town.	This burger is on a plate with a pickle and fries.
PN18	This bridge looks very pretty when it is lit up by the New Year's fireworks show.	This bridge is the only way to drive to the island on the other side.
PN19	This baby seal is digging a hole so it can keep itself warm and cozy.	This baby seal is trying to climb back up on the ice.
PN20	These cute puppies are at the park and ready to play.	These puppies are up for adoption at the animal shelter.
PN21	These shiny gold bars are worth thousands of dollars.	These gold bars are kept in a safe.
PN22	This snowman was made by kids who were happy to get the day off at school.	This snowman will eventually melt when it gets warmer.
PN23	These cupcakes are in all different flavors	These cupcakes have different types of

	and they all taste great.	food coloring.
PN24	These little foxes just met and are saying 'hi' to each other.	These foxes are eating their breakfast next to their cave.
PN25	This bird loves to perch on its friend the snowman.	This bird wants to eat the peanuts on the snowman's buttons.
PN26	This silly cat is trying to play the piano.	This cat is trying to smash a bug he spotted on the piano.

Narratives accompanying negative images

Image	Matching (negative narrative)	Reappraisal (neutral narrative)
NH01	This man is sad because his wife is very sick and will not get better.	This man's wife is starting to feel better and will be able to go home very soon.
NH02	This boy is very upset and sad because he found out that his pet ran away.	This boy's dad picked him up after he fell; he got scared, but is totally okay.
NH03	This girl is watching a scary movie and is afraid to watch.	This girl was watching TV but got tired and fell asleep.
NH04	All of these men are injured and some of them won't be able to walk again.	These men are waiting to see a doctor who will help them be able to walk again.
NH05	This soldier is sad because he and his friends were hurt in the war.	This soldier is so happy he is crying; the war is over and he is going home.

NH06	This was a very bad car accident; they're checking if the driver is ok.	This car was destroyed for a movie set; no one was inside.
NH07	This family is stuck in a flood and they are trying to get help.	This family is at the beach and they are waiting for a wave to come.
NH08	This boy just fell and scraped his knee.	This boy just woke up and he is yawning.
NH09	This is a dangerous fish with large, sharp teeth.	This is a fish at the market and cannot bite anyone.
NH10	There was a very heavy storm that flooded this man's house and his neighborhood.	A pipe broke in this man's house and he is emptying the water out the window.
NH11	This boy is having a cavity filled; he is in a lot of pain.	This boy is having his teeth cleaned; it feels funny but doesn't hurt.
NH12	This family is sad because their friend just passed away.	This couple is remembering all the good memories they had with their friend.
NH13	This car slipped off the road and is falling down the cliff.	This car is being safely pulled back onto the road.
NH14	These girls are being chased by a large hungry shark.	These girls just jumped off of their inflatable shark float.
NH15	These scary people are hiding in the dark.	These boys are wearing masks for a Halloween party.
NH16	These are yucky toes with fungus under the nails.	These toenails are about to be clipped and painted.

NH17	This woman is crying because her son was lost in the war.	This woman is upset about the war, but relieved that her son is ok.
NH18	These women are being hit by the policemen.	These women are being protected by the policemen's shields.
NH19	This man is about to eat a very poisonous sea animal.	This man is eating his favorite food and it is very tasty.
NH20	This boy is crying because his parents are fighting.	This boy just bumped his head and is holding an ice pack on it to feel better.
NH21	These girls played very badly and lost the soccer championship.	These girls are humming their team song for good luck before their soccer game.
NH22	These women are very angry about the election.	These women are full of emotions because the war is finally over.
NH23	This boy is very angry and frustrated because he is not allowed to play.	This boy is playing 'hide and seek' and is yelling 'ready or not here I come'.
NH24	These boys have to work in the factory and don't ever get to play.	These boys got to miss school and go to work with their dad for a day.
NH25	This man went to jail for biting people with his fangs.	This man dresses up like a tiger for a carnival show.
NH26	This bull is very angry and he is chasing after the man.	This man is challenging his lazy bull to a race.
NH27	This boy is sad because his father is leaving to go to another country.	This mother is holding the boy tight to keep him warm in the wintertime.
NH28	This building where many children	This structure was blown up on the set of

	went to school is burning down.	an action film.
NH29	This woman is upset because the fish are dying from a disease.	This woman is relieved that there are a lot of fish to eat this fishing season.
NH30	These men are very sad because one of them dropped the baton in the relay race.	These men are exhausted after finishing the very long race.
NH31	This girl is at the doctor who is about to give her a shot.	This girl just swallowed a piece of ice and it feels very cold in her tummy.
NN01	This is a poisonous snake that is very dangerous.	This is a snake that is completely harmless; it doesn't even have teeth.
NN02	This is a picture of Jaws, a shark that has eaten many people.	This is a trained shark whose keeper is feeding him a fish.
NN03	This cruel turtle is slowly torturing the worm before eating it.	This turtle picked up the worm she found on the ground.
NN04	This terrible storm has destroyed many people's homes.	This storm is dying away; it is harmless and everyone is safe.
NN05	These disgusting bugs are crawling all over the food and ruining it.	These bugs are eating the delicious leftover pizza.
NN06	This disgusting garbage is right on the side of the road and smells awful.	This trash is about to be recycled so that it doesn't harm the environment.
NN07	This car flipped over and the driver is stuck inside.	This old car is at the junkyard, and people can use its parts to fix their cars.
NN08	This is a wild, dangerous dog that	This dog just went to the dentist- look

	will attack anyone.	how clean her teeth are.
NN09	These are giant bugs that eat away at the foundations of houses.	These bugs are in a glass tank as part of an exhibit at the museum.
NN10	This moldy bread would make anyone who eats it sick.	This bread was baked with blue food-coloring, but it didn't mix properly.
NN11	This food that has been left out will attract a bunch of cockroaches.	These are the dishes that are leftover from dinner.
NN12	This was a terrible plane crash; people got badly hurt.	Luckily, everyone was okay after the plane crash.
NN13	This explosion happened suddenly; many people were badly burned.	This was the result of a wildfire; everyone was able to evacuate in time.
NN14	This building was rotting and completely fell apart; the family cannot live there anymore.	This old building was knocked down; everyone was happy to see it go.
NN15	These scary masks were made from the heads of fierce animals.	These beautiful masks were made by a skilled artist.
NN16	These dangerous baboons have very sharp teeth that they use to attack other animals.	These baboons are making calls to their children, telling them they have found food.
NN17	These dirty cockroaches were found in a person's bed.	These different kinds of insects are on display in a museum.
NN18	These seagulls are eating dangerous trash that will damage their	These seagulls have found a lot of good food that people have thrown out.

	stomachs.	
NN19	This ship is sinking and many people are drowning.	Another ship came just in time to save all these people; everyone will make it.
NN20	This dog will not be able to walk without limping.	This dog is making a quick recovery and will be able to play fetch soon.
NN21	These vicious fish are known to attack people bathing in rivers.	These fish will be enough to feed a hungry family.
NN22	This bear is hungry and might attack people.	This bear is on the endangered species list and is protected in a national wildlife reserve.
NN23	This house was wiped out by the hurricane, and its owners lost everything.	This house survived the storm because of how well it was constructed.
NN24	This jack-o-lantern is rotting away and covered in bugs.	This little jack-o-lantern was made from a baby pumpkin
NN25	This plane dumped poisonous pesticides and killed everything in the forest.	This plane is dropping water to put out the wild fire.
NN26	This bat bit someone and infected them with a deadly disease.	This bat stays in the cave most of the time and is harmless to humans.
NN27	This gross centipede is very slimy and is making a mess all over the desk.	This centipede is about to climb out the window to live outside

NN28	This strawberry has gone rotten and will make whoever eats it sick.	This strawberry can still be used for its seeds to grow more strawberries.
NN29	This dog is stronger than the other and will badly hurt it.	These dogs are playing with each other by the river.
NN30	This car is floating away in the flood with the driver inside.	This car will be able to drive again once the water drains.
NN31	This explosion was very large and destroyed many cities.	This explosion was part of a test; it happened in the middle of an empty field.

Appendix A

The dissertation proposal included a plan to examine encoding data by subsequent memory performance. Due to the low incidence of subsequent miss trials, across both studies, this analysis was not included in the manuscript proper. For the purpose of the dissertation, however, analysis of encoding responses by subsequent memory for Study 1 is reported below (the trial counts in Study 2 were far too few to attempt an informative analysis).

For the analysis of subsequent memory at encoding, there were 6 conditions: positive hit, positive miss, neutral hit, neutral miss, negative hit, and negative miss (where ‘hit’ and ‘miss’ were qualified by participants’ button presses at the recognition session, and the responses were used to sort encoding trials by subsequent hits and misses). To be included in analyses, participants were required to provide at least 5 clean trials in at least two of three ‘hit’ conditions. In the older group, seven participants were excluded from analyses due to experimental error (*n* = 6), or attrition after Session 1 (*n* = 1), thus a total of 15 participants were included in analysis. In the younger group, ten participants were excluded from analysis due to experimental error (*n* = 3), insufficient trial count (*n* = 4), excessive noise in EEG data (*n* = 2), or incompletion of the session (*n* = 1), thus a total of 14 participants were included in analysis. Mean trial counts (and *SD*s) for the older group are as follows: positive hit = 11.80 (4.43), positive miss = 1.93 (1.44), neutral hit = 12.13 (4.69), neutral miss = 1.87 (1.96), negative hit = 12.27 (5.40), and negative miss = 1.67 (1.84). And for the younger group: positive hit = 9.43 (3.88), positive miss = 2.93 (2.06), neutral hit = 7.57 (3.96), neutral miss = 4.36 (1.98), negative hit = 9.86 (3.21), and negative miss = 3.14 (2.14).

Results

To examine subsequent memory, or encoding success, we calculated a 4 (Window) x 2 (Memory: subsequent hit, subsequent miss) x 3 (Emotion) x 2 (Hemisphere) x 2 (Age) mixed ANOVA on the measure of mean amplitude in the 3 clusters (posterior, central, frontal). Waveforms for younger and older children are plotted in Figures 1 and 2, respectively (posterior, central, and frontal clusters plotted in Panels a, b, and c, respectively).

Posterior cluster. The interaction of window, memory, emotion, hemisphere, and age was observed, *F*(6, 162) = 2.87, *p* = .011, $p\eta^2$ = .096. Follow-up analysis was pursued by age group. In the younger group, there was a main effect of memory, *F*(1, 13) = 9.35, *p* = .009, $p\eta^2$ = .418, whereby the amplitude of subsequent hits was larger than subsequent misses (subsequent hit: *M* = 13.25 μV, *SD* = 9.05; subsequent miss: *M* = 8.05 μV, *SD* = 8.87). The effect was qualified by the interaction of memory, emotion, and hemisphere, *F*(2, 26) = 4.04, *p* = .030, $p\eta^2$ = .237. Follow-up analysis by hemisphere led to a main effect of memory in the left hemisphere only, *F*(1, 13) = 8.88, *p* = .011, $p\eta^2$ = .406, whereby responses to subsequent hits were larger than subsequent misses (subsequent hit: *M* = 10.67 μV, *SD* = 8.82; subsequent miss: *M* = 5.96 μV, *SD* = 8.54). No other effects or interactions involving memory were observed in the younger group.

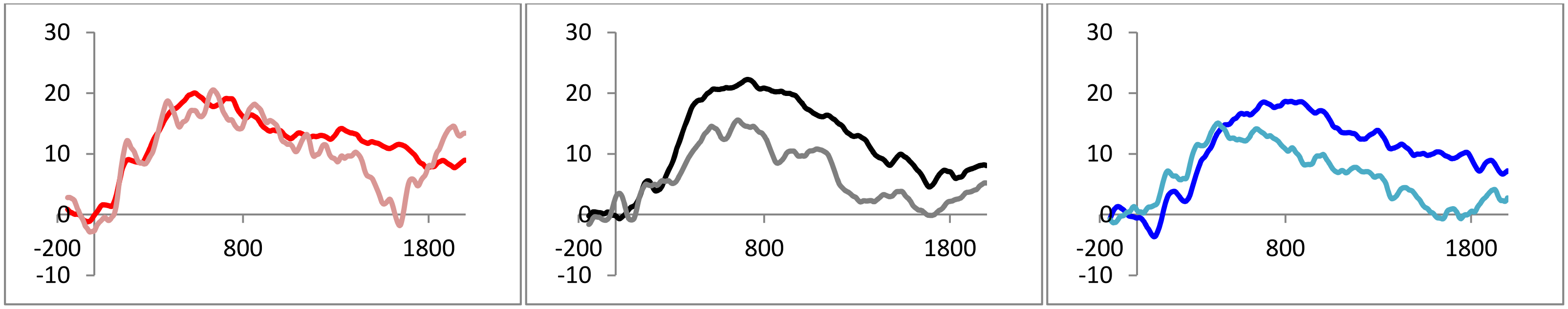
In the older group, the interaction of memory and emotion was observed, *F*(2, 28) = 5.90, *p* = .007, $p\eta^2$ = .296. Follow-up analysis by emotion condition indicated that the interaction was driven by a main effect of memory in the positive condition, *t*(14) = -2.16, *p* = .048, whereby the amplitude of subsequent misses was larger than subsequent hits (subsequent miss: *M* = 18.32 μV, *SD* = 9.84; subsequent hit: *M* = 11.48 μV, *SD* = 7.75). Memory effects were not observed in the other emotion conditions.

Central cluster. The interaction of window, memory, hemisphere, and age was observed, *F*(3, 81) = 2.72, *p* < .05, $p\eta^2$ = .091. Follow-up analysis in the younger group did not reveal significant memory effects. In the older group, a main effect of memory was observed, *F*(1, 14) = 4.47, *p* = .05, $p\eta^2$ = .242, whereby responses to subsequent misses were larger than subsequent hits (subsequent miss: *M* = 1.12μV, *SD* = 9.66; subsequent hit: *M* = -3.57μV, *SD* = 4.60). The effect was qualified by the interaction of window and memory, *F*(3, 42) = 7.02, *p* = .001, $p\eta^2$ = .334. Follow-up analysis by window indicated main effects of memory in the first and second windows only, *t*s(14) > 2.72, *p*s < .018. Responses in both windows were larger to subsequent misses than subsequent hits (first window: subsequent miss: *M* = -9.82μV, *SD* = 9.03; subsequent hit: *M* = -15.95μV, *SD* = 6.53; second window: subsequent miss: *M* = 4.64 μV, *SD* = 8.57; hit: *M* = -3.91 μV, *SD* = 4.30).

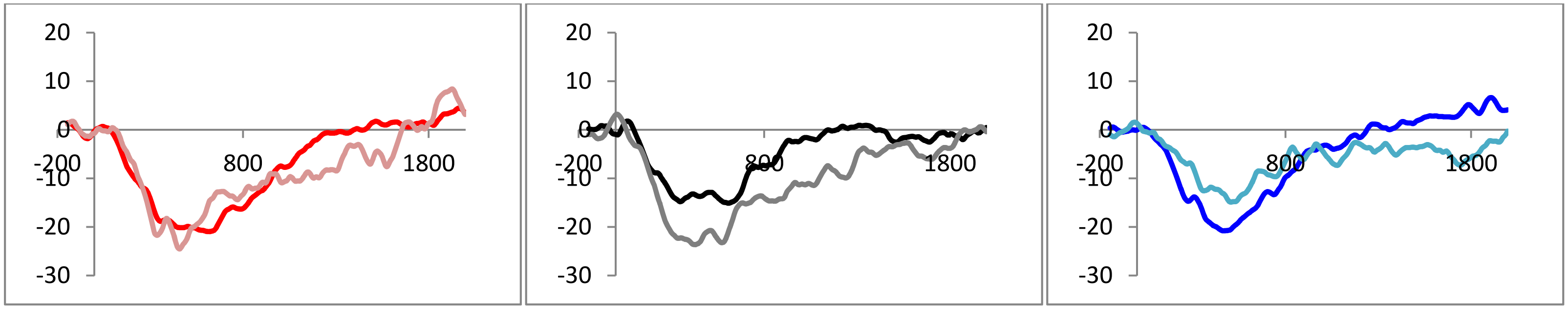
Frontal cluster. The interaction of window, memory, emotion, hemisphere, and age was observed, *F*(4.07, 109.79) = 2.62, *p* = .038, $p\eta^2$ = .088. Follow-up analysis in the younger group did not reveal significant memory effects. In the older group, follow-up analysis led to the interaction of window and memory, *F*(3, 42) = 5.04, *p* = .005, $p\eta^2$ = .265. Follow-up analysis revealed a main effect of memory in the second window only, *t*(14) = -2.98, *p* = .010, whereby responses to subsequent misses were larger than to subsequent hits (subsequent miss: *M* = -0.65 μV, *SD* = 10.23; subsequent hit: *M* = -9.45 μV, *SD* = 6.01).

Summary of subsequent memory effects. Generally, younger and older children showed different patterns of subsequent memory, whereby better encoding (subsequent hits relative to misses) was demonstrated by a more positive deflection in younger children, and a more negative deflection in older children. Both groups showed subsequent memory effects across all windows in the posterior cluster. In younger children the effect was observed across conditions, and focused on the left hemisphere only. And in older children, the effect was observed for the positive condition only. In the central and frontal clusters, subsequent memory effects were more robust for older children (some weak interactions that were not further examined were observed in the younger children). The memory effects in older children were observed across conditions, in the early two windows in the central cluster, and in the second window in the frontal cluster. However, strong caution is issued for interpreting memory effects, especially in the older group, given the low incidence of miss trials.

a) Posterior



b) Central



c) Frontal

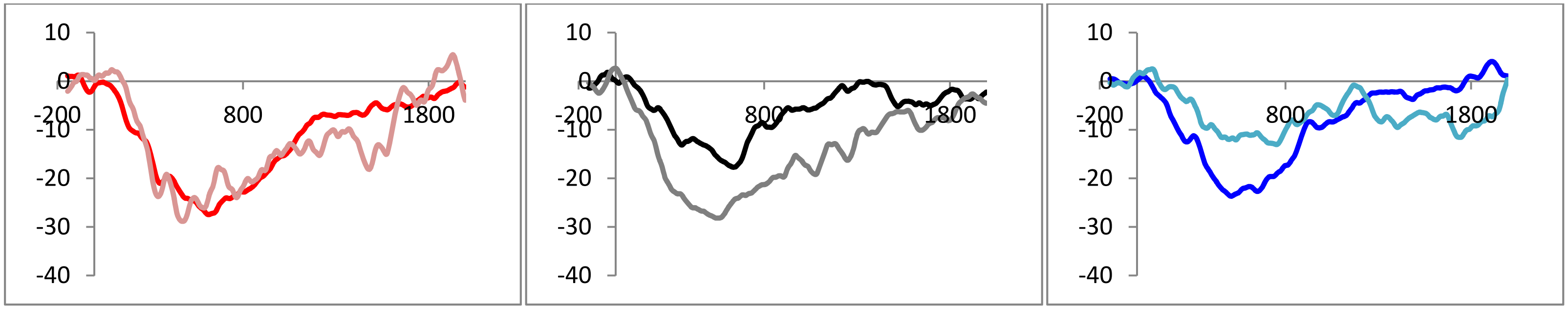
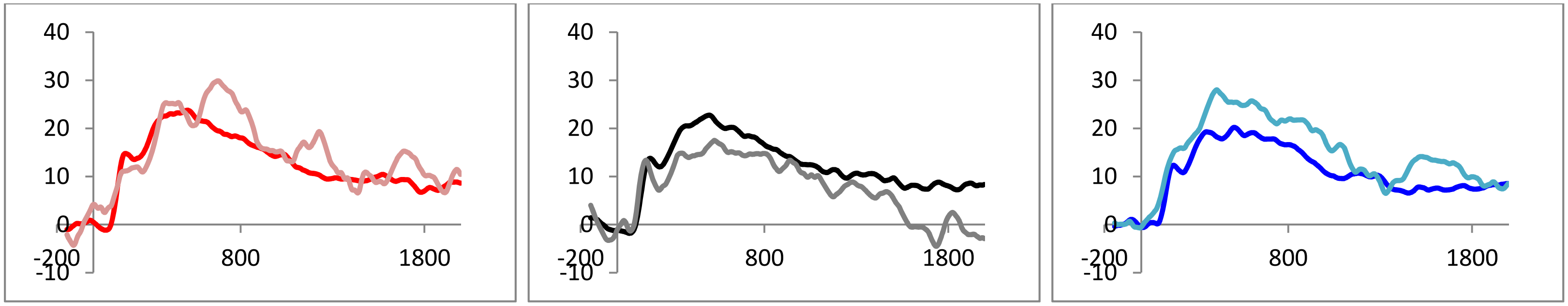
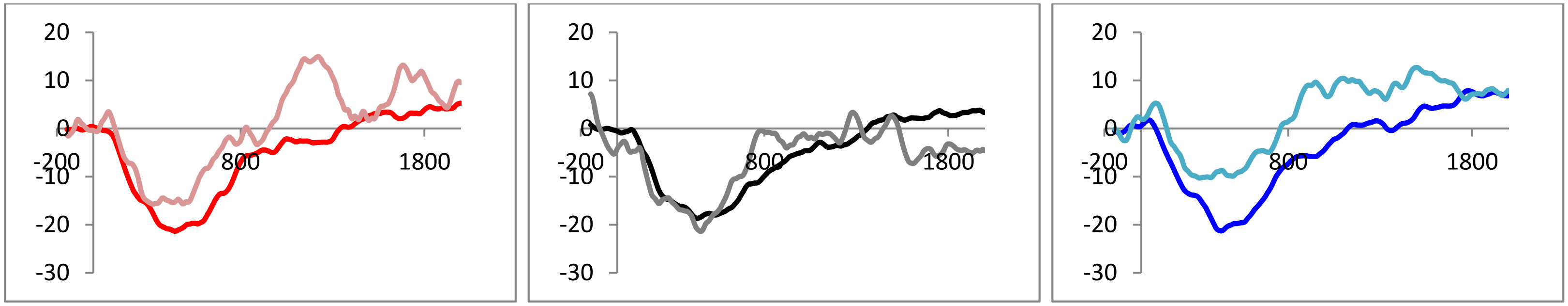


Figure 1. Grand averaged waveforms at encoding representing subsequent memory from younger participants at posterior, central, and frontal clusters, panels a, b, and c, respectively (positive is plotted in blue, neutral in black, and negative in red; ‘hit’ is in darker shades, ‘miss’ in lighter shades).

a) Posterior



b) Central



c) Frontal

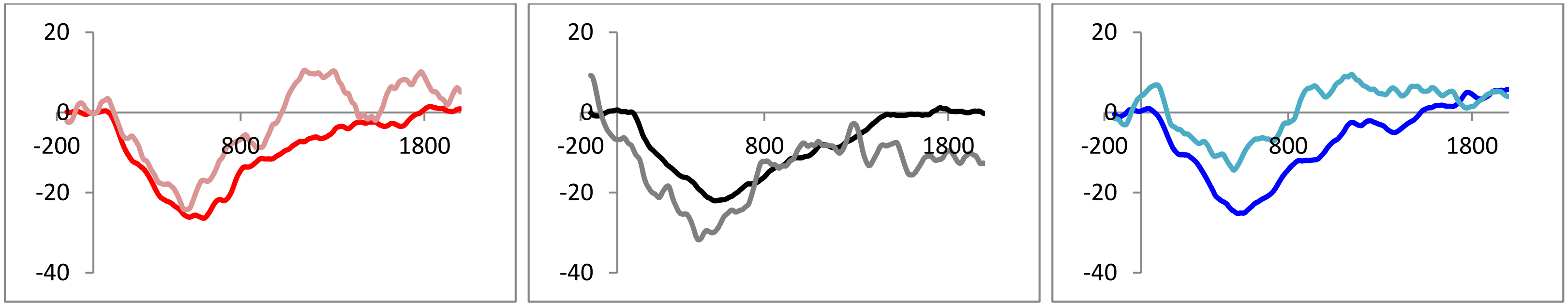


Figure 2. Grand averaged waveforms at encoding representing subsequent memory from older participants at posterior, central, and frontal clusters, panels a, b, and c, respectively (positive is plotted in blue, neutral in black, and negative in red; ‘hit’ is in darker shades, ‘miss’ in lighter shades).

General Discussion

In this dissertation, I examined children’s memory for emotion stimuli as a function of two factors: individual differences in temperament and depressive symptomatology (Study 1), and manipulated arousal at the time of encoding (Study 2). The research was designed to address three main questions: What is the status of emotional memory in school-age children?, What is the role of individual differences, related to temperament and depression, on emotional memory?, and What is the role of arousal on emotional memory?. Findings from the two studies reported here address these three questions.

Findings from Study 1 indicate that emotion effects on memory emerge during the school-age years. Specifically, ERP indices of recognition memory revealed emotion effects on memory in older children (ages 7.5 -8), whereas no differences by emotion were observed in younger children (ages 5-7.5). The emotion effect in older children was specific to negative stimuli. Children’s behavioral recognition performance did not significantly differ by emotion, but qualitative examination of the data suggest better memory for negative than positive stimuli among older children (mean differences by condition in younger children were smaller and not interpreted). Thus by age 8, children begin to demonstrate emotion effects on memory, but the pattern is not adult-like where in behavior and ERPs, recognition is stronger for both negative and positive emotional stimuli versus neutral.

The observation of emerging emotion effects on memory in older children, and absence of evidence in younger children suggests that emotion and memory processes are less tightly connected in children. This conclusion is further substantiated by the observation of adult-like emotion effects at the time of encoding (i.e., larger LPPs to emotional vs. neutral stimuli) and adult-like ratings of the stimuli (i.e., emotional stimuli rated as more emotional and arousing than neutral stimuli), indicating that children experienced the emotional stimuli as emotionally arousing. The enhancing effect of emotion on memory in adults has been attributed to emotional arousal at the time of encoding, yet even though children in this study experienced the stimuli as emotionally arousing, recognition memory was minimally affected by emotion. In response to this, I offer two conclusions. First, as mentioned above, emotion and memory processes are less tightly connected in children than in adults. Children certainly experience emotion from an early age, however the findings presented here suggest that—at least as tested here--emotional experience does not carry a privileged status in memory processes until middle childhood. Rather, emotion effects may be limited to the initial experience of emotion, which is not differentially encoded into the memory process. Alternatively, a different conclusion may be that the paradigm tested here did not allow for the opportunity for emotion effects on memory to be expressed. Specifically, we tested recognition memory after a 24-hour delay. It is possible that a recognition paradigm (as opposed to a recall paradigm which puts greater demands on retrieval processes) was not a strong enough test to detect emotion as a variant of memory strength. Further, the brief delay of only 24-hours might not have been sufficient to allow consolidation processes to enhance emotion effects on subsequent memory (e.g., Hamann, 2001). Thus further work examining consolidation and retrieval processes remains to be done to further elucidate the status of emotional memory in school-age children.

In Study 1, I explored the possibility that individual differences in the experience of emotion may be obscured by group patterns of emotional memory. The question was initially motivated by observation of enhanced memory for negative events in cases of depression (e.g., Lappanen, 2006), which suggested that individual differences in the experience of emotion at encoding, due to reactivity and regulation of emotion, may relate to subsequent memory. Thus individual differences in depressive symptomatology were explored, as well as individual differences in temperament, which may be a developmentally foundation component to the emergence of mood disorders, such as depression (e.g., Clark et al., 1994). Findings indicated that more parent-reported withdrawn/depressed behaviors was associated with a stronger ERP recognition response to positive stimuli and a reduced recognition response to negative stimuli (relations with anxious/depressed behaviors and temperament were generally not observed). The pattern observed here was opposite that observed in adults in previous research (enhanced memory for negative events, whereas we observed reduced memory for negative events and enhanced memory for positive events). It is unclear why such differences emerged, but one possible explanation is differences in measurement. The adult pattern of emotional memory and depression has been illustrated in behavioral measures, but yet to be tested in an ERP paradigm. We observed no relations with depressive symptomatology and behavioral recognition; it was only in the ERP measures that relations were apparent. Further, we tested the question in a non-clinical sample of school-age children, and it is possible that there exists a more nuanced pattern of depression and emotional memory when a full spectrum of healthy and depressed individuals is considered. Nonetheless, it is notable that these relations were observed in our sample, given that it was a community sample with mostly sub-clinical levels of depression and other psychopathologies (as measured by the CBCL). Thus it is clear that individual differences within a healthy spectrum of emotion processing may underlie group patterns in emotional memory.

In Study 2, I examined the role of arousal on the enhancing effect of emotion on subsequent memory. The question was tested in 8-year-old girls since findings from Study 1 indicated that emotion effects on memory begin to emerge by age 8 (and the focus on girls was due to the study being part of a larger ongoing study in the lab, with the restriction to girls to limit a prolonged data collection period). I used a reappraisal paradigm to manipulate arousal with the motivation that reappraisal should down-regulate and reduce emotional arousal. This is exactly what was observed in the case of negative stimuli, but not positive. That is, reappraisal reduced emotion responses as measured by ERPs, for negative stimuli only. Further, the effect extended to ERP and behavioral measures of memory, whereby recognition memory was reduced for reappraised versus non-reappraised negative stimuli. Reappraisal did not affect memory for positive stimuli, but memory for all positive stimuli was stronger than for neutral stimuli. Thus the findings support the role of arousal in explaining the enhancing effect of emotion on subsequent memory.

Further, the findings from Study 2 clarify the findings and conclusions from Study 1, which questioned the connection of emotional experience at encoding with subsequent memory processes. Together, the findings suggest that there is a developmental emergence of connecting emotion and memory processes in the school-age years. Specifically, the lack of an emotion effect on memory in children under 7.5

years suggests some isolation of initial emotional experience from subsequent memory processing, whereas the emergence of emotion effects in children older than 7.5 and the weakening effect of reduced arousal in 8-year-olds indicates some level of integration of emotion and memory processes in middle childhood. Thus the school-age years appears to be a ripe period for the integration of emotion and memory processes, whereby the adult-like emotion effect on memory begins to emerge.

The findings motivate several directions for future research. Firstly, the absence of emotion effects on memory, in both behavior and ERPs, in children under 7.5 years is notable. Are emotion and memory processes truly separate in young school-age children? This is a strong and possibly premature conclusion. Emotional memory was tested in a recognition memory paradigm after a delay of only 24 hours, thus it is possible that not enough forgetting occurred to detect emotion effects (assuming forgetting would be faster for neutral versus emotional stimuli). In future research, memory could be tested after a longer delay, and in a recall format, thereby putting greater demands on the memory system that might uncover enhancing effects of emotion. Another remaining question raised by the current findings has to do with the role of reappraisal on subsequent memory. Findings from the present research suggested that reappraisal of negative experience reduces subsequent memory. The finding is opposite that predicted by theories of emotion regulation (e.g., Gross, 2002), whereby reappraisal is an adaptive emotion regulation strategy that changes emotional experience and behavioral expression early on in the emotion process, and does not necessitate costly self-regulation efforts, thus leaving memory intact. It is possible that reappraisal, a cognitive emotion regulation strategy, *is* costly—at least in children— and this is why memory was reduced. Or, returning to the original conclusion, the change in emotional experience due to reappraisal, that is, reduced arousal at encoding, reduces the enhancing effect of emotion on subsequent memory of negative events without involving cognitive processes to blame for poorer encoding or retrieval (Gross's argument for impairing effects by emotion regulation strategies). The ERP findings are in line with the latter conclusion, suggesting reduced arousal due to reappraisal (as opposed to increased cognitive efforts). Future research should continue to examine the effect of reappraisal and other arousal-reducing emotional regulation strategies on memory in other samples, for both negative and positive stimuli, extending to boys, adolescents, and adults to clarify the role of arousal on the enhancing effect of emotion on subsequent memory.

Finally, there remains the question of how memory for experimentally-controlled emotional stimuli relates to memory for personally experienced emotional events. Both stimuli involve emotion processes, but personal or autobiographical events involve additional processes and systems, such as the self and meaning-making. Future research should examine memory for both kinds of emotional stimuli within the same individual to decipher the shared components and make informed predictions about personally experienced emotional events from findings on experimental stimuli when the stimuli permit different kinds of investigation. Such research will advance our understanding of emotional memory processes, and elucidate healthy emotion processing.

There were a few limitations in the present research. Firstly, we did not have the opportunity to examine encoding as a function of subsequent memory performance (due to the low incidence of subsequent 'miss' trials. A test of this kind would permit direct examination of the role of arousal, as measured by LPP amplitude, on memory performance. Future research should modify the paradigm to increase the incidence of ’miss’ trials, perhaps by increasing the delay between encoding and retrieval. Secondly, it remains unclear how the findings with pictorial representations of emotional events is generalizable to processing and subsequent memory for personally experience emotional events (i.e., autobiographical experiences). Future research should include both kinds of stimuli (i.e., pictorial and personal emotional events) to examine the overlapping components of processing different kinds of emotional events and memories. Lastly, Study 2 tested only girls and future research remains to be done to test if the effects extend to boys as well.

The current research furthers our understanding of the status of emotional memory in school-age children. Most of the extant literature on children’s emotional memory has focused on personally experienced emotional events, often unique or stressful events, and has demonstrated that children as young as 3 are capable of remembering such events. The stimuli included here featured more commonplace emotional events depicted in scenes, such as a gross bug or a cute baby, and findings complement the existing literature demonstrating that children remember emotional events, and add that emotional arousal may drive enhanced memory for negative emotional events by middle childhood. The data further suggest that individual differences in emotion processing (i.e., related to depressive symptomatology), may relate to emotional memory, and may be clouded by group analysis. Further research should continue to examine these questions in a broader spectrum of ages and emotional well-being to chart the developmental trajectory of emotional memory.

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