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Developmental continuity in emotion effects on memory: Evidence from behavior and event-related potentials

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An abstract of
A dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in Psychology
2017

Abstract

Emotion has powerful effects on memory, and emotional memories can impact individuals' well being both in the present moment and over time. These emotional memory enhancement (EME) effects have been studied extensively in adults, but much less is known about EME across development. In the present research, we examined the developmental trajectory of emotion effects on recognition memory between middle childhood and adulthood (8-30 years), using the same stimuli, paradigm, and analyses for all participants, in order to make direct comparisons of EME effects across this age range and between genders. In Paper 1, we examined a) the magnitude of EME effects for negative and positive versus neutral pictures across the age range and between genders, and b) whether age or gender impacted participants' subjective ratings of the pictures or their mood over the course of the study. In Paper 2, we employed event-related potentials (ERPs) to assess the neural activity elicited by processing emotional and neutral pictures, and tested for age and gender difference in the ERPs elicited by negative, neutral, and positive pictures during memory encoding. In Paper 3, we again utilized ERPs to examine emotion effects, this time on neural activity elicited during a recognition memory test. Together, the results reported in these papers suggest that there is remarkable consistency in how emotion impacts both processing of and memory for pictures between genders and across the developmental window spanning middle childhood through adulthood.

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General Introduction

Emotion is a powerful psychological force. The wellbeing of individuals from moment-to-moment and across time is profoundly impacted by their emotions and by their memory for past emotional events. Beyond the present moment, memories of emotional experiences can reverberate for a lifetime. Emotion acts from cellular to phenomenological levels to influence cognition and behavior. It can be elicited by ‘bottom-up’ triggers, such as percepts (e.g., the sight of snake) or pharmacological manipulations (e.g., the pleasant effects of alcohol), as well as by ‘top-down’ cognitive processes, including thoughts (e.g., imagining a vacation) and memories (e.g., of a car crash or first kiss). In short, emotions emerge from different sources and unfold across physiology, brain activity, cognition, and behavior. This complexity is amplified by changes in emotion processing over the course of human development. Some of these changes result from physical development (e.g., hormonal levels and brain development), whereas others follow from experience (e.g., learning emotion regulation techniques or experiencing trauma) (for reviews see, e.g., Carver, 2014; Fivush, 2011; Hamann & Stevens, 2014; Hyde, Mezulis, & Abramson, 2008). Thus, emotion is ubiquitous, but not static, across the lifespan.

There has been substantial progress in understanding how adults process and remember emotional events. At present, however, accounts of how emotion processing and memory changes during development are limited. Emotion impacts memory formation, consolidation, and retrieval (for reviews see, e.g., LaBar & Cabeza, 2006; Roozendaal & McGaugh, 2011; Talmi, 2013). Thus, the study of emotion and memory are inextricably linked. Their relation has been studied extensively (e.g., James, 1894;

LeDoux, 1993). Much of the adult literature has investigated how emotion at encoding impacts the way in which an item or event is later remembered (e.g., Anderson, Wais, & Gabrieli, 2006; Dolan, Lane, Chua, & Fletcher, 2000; Kensinger & Corkin, 2003; for reviews see, e.g., Kensinger & Schacter, 2008; Talmi, 2013). These studies have consistently found that emotion enhances subsequent memory; this phenomenon is referred to as the *emotional memory enhancement (EME)*. This effect is robust, and has important consequences for both cognition and psychological wellbeing. Most generally, emotional stimuli impact memory formation by attracting attention, often at the expense of neutral stimuli. For instance, Loftus, Loftus, and Messo (1987) documented the so-called 'weapons-focus effect,' which refers to the bias for remembering a weapon from a scene, at the expense of memory for less emotionally salient elements. This bias towards emotional information can also affect mental health. For instance, Banich and colleagues (2009) review multiple studies that have documented an amplified neural response to negative stimuli and subsequent memory bias amongst individuals diagnosed with post-traumatic stress disorder. Because of the importance of emotion to the quality of everyday life and to mental health, it is crucial that we understand emotion processing and its effects on memory across the lifespan.

Emotion effects on memory have been studied in children and adults. Yet there are important differences between the two literatures. One notable gap between the adult and developmental research programs is apparent in the study of EME effects. These effects have been studied extensively in adults (for reviews see, e.g., Kensinger & Schacter, 2008; LaBar & Cabeza, 2006; Talmi, 2013). Critically, these studies have investigated the impact of emotion on memory in both laboratory and "real life" contexts.

Many of these studies have included manipulation of emotion at the time of memory encoding, and have examined the effects of emotion on different types of memory, including recognition and recollection (e.g., Dolcos & Cabeza, 2002; Spalek et al., 2015). Emotion effects on memory have also been investigated in children as they develop (e.g., Bauer, Stevens, Jackson, & Souci, 2012; Leventon & Bauer, 2013; Van Bergen, Wall, & Salmon, 2015) and in aging adults (for a review, see Murphy & Isaacowitz, 2008). There are rich bodies of research on emotion broadly construed for each of these age groups. However, there are substantive differences in how emotion is operationalized and tested in children and adults. A critical distinction between studies of EME is whether they test *memory for emotional events*, such as birthdays or break-ups, or the *effects of emotion on memory*, such as the relation between emotional arousal at encoding and subsequent memory. Adult research has addressed both, whereas developmental research has predominantly focused on the former. This prevents direct comparisons of emotion processing across development. Thus, at present, there is limited evidence about continuity and change in emotion processing across the life span.

Whereas the adult EME literature has examined how emotion impacts subsequent memory, the developmental literature has primarily examined how emotional events are later remembered. For example, Bauer, Burch, Van Abbema, and Ackil (2007) probed how children remembered a tornado that devastated their hometown; Quas and colleagues (1999) examined children’s memory for invasive medical procedures; and Goodman, Quas, and Ogle (2010) studied memories of childhood maltreatment. These studies offer high ecological validity, and provide important information about how emotional experiences are later remembered. However, because most developmental studies of emotion and memory do not systematically manipulate emotion at the time of encoding, they cannot directly address how emotion impacts memory encoding, consolidation, and subsequent recognition and/or recall.

There are notable exceptions to this generalization: a handful of studies have addressed emotion processing and memory in childhood (Cordon, Melinder, Goodman, & Edelstein, 2012; Leventon & Bauer, 2013; Pinabiaux et al., 2013; Van Bergen et al., 2015). Van Bergen and colleagues (2015) found that 5- and 6-year-olds recalled more information from negative and positive than from neutral short stories. Leventon and colleagues (2014) recorded electroencephalogram (EEG) data while 5- to 8-year-olds saw negative, positive, and neutral pictures. Unlike adults (e.g., Dolcos & Cabeza, 2002; Weymar, Löw, Melzig, & Hamm, 2009), memory was not significantly better for the emotional pictures. However, an ERP index of recognition memory was enhanced at test for old negative items among the older children (7- to 8-year-olds). Pinabiaux and colleagues (2013) found that emotion effects on memory increased with age from middle childhood (8-year-olds) to late adolescence (17-year-olds). In addition, they observed distinct neural correlates of successful memory encoding between the two age groups. In the younger children, successful encoding of fearful faces engaged the amygdala, but not medial temporal lobe structures, relative to neutral faces. In contrast, successful encoding of the fearful faces in adolescents differentially activated both the amygdala and medial temporal lobe structures. Together, these studies suggest that emotion processing and its effects on memory could shift across development.

Why might there be developmental change in EME effects? There are multiple reasons to think that EME effects could change across development. Many of the brain structures that are critical for emotion processing, particularly the amygdala and hippocampus, mature early, prior to middle childhood (e.g., Gogtay et al., 2006; Østby et al., 2009). However, whereas the subcortical brain structures implicated in emotion effects on memory, including the amygdala and hippocampus, mature very early in life, the relevant cortical structures, particularly the prefrontal cortex, continue to mature through adolescence (e.g., Gogtay et al., 2006; Østby et al., 2009; for a review see, e.g., Carver, 2014). For instance, one recent study found that functional connectivity between the amygdala and prefrontal cortex is positive in children younger than 10, and then becomes negative during adolescence (Gee et al., 2013). Another recent study found that activity in the amygdala and hippocampus during the processing of emotional versus neutral pictures decreased with age (between 10- and 24-year-olds), whereas activity in ventrolateral prefrontal cortex increased with age (Vink, Derks, Hoogendam, Hillegers, & Kahn, 2014). These types of changes in amygdala-prefrontal connectivity are likely to impact individuals' a) response to emotional events and b) ability to regulate that response (Carver, 2014). This prediction is supported by studies that document age-related change in both the emotion regulation strategies used by individuals (e.g., Gullone, Hughes, King, & Tonge, 2010) and how successfully individuals regulate their response to emotional events (e.g., McRae et al., 2012; Silvers et al., 2012). Developmental change in these brain structures impacts emotion processing, and, in turn, most likely affects EME.

There are also developmental changes in memory. Many of the brain structures involved in recognition memory, the ability to distinguish previously experienced from new events, mature prior to adolescence (e.g., Ghetti & Bunge, 2012; Gogtay et al., 2006;

Ofen, 2012). These are primarily medial temporal lobe structures, including the hippocampus, perirhinal cortex, and posterior parahippocampal gyrus (e.g., Ghetti & Bunge, 2012; Ofen, 2012). More generally, episodic memory is supported by these MTL structures and also by the prefrontal cortex (PFC). In contrast to the early maturation of MTL structures, both the PFC and connectivity between the MTL and PFC continue to develop between middle childhood and adulthood (for reviews see, e.g., Carver, 2014; Ghetti & Bunge, 2012; Ofen, 2012). This pattern of neural development is reflected in behavioral performance. Specifically, children achieve adult-like performance on recognition memory tasks during middle childhood, whereas performance on memory tasks that entail recall or the use of mnemonic strategies is slower to reach adult-like levels (e.g., Cycowicz, Friedman, Snodgrass, & Duff, 2001; Ghetti & Angelini, 2008; for reviews see, e.g., Ghetti & Bunge, 2012; Ofen, 2012).

At present, we do not know how developmental change in each of these realms—emotion and memory—interact. Presumably, development in brain structures that facilitate memory and emotion processing (i.e., the amygdala, hippocampus, prefrontal cortices) could impact the relations between emotion and memory. For instance, connectivity between the amygdala and both the hippocampus and prefrontal cortices undergoes changes through early adulthood (Gee et al., 2013; Guyer et al., 2008). Adult research has shown that EME is facilitated by interactions between these structures, therefore, changes in their interactions across development could contribute to developmental change in EME effects (for reviews see, e.g., Cahill & McGaugh, 1998; Phelps, 2004). In addition, emotion could impact task performance differently across development. For instance, children and adolescents are typically less able than adults to regulate their response to emotional stimuli (e.g., McRae et al., 2012; Silvers et al., 2012). One recent study from our lab demonstrated that emotion regulation modulates memory for emotional stimuli in children as young as 8 years old (Leventon & Bauer, 2016). Thus, developmental changes in emotion regulation ability are likely to impact EME effects. Indeed, another study from our lab indicates that children's neural response to emotional pictures, as measured with event-related potentials, changes between 5 and 8 years of age (Leventon, Stevens, & Bauer, 2014). In short, changes in both the brain and the effects of emotion on task performance are potential sources of developmental change in EME effects.

At present, there is little research that examines EME between middle childhood and adulthood. In that developmental window, individuals move through childhood, adolescence, emerging adulthood, and, finally, into adulthood. Along the way, there are dramatic changes in the individual's physiology, cognitive capacities, social environment, and behavioral repertoire (e.g., Blakemore & Mills, 2014; Casey, 2015; Larson, Richards, Moneta, Holmbeck, & Duckett, 1996; Steinberg, 2008; Suleiman, Galván, Harden, & Dahl, 2016). Developments in the subjective experience of emotional events and in memory for them are inextricably related to these changes (Del Piero, Saxbe, & Margolin, 2016; Heller & Casey, 2015; Larson, Moneta, Richards, & Wilson, 2002; Leventon & Bauer, 2016; Silk et al., 2009). For instance, adolescents appear to be more sensitive to threat and reward cues that either younger children or adults (Dreyfuss et al., 2014). Physiological responses to emotional stimuli also change during adolescence, as a function of pubertal development (Silk et al., 2009). It is particularly important to understand developmental change in the processing of emotional events and experiences, given its impacts on well-being and mental health (e.g., Dahl & Gunnar, 2009; Larson et al., 2002; Silk, Steinberg, & Morris, 2003). In adults, emotion effects on memory have been linked to both well-being and mental health (e.g., Altemus, 2006; Haas & Canli, 2008), however, there is a paucity of research on EME across development. As a consequence, it is not clear whether EME effects change between childhood and adulthood, and if any such changes are related to the increased prevalence of mental health issues in this developmental window (e.g., Casey, 2015; Paus, Keshavan, & Giedd, 2008).

Adolescence has been increasingly studied over the last two decades. Yet to date little is known about changes in basic emotion processing and emotion cognition interactions in this phase of human development (for reviews see, e.g., Del Piero, Saxbe, & Margolin, 2016; Heller & Casey, 2015). The dramatic and gender-specific physiological changes that unfold across adolescence also make it an ideal window in which to investigate the relations between gender and emotion effects on recognition memory. It has been argued that emotion effects on memory are, to some extent, gender-specific. There are mixed findings in the literature (gender differences reported by, e.g., Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004; Canli, Desmond, Zhao, & Gabrieli, 2002; absence of gender differences reported by, e.g., Spalek et al., 2015). There is some research that indicates that that gender differences in individuals' hormonal milieu modulate EME (e.g., Andreano, Arjomandi, & Cahill, 2008; Nielsen, Ahmed, & Cahill, 2014; Nielsen, Ertman, Lakhani, & Cahill, 2011). Presumably, if there are gender differences in emotion effects on recognition memory that are related to change in gonadal hormone levels, then those differences should be apparent at some point within this developmental window.

It is clear that both behavioral performance and measures of physiological and neural processes are important sources of information regarding developmental change in memory and emotion processing. Most obviously, behavior, and specifically memory performance, are the outcome of interest for most purposes. However, behavioral data alone tell only part of the story, as a particular behavioral outcome can obtain from multiple different pathways, be they cognitive processes, neural activations, or patterns of physiological response. The conjunction of behavioral measures with other measures of covert processing can provide more information. For instance, a study from our lab examined EME effects on recognition memory performance in 5- to 8-year-olds (Leventon et al., 2014). In addition to assessing behavioral memory performance, event-related potentials (ERPs) were examined during both memory encoding and test. There was no behavioral evidence of EME, yet the ERPs from both encoding and test revealed that ERPs from the older participants (7.5-8.9 years) were modulated by emotion. In contrast, the younger participants (5-7.4 years) ERPs at encoding were impacted by emotion only later in the response window, and at test there was no evidence of emotion effects. These results illustrate the utility of combining multiple measures to assess developmental change in EME.

As the results of Leventon and colleagues (2014) suggest, event-related potentials (ERPs) can enrich understanding of EME across development. In addition, ERPs provide a practical and affordable measure of neural activity that is relatively “kid-friendly.” Event-related potentials are a direct measure of neural activity that affords exquisite temporal resolution. This feature of ERPs enables identification of the time-course of cognitive processes, and thereby provides information about the effects of stimuli (i.e., emotional versus neutral) and task demands. There is copious evidence of emotion effects on ERPs at encoding and during memory tests in the adult literature (e.g., Johansson, Mecklinger, & Treese, 2004; Weymar, Löw, Melzig, & Hamm, 2009; for a review see, Olofsson, Nordin, Sequeira, & Polich, 2008). Studies of emotion effects on ERPs during encoding have documented multiple "signatures" of the neural response to emotional versus neutral stimuli. Two of the most widely documented are the Early Posterior Negative and the Late Positive Potential (for a review see, Olofsson et al., 2008). Few studies have examined these ERP components in children, but there is limited evidence that the Late Positive Potential, but not the Early Posterior Negativity, is modulated by emotion in children as young as 5 years (Hajcak & Dennis, 2009).

Event-related potentials have also been used to examine neural processes associated with EME during memory tests in adults (e.g., Schaefer, Pottage, & Rickart, 2011; Weymar, Löw, & Hamm, 2011). Together, these studies suggest that emotion impacts neural activity during successful recognition memory performance, and that these effects are maintained even when only correctly remembered neutral and emotional items are compared. To our knowledge, the only developmental study on this topic is from our lab (Leventon et al., 2014). The results indicated an adult-like effect for negative correctly remembered negative, but not neutral or positive, stimuli in children aged 7.5-8.9 years (Leventon et al., 2014). To summarize, ERPs have been extensively used to examine emotion effects on emotion processing in adults, and there is a smaller literature that has used ERPs to examine emotion processing in children. When compared, the findings of these studies suggest that at encoding, early emotion effects on ERPs could be specific to adults, whereas later emotion effects are more consistent across development. There is a smaller literature that has shown that emotion also modulates this activity during memory tests. At present, the lion's share of these studies sample from young adults (i.e., university undergraduate students). Thus, there remains a need to map the developmental trajectory of these emotion effects on memory encoding and performance between childhood and adulthood.

To date, there is an asymmetry between adult and developmental research on EME. Namely, we know much less about the effect of emotion on memory in children than in adults. In order to elucidate the developmental trajectory of EME effects, behavioral and neural data from studies that directly compare the effects of emotion manipulations across development and between genders are needed. In addition, it is clear that, by using multiple measures of EME, we can obtain detailed insights into the developmental trajectory of EME effects. The purpose of the present research was to collect and analyze such a dataset. The present studies thus included participants from 8- to 30-years old, in order to sample individuals before, during, and after adolescence. In addition to memory performance data, we collected ERPs during both memory encoding and a test of recognition memory. To preserve statistical power, we maintained age as a continuous variable, rather than "bining" participants into age groups. This approach is somewhat novel for ERP analyses, which typically utilize group-based analyses. In a series of three studies, we examined EME effects across this age range and between genders in both brain and behavior.

The first aim of the present research was to **elucidate the developmental trajectory of emotion effects on memory across a continuous age range**, spanning from middle childhood through adulthood (8-30 years old). All participants completed a two-session study with virtually identical parameters, regardless of age. At Session 1, participants encoded negative, neutral, and positive pictures from a developmentally-appropriate subset of the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). Approximately two weeks later, participants completed Session 2, which included a recognition memory test. We sought to identify any age- or gender-related change in multiple aspects of emotion processing and task performance. Thus, in Study 1, we examined emotion elicitation and task effects on participant mood, in addition to testing emotion effects on subsequent memory. The purpose of the approach was to assess the relations between emotion elicitation, effects of the paradigm on participant mood, and EME. More specifically, we wanted to examine whether age- and/or gender-related differences in either emotion elicitation or mood might either account for or obscure developmental or gender differences in EME effects.

The second aim of the present research was to **examine whether emotion processing during memory encoding changes** between middle childhood and adulthood, and if there are gender differences within that developmental window. To examine possible age- or gender-related differences in the encoding of emotional and neutral events, we recorded ERPs while participants encoded negative, neutral, and positive IAPS pictures. We then examined emotion effects on two ERP components, the Early Posterior Negativity and the Late Positive Potential, and tested for age- and gender-related differences in those effects on each component. In addition, we examined emotion effects on ERPs for correctly remembered events, in order to ascertain the extent to which emotion effects on neural processing persist when memory performance is controlled (i.e., when processing of correctly remembered neutral and emotional events is directly compared).

The third aim of the present research was to **examine whether ERP indices of recognition of emotional versus neutral memories change** between middle childhood and adulthood. We recorded ERPs while participants performed a recognition memory task that included the pictures they had encoded at Session 1 and new negative, neutral, and positive IAPS pictures. We then tested for both age differences and emotion effects on two ERPs that have been shown to index correct recognition: the early frontal-central and late central-parietal old/new components (e.g., Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Schaefer et al., 2011; Weymar et al., 2009). These data were examined to assess possible relations between age and ERP indices of successful recognition memory performance, both in general and specifically for emotional versus neutral conditions.

Paper 1

Emotion effects on memory from childhood through adulthood: Consistent enhancement and adult gender differences

Anaïs F. Stenson, Jacqueline S. Leventon, and Patricia J. Bauer

Abstract

Emotion typically enhances memory. This emotional memory enhancement (EME) effect has been extensively studied in adults, but its developmental trajectory is unclear. Developmental studies that have manipulated emotion at encoding and then tested subsequent memory have yielded mixed results. To further elucidate the developmental trajectory of EME, we examined EME in 8- to 30-year-olds, using the same stimuli, paradigm, and analyses for all participants. At encoding, participants saw negative, neutral, and positive pictures while completing an incidental task. Two weeks later, participants completed a recognition memory test. We calculated negative-neutral and positive-neutral memory difference scores for each participant and then tested whether EME were predicted by age or gender. We also examined whether key aspects of the paradigm, including emotion elicitation and how the task impacted participants' mood and affect, changed with age or between genders, as well as if they predicted EME for individuals. There were no significant relations with mood, affect, and magnitude of EME. Negative pictures were remembered better than neutral; the magnitude of this difference diminished in older males, but not older females. Positive pictures were also remembered better than neutral, but this EME effect was small and did not change with age or by gender. These results suggest that emotion effects on recognition memory are apparent by middle childhood and remain consistent through young adulthood for females, whereas for males the effect of negative emotion diminishes with age.

Keywords: memory, recognition memory, development, emotion, gender

Introduction

Emotion has powerful, well-documented effects on memory (see, e.g., Banich et al., 2009; Kensinger & Schacter, 2008; Roozendaal & McGaugh, 2011, for reviews). Yet, there are gaps in the account of how emotion impacts memory across development (see, e.g., Carver, 2013; Hamann & Stevens, 2013, for reviews). Specifically, many adult studies use laboratory paradigms that systematically manipulate emotion during memory encoding and then test subsequent memory performance (see, e.g., Kensinger & Schacter, 2008; Talmi, 2013, for reviews). In contrast, developmental studies typically investigate children's memories for naturally-occurring emotional events, thus precluding manipulation of emotion (see, e.g., Goodman, Quas, & Ogle, 2010, for a review). When emotion is manipulated, there are mixed findings (contrast, for e.g., Cordon, Melinder, Goodman, & Edelstein 2012; Leventon, Stevens, & Bauer, 2014). There are thus two gaps between the developmental and adult accounts of emotional memory enhancement (EME). First, studies that have tested emotional memory enhancement (EME) in childhood versus adulthood have used different paradigms. Second, studies of EME in childhood have produced varied results, whereas findings from studies with adults predominantly report consistent EME effects. Thus, it is not yet clear if EME effects are consistent across development. The present study addressed this question by examining the developmental trajectory of emotional memory enhancement (EME) effects on recognition memory from middle childhood through early adulthood.

Studies of EME in adults typically assess how emotion at encoding impacts subsequent memory by presenting emotional and neutral stimuli and then comparing subsequent memory for those stimuli. Typically, memory is significantly better for emotional stimuli, relative to neutral (see, e.g., Murphy & Isaacowitz, 2008; Kensinger & Schacter, 2008; Talmi, 2013, for reviews). These studies often use stimuli from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) or the Affective Norms for English Words (ANEW; Bradley & Lang, 1999) to elicit emotion (e.g., Kensinger & Corkin, 2003; Kensinger & Schacter, 2006). These large, standardized stimulus sets facilitate direct comparisons of EME effects both within- and between-subjects, as well as across studies. This approach has yielded a detailed account of EME in the laboratory context in adults.

Developmental studies have shown that valence modulates children's recollection of personally relevant events, such that emotional events are recalled in greater detail than neutral events (e.g., Ackil et al., 2003; Bauer et al., in press; Fivush et al., 2003; reviewed by, e.g., Goodman, Quas, & Ogle, 2009). These studies provide insight into emotion effects on memory "in the wild." However, because they examine retrospective reports of personal experiences, their results are not directly comparable with those from the adult EME literature. Relatedly, the nature of these studies precludes both systematic manipulation of emotion at the time of memory encoding and direct comparison of emotion effects between subjects.

Some developmental studies have systematically manipulated emotion at encoding and then tested subsequent memory in a manner that parallels adult EME studies. Their results are mixed. Cordon, Melinder, Goodman, and Edelstein (2012) showed 7- to 9-year-olds and young adults negative and neutral pictures and conducted a recognition memory test one week later. Adults remembered more neutral pictures than children, but memory performance for negative pictures was equivalent for both age groups. Leventon, Stevens, and Bauer (2014) showed 5- to 8-year-olds negative, neutral, and positive IAPS pictures and tested recognition memory 24 hours later. Memory performance was statistically equivalent for all emotion conditions. Vasa et al. (2011) showed 12- to 17-year-olds and adults negative, neutral, and positive IAPS pictures. Approximately 30 minutes after encoding, participants completed a surprise recall task. EME effects were robust for both age groups. These three studies each tested different age ranges and used different paradigms. As a consequence, it is difficult to offer a robust interpretation of their mixed results.

To elucidate the developmental trajectory of EME, studies that use consistent stimuli, paradigms, and analyses across a wide age range are required. This approach would enable direct comparison of emotion effects on performance across development. In the present research, we initiated this effort by examining recognition memory from middle childhood to adulthood. Recognition memory performance approaches adult-like levels in middle childhood or early adolescence (e.g., Ghetti & Angelini, 2008; see e.g., Bauer, 2007, for a review). We reasoned that because age-related differences in episodic memory for neutral stimuli are minimized in recognition paradigms (but see Cordon et al., 2012), observed developmental differences in EME effects could reasonably be attributed to shifts in emotion processing.

There are several potential sources of age-related differences in emotion processing that might contribute to age-related differences in EME effects (see, e.g., Del Piero, Saxbe, & Margolin, 2016, for a review). First, there is evidence of differences in emotion processing between middle childhood and adulthood. For example, Bauer, Hermes and Xu (2016) used measures of visual attention to compare how children and adults processed IAPS pictures. Children fixated on emotionally salient areas within the emotional pictures longer than adults, suggesting that emotion may capture attention longer in children than in adults. Hajcak and Dennis (2009) documented developmental differences in 5- to 8-year-old children's neural activity, as measured with event-related potentials (ERPs), following presentation of emotional IAPS pictures, relative to adults. Children's ERPs did not differ according to emotion until a late window (>1s post-stimulus), whereas adults' ERPs are typically modulated by emotion in both an early (<500ms post-stimulus) and the late window. This result suggests that emotion processing could unfold more slowly in children than in adults. Using fMRI, Vink, Derks, Hoogendam, Hillegers, and Kahn (2014) also documented developmental differences in the neural response to emotional versus neutral IAPS pictures viewed by participants aged 10 to 24 years. Age was negatively correlated with hippocampal and amygdala activity, and positively correlated with activity in prefrontal cortex. These results point to developmental changes in the neural processing of emotional pictures. Presumably, such developmental differences in emotion processing could modulate subsequent EME effects, via effects on either attention at encoding or memory consolidation processes.

A second potential source of developmental differences in emotion processing is that connectivity between neural structures that support emotion processing, including the amygdala, prefrontal cortex, and hippocampus, continues to develop through adolescence (e.g., Gabard-Durnam et al., 2014; Goddings et al., 2014; Gogtay et al., 2004; see, e.g., Blakemore, 2012; Casey, Getz, & Galvan, 2008, for reviews). These structures play a central role in EME (reviewed by, e.g., Carver, 2014). As such, their relative developmental immaturity may contribute to age-related differences in EME effects. For instance, connectivity between the prefrontal cortex and subcortical regions, including the amygdala hippocampus, develops slowly. Mounting evidence indicates that prefrontal-subcortical connectivity enables cognitive processes, such as attention and response inhibition (see, e.g., Pessoa, 2008 & 2010, for reviews). Indeed, multiple fMRI studies have compared neural processing of emotional and neutral stimuli across development and found that prefrontal activity is greater in adults than children when viewing emotional stimuli (e.g., Guyer, et al. 2008; Vink et al., 2014). The ongoing development of both the brain structures that are understood to support EME, as well as the connectivity between these regions, could be reflected in developmental differences in EME effects.

A third potential source of developmental differences in EME are age-specific effects of the experimental task on mood, or the degree to which the stimuli elicit emotion (reviewed by, e.g., Hamann & Stevens, 2014; Henderson & Fox, 2007). Including emotional stimuli in experimental tasks impacts how adults process and respond to task demands (see, e.g., Lench, Flores, & Bench, 2011, for a review). For instance, Kaspar et al. (2013) demonstrated that emotional context impacts how adults view neutral stimuli and Lench et al. (2011) reported that the magnitude of emotion elicitation varies according to what emotions are compared. These findings lend credence to the possibility that tasks that evoke emotional responses could impact children and adults differently. Studies have used the IAPS to directly compare emotion elicitation in children and adults. McManis, Bradley, Berg, Cuthbert, and Lang (2001) and McRae et al. (2012) both tested whether subjective ratings of negative, neutral and positive IAPS pictures change between middle childhood and young adulthood, and both studies indicated that children and adults rate the pictures valence and arousal similarly. These findings suggest that IAPS are appropriate for developmental studies because the pictures elicit comparable emotional responses across a wide age range. At the same time, rigorous examination of EME across development necessitates assessment of emotion elicitation and impact of the task on mood, so that any developmental differences in participants' response to the stimuli or task performance can be identified.

The present research examined EME of recognition memory from middle childhood through young adulthood (ages 8-30 years). The lower age bound was set because including participants younger than 8 years would have further restricted the range of stimuli that could be used to elicit emotional responses with participants of all ages. To facilitate comparison of performance across this age range, the same stimuli, paradigm, and analyses were used for all participants. To evaluate whether age impacted these outcomes we assessed both, a) the emotion elicited by the pictures and b) the impact of the task on participants' mood. This study design allows for direct comparison of EME effects on recognition performance across a wide age range, while testing for other potential sources of developmental differences, such as differential emotion elicitation. Because some prior studies have documented gender differences in EME effects, and our participants' age range spans adolescence, when physiological gender differences increase, we also planned to examine gender differences in outcomes measures. Thus, we sought to determine whether EME effects on recognition memory change between middle childhood and early adulthood, if gender was related to memory performance, and if any observed developmental changes would be gender-specific.

Method

Data were collected at a large private Southeastern university. Altogether, 151 children (75 females), ages 8 to 16, and 88 young adults (45 females), ages 18 to 30, enrolled in the study (total *N* = 239). Twelve children (five females) and four adults (one female) were lost to attrition between Sessions 1 and 2. Sixteen children (five females) and five adults (four females) were excluded from analyses due to technical errors, failure to perform the task, or experimenter error. Ultimately, 127 children (65 females) and 79 adults (40 females) were included in the study (final *N* = 206). Children were recruited from a database of families that had previously expressed interest in study participation through the university's Child Study Center. Although detailed data on socioeconomic status were not collected, the pool is comprised primarily of families from educated middle- to upper-middle-class SES. Guardian report of highest educational achievement in the household indicated that 6% had completed some college, 6% completed a technical or associate's degree, 22% completed a college degree, 9% completed some graduate school, and 55% completed a post-graduate degree; 2% did not provide this data. Information about education was not systematically collected from adult participants. Self- or parent-reported race and ethnicity was collected for all participants. Ethnicity was reported for 200 participants; 12 identified as Hispanic or Latino and 188 identified as not Hispanic or Latino. Race was reported for 202 participants; 26 identified as Asian, 37 identified as Black or African-American, 14 identified as bi- or multi-racial, and 125 identified as White or Caucasian. Prior to testing the children, their guardians provided written informed consent. The children received a gift card to a major retail chain for their participation. Adult participants were recruited through the university psychology subject pool. They provided written informed consent and received course credit for their participation. All procedures were reviewed and approved by the IRB.

Materials

A set of 165 child-appropriate pictures (57 negative, 53 neutral, and 55 positive) was selected from the International Affective Picture System (IAPS; Lang et al. 2008) and a lab-collected set of similar pictures. Of these 165 pictures, 150 pictures (50 per valence) were included in the memory task. This set of 150 pictures was used to create eight presentation orders that were used for both child and adult participants. The same pictures were used for all participants, regardless of age. However, before child participants came to the lab, thumbnail images of the picture set were sent via email to the guardian to approve (procedure approved by Lang, personal communication). If the guardian requested that specific pictures be removed, they were replaced with alternate pictures of the same valence. There were no requests to replace neutral or positive images. The seven negative pictures that were not included in the original picture set were used to replace any negative picture(s) that the guardian wanted removed. The remaining five positive pictures were presented at the end of picture presentation so that the session ended on a positive note. The three remaining neutral images were used for participants to practice the task. To control for previously reported biases in affective processing of stimuli with humans (Proverbio et al., 2009), within each emotion condition, half of the images included humans and half did not.

The study consisted of two sessions separated by approximately 14 days (*M* = 14.1 (0.91), *Range* = 11-20). During Session 1, participants viewed pictures and engaged in a behavioral task to ensure attention to the pictures. Before starting the picture viewing and again afterwards, all child participants rated their mood, using a 5-point emoticon scale (see Fig. 1, Panel A), and all participants who were age 11 or older completed the Positive and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988). During Session 2, participants viewed all pictures from Session 1, along with new pictures, and completed a recognition memory task. Like Session 1, participants provided mood and/or PANAS ratings both before and after the picture task. At the end of Session 2, participants provided subjective ratings of valence and arousal for a subset of the pictures (45) using the modified Self-Assessment Manikin shown in Fig. 1, Panel B (SAM; Bradley & Lang, 1994).

Session 1.

During the encoding task, participants viewed pictures and used a game controller to indicate whether each picture contained a human. All pictures were presented in full color at 30.5 cm (h) × 23 cm (w) in size, subtending a visual angle of approximately 15.6° (h) × 20.6° (w). Each picture was presented for 3000ms and immediately followed by a decision screen lasting for 3000ms that prompted participants to indicate whether the prior picture contained a human. A 850 to 1250ms inter-stimulus interval followed. Stimulus presentation was controlled using Advanced Neuro Technology eevoke™ software. A trial schematic is presented in Fig. 2, Panel A. The encoding task lasted approximately 9 minutes of the approximately 90 minute Session 1.

After orientation to the encoding task, participants completed three practice trials to ensure they understood the task. They then viewed 90 pictures (30 negative, 30 neutral, and 30 positive) presented in one of eight pseudo-randomized orders. No more than two images of the same valence were presented consecutively. The images and presentation order were counterbalanced across participants. Five positive pictures were shown at the end of each presentation so that the session ended on a positive note. These final positive trials were not included in analyses.

Session 2.

During the recognition task, participants viewed 150 pictures (50 negative, 50 neutral, and 50 positive). These included the 90 pictures from Session 1 and 60 new pictures (20 negative, 20 neutral, and 20 positive), which the participant had not seen before. Like Session 1, the order of picture presentation was pseudo-randomized so that no more than two images of the same valence were presented consecutively. Both picture sets and presentation orders were counterbalanced so that across participants, all pictures were used equally in the old and new conditions. Five positive images were added to the end of each presentation so that the session ended on a positive note. These trials were not included in any analyses.

After each picture was presented, participants indicated whether they thought it was ‘definitely old,’ ‘maybe old,’ or ‘new’ via a button press on a game controller. The position of the response options was counterbalanced across participants. Participants completed three practice trials (same images as Session 1 practice trials) to ensure that they understood the task. Once the participants affirmed they understood the instructions, picture presentation and data recording began. Each picture was presented for 3000ms, followed by the old/maybe old/new decision screen for 3000ms. Trials were separated by a variable 850-1250ms inter-stimulus interval. A trial schematic is presented in Fig. 2, Panel B. Stimulus presentation was controlled using Advanced Neuro Technology eevoke™ software. The task lasted approximately 18 minutes for all participants.

Following the recognition task, participants provided subjective valence and arousal ratings for 45 of the pictures (15 from each emotion condition) using the modified SAM, shown in Fig. 2. The SAM was abbreviated from the full 9-point version of the scale to reduce participant burden for the children (Leventon et al., 2014). The modified SAM consisted of one 5-point scale for valence (1 = very unpleasant, 3 = neutral, and 5 = very pleasant), and another for arousal (1 = very low arousal, 5 = very high arousal).

Analytic Approach

We first evaluated the results of additional measures that were taken in order to address alternative sources of age- and/or gender-related differences that could impact performance. Specifically, we evaluated two factors that can modulate EME: participants' valence and arousal ratings of the pictures, as well as the impact of the task on participants' mood. We tested whether the tasks at Session 1 or 2 impacted participants' mood according to their age and/or gender by calculating pre- to post-task mood change. Similarly, we calculated a difference score from participants' pre- and post-task PANAS ratings to quantify changes in affective state from the beginning to the end of each session. Positive and negative affect were analyzed separately because they were scored separately. We regressed age and gender on the pictures ratings, mood, positive affect, and negative affect change scores to evaluate whether the task had significantly different effects across the age range or between genders.

Following prior research, we evaluated participants' discrimination between old and new images by calculating *d',* a discriminability index, and *C,* an index of response bias (e.g., Banks, 1970, Snodgrass & Corwin, 1988, Macmillan & Creelman, 2005; Wixted, 2007). In order to conduct this analysis, 'maybe old' and 'definitely old' responses were combined and both treated as ‘old.’ We calculated *d’* by first calculating *z* scores for hit (HR) and false alarm (FA) rates, and then subtracting z(FA) from z(HR). Thus, for each participant $d' = z(\text{HR}) - z(\text{FA})$. This *d’* value indexes how well participants distinguished old items from new items. We calculated *C* using z(FA) and z(HR) in the following formula: $C = -.5 * (z(\text{HR}) + z(\text{FA}))$. The resulting *C* value indexes the tendency to respond *old,* rather than *new.* Hit and FA rates of 1 or 0 were corrected in accordance with Macmillan and Kaplan’s (1985) recommendation: rates of 0 were replaced with $0.5 / n$ and rates of 1 were replaced with $(n - 0.5) / n$, where n is the total possible number of hits or false alarms.

Next, we analyzed the difference in memory performance for the negative, neutral, and positive pictures. The outcome measures were the difference scores for each emotion condition relative to neutral (i.e., negative *d’* – neutral *d’*, negative *C* – neutral *C,* positive *d’* – neutral *d’*, and positive *C* – neutral *C*). We then examined the effects of age and gender on the negative-neutral difference and positive-neutral difference by constructing separate linear models for each of these four difference scores. The approach allowed us to treat age as a continuous variable, which maximized statistical power and prevented overlooking differences that might emerge gradually across development.

Results

This section includes analyses of four different measures: mood ratings, Positive and Negative Affect Scale (PANAS) ratings, picture valence and arousal ratings, and recognition memory performance. In order to establish the validity of the manipulations for participants of all ages and both genders, we first present the results of the mood, PANAS, and picture ratings. We then present the memory data. All analyses were conducted with R version 3.2.2.

Mood Ratings

We evaluated 8- to 16-year-old participants' mood change during each session by subtracting the rating provided at the beginning of each session from the rating provided at the end of that session. Participants missing either rating were excluded from the mood analyses for that session ($N_{Session1}$ = 17, $N_{Session2}$ = 13). Summary statistics for both mood ratings and change during Session 1 and 2 are provided in Table 5, Panel A. Neither age, negative-neutral *d'*, nor positive-neutral *d'* was significantly correlated with mood change during either encoding or recognition (absolute value of all *r*s < .18 and all uncorrected *p*s > .05).

Participants' reported mood did not change significantly during either Session 1 or Session 2. Paired *t*-tests indicated a decrease in mood at Session 1, yet the effect fell below the level of statistical significance, $t(109) = -1.90$, $p = .06$. There was also not a significant decrease in mood across Session 2, $t(113) = 1.41$, $p = .16$. There were not significant gender differences in mood change during Session 1 (M_{female} = -0.09(0.90), M_{male} = -0.21(0.77)), $t(105.52) = -0.74$, $p = .46$, or Session 2 (M_{female} = -0.13(0.72), M_{male} = -0.07(.81)), $t(110.19) = -0.43$, $p = .67$. Mood change was not predicted by age, gender, or their interaction for Session 1, $R^2 = -.006$, $F(3,106) = 0.77$, $p = .51$, or Session 2, $R^2 = .004$, $F(3,110) = 1.17$, $p = .33$.

Positive and Negative Affect Scale (PANAS) Ratings

We evaluated whether 11- to 30-year-old participants experienced changes in positive or negative affect during each session by subtracting the PANAS ratings provided at the end of each session from those provided at the beginning of that session. Participants missing either rating were excluded from the PANAS analyses for that session ($N_{Session1} = 14$, $N_{Session2} = 17$). Summary statistics are provided in Table 5, Panel B. Change in positive affect ratings from pre- to post-encoding was modestly negatively correlated with magnitude of the negative-neutral *d'*, $r = -.18$, uncorrected $p < .05$. All other correlations between change in reported affect, age, and magnitude of EME (difference in *d'* between valence categories) were not statistically significant (absolute value of all *r*s ≤ .15)

Positive affect scores increased significantly from the beginning to the end of Session 1, $t(150) = 7.79$, $p < .0001$. This increase was larger for older participants, $\beta = .26(.11)$, $p = .03$, but neither gender nor the interaction of age and gender predicted change in positive affect, $R^2 = .04$, $F(3,146) = 3.12$, $p = .03$. Positive affect scores also increased significantly from the beginning to the end of Session 2, $t(148) = 7.80$, $p < .0001$. However, as for Session 1, this change was not predicted by age, gender, or their interaction, $R^2 = .02$, $F(3,144) = 2.01$, $p = .12$. Negative affect scores did not change significantly during Session 1, $t(150) = 1.04$, $p = .30$, or Session 2, $t(147) = 0.56$, $p = .58$. Neither age, gender, nor their interaction predicted change in negative affect at Session 1, $R^2 = -.01$, $F(3,146) = 0.43$, $p = .73$, or Session 2, $R^2 = -.01$, $F(3,143) = 0.60$, $p = .62$.

Subjective Ratings of Picture Valence and Arousal

To evaluate the success of the emotion manipulation for participants of all ages and of both genders, participants ($N = 204$) provided subjective ratings of picture valence and arousal. Two participants did not provide complete ratings due to time constraints. Summary statistics for the ratings are provided in Table 2.

Participants' valence and arousal ratings for negative, neutral, and positive pictures were not significantly correlated (all *r*s between .01 and .12) with the magnitude of their EME (negative-neutral and positive-neutral *d′* difference scores). Age was negatively correlated with arousal ratings for neutral (r = -.26, uncorrected p < .001) and positive (r = -.25, uncorrected p < .001) pictures, indicating that younger participants rated these as more arousing than older participants. See Table 3 for all correlations.

Valence ratings differed significantly according to picture emotion, F(2, 609) = 1193, p < .0001. Participants rated negative pictures as significantly more unpleasant than either neutral or positive pictures, and positive pictures as significantly more pleasant than either neutral or negative pictures. Arousal ratings also differed significantly according to picture emotion, F(2, 609) = 183.3, p < .0001. Negative pictures were rated as more arousing than both and neutral pictures. Positive pictures were rated as significantly more arousing than neutral. All statistical comparisons are reported in Table 4.

The average difference in valence ratings for negative versus neutral pictures was larger for females than males, β = .26(.07), p < .001, but was not predicted by age, β = -.02(.05), p = .75, or the interaction of age and gender, β = -.01(.07), p = .95, total R^2 = .06, F(3,200) = 5.15, p = .002 . The difference between arousal ratings for negative and neutral pictures was significantly predicted by age, β = .25(.07), p = .01, gender, β = -.14(.11), p = .04, and their interaction, β = -.29 (.11), p < .04, R^2 = .04, F(3,200) = 03.91, p = .01. The difference in valence ratings for positive versus neutral pictures was predicted by gender, β = -.19(.05), p = .005, but not age or their interaction, R^2 = .03, F(3,200) = 3.33, p = .02. The difference in arousal ratings for positive versus neutral pictures was not predicted by gender, age, or their interaction, $R^2 = -.002$, $F(3,200) = 0.85$, $p = .47$. These regressions reveal significant but small effects of age and gender on picture ratings.

Recognition Memory Performance

To assess overall memory performance, we conducted separate t-tests for *d'* and *C* to determine if performance was significantly different than chance. Participants successfully distinguished old and new pictures ($M_{d'} = 1.58(0.55)$), $t(205) = 40.94$, $p < .0001$. Mean *C* values were significantly greater than 0 ($M_C = 0.26(0.43)$), $t(205) = 8.55$, $p < .0001$, indicating that participants were more likely to respond *old* than *new*. This bias reflects the relative proportions of old (2/3) and new (1/3) pictures presented during the memory test.

We evaluated the effects of emotion on *d'* and *C* by conducting separate one-way analyses of variance with the factor emotion. For cases that did not satisfy the assumption of sphericity, Greenhouse-Geisser corrections were applied. There were significant differences in both *d'*, $F(2, 615) = 45.22$, $p < .0001$, and *C*, $F(2, 615) = 20.33$, $p < .0001$, between emotion conditions. Participants' memory was best for negative pictures, followed by positive and then neutral pictures. Participants' response bias followed the same pattern: *C* was lowest for negative pictures, slightly higher for positive, and highest for neutral pictures. See Table 1, Panel A for descriptive statistics.

We assessed whether EME effects changed with age by calculating the difference in memory performance for negative and positive versus neutral pictures to derive negative-neutral and positive-neutral difference scores for both *d'* and *C*. A positive difference score for *d'* indicates greater accuracy for the emotional versus neutral pictures. Conversely, greater accuracy for neutral versus emotional pictures would produce a negative *d'* value. We conducted separate multiple regression analyses for the negative-neutral and positive-neutral *d'* and *C* difference scores, entering age and gender as predictors in the models. Model details are provided in Table 9 for *d'* and in Table 10 for *C*.

The magnitude of memory enhancement for negative versus neutral pictures was not predicted by age, $p = .92$, or gender, $p = .33$; however, their interaction approached statistical significance, $p = .06$, and the model explained a small but significant proportion of the variance, $R^2 = .03$, $F(3, 202) = 2.86$, $p = .04$. Therefore, we stratified participants by gender and conducted linear regression to assess possible gender differences in the relation between age and the negative-neutral *d'* difference. Age did not significantly predict EME for females, $p = .93$. In contrast, for males older age significantly predicted smaller EME, $\beta = -.29(.09)$, $p = .003$, $R^2 = .08$, $F(1, 99) = 9.14$, $p = .003$. Neither age, $p = .81$, gender, $p = .46$, nor their interaction, $p = .86$, predicted negative-neutral memory bias (*C*) differences, $R^2 = -.01$, $F(3, 202) = 0.29$, $p = .83$.

For females, memory for negative pictures was enhanced relative to neutral; age did not predict the magnitude of this EME. Males also had better memory for negative versus neutral pictures, but this negative-neutral difference diminished for older males. As shown in Figure 4, Panel A, the regression line slopes differed by gender, yet their 95% confidence intervals overlapped across the age range. Thus, both genders demonstrated enhanced memory for negative versus neutral pictures across the age range, but the magnitude of this enhancement shifted with age only for males.

We used a parallel set of multiple regression analyses to evaluate the effects of age and gender on the positive-neutral difference in *d'* and *C* values. Neither age, $p = .83$, gender, $p = .90$, nor their interaction, $p = .14$, explained a significant proportion of the variance in the positive-neutral *d'* difference, $R^2 = .011$, $F(3, 202) = 1.76$, $p = .16$. As shown in Figure 4, Panel B, memory was better for positive versus neutral pictures across the age range for females and males alike. The positive-neutral *C* difference also was not moderated by age, $p = .31$, gender, $p = .33$, or their interaction, $p = .95$. Together, these predictors did not account for a significant proportion of the variance in *C*, $R^2 = .001$, $F(3,202) = 1.04$, $p = .38$. These results indicate that the memory advantage for positive relative to neutral stimuli did not change significantly across the tested age range or between genders, and that there were not age or gender differences in participants' response bias for positive versus neutral pictures.

Discussion

Emotion has powerful effects on memory. Although these effects have been studied extensively, particularly in adults, there are gaps in our understanding of how emotion impacts memory across development (reviewed by, e.g., Banich et al., 2009; Carver, 2014; Hamann & Stevens, 2014; Kensinger & Schacter, 2008; Roozendaal & McGaugh, 2011). We addressed this gap by examining EME effects from middle childhood through early adulthood. To facilitate comparisons with prior research, we used both a common paradigm from adult EME studies and the widely used IAPS stimuli. Specifically, 8- to 30-year-old participants saw negative, neutral, and positive IAPS pictures during an encoding session and then completed a recognition memory test two weeks later. This design enabled us to compare memory performance between emotion conditions within-subjects and treat age as a continuous variable, thereby affording greater power to detect differences linked to age.

In keeping with prior research, we found a robust main effect of emotion on memory performance: participants' memory for negative and positive pictures was significantly better than for neutral pictures. As shown in Figure 3, Panels A and B, the negative-neutral memory difference was larger than the positive-neutral difference; this result also mirrors prior research (reviewed by, e.g., Kensinger & Schacter, 2008). For both negative and positive pictures, EME relative to neutral was largely consistent from middle childhood through early adulthood. However, the negative-neutral memory advantage significantly diminished with age for males, whereas for females it remained stable. This gender-specific age effect was small but significant. As shown in Figure 4, Panel A, the 95% confidence intervals around the regression lines for females and males overlapped substantially. Figure 3, Panel A shows that although the negative-neutral EME effect decreased slightly across the age range, the effect remained robust even in the oldest participants. In contrast, Figure 3, Panel B shows that although there were not statistically significant age differences in the positive-neutral memory advantage, this small advantage is virtually eliminated by early adulthood.

These findings extend the EME and developmental memory literatures by providing robust evidence that emotion enhances recognition memory from middle childhood onwards. Given our large sample size and within-subjects analysis of EME, these results provide compelling evidence that, at least as tested in the present research, EME effects on recognition memory are largely consistent from middle childhood through early adulthood for both genders. The exception to this account is the small but significant decrease in negative-neutral EME in males, but not females. There are two likely explanations for this gender difference. First, the impact of negative emotion on memory might diminish with age for males. Second, the negative pictures might have elicited a muted emotional response in older males, relative to females and younger males. For reasons discussed next, we favor the second explanation.

Participant ratings of the pictures' valence and arousal differed between genders and, for negative pictures, across the age range. Females rated negative pictures as both more negative and more arousing than males, and older participants rated negative pictures as less arousing than did younger participants. Females also rated positive pictures as more positive than did males, however, there were no age differences. Arousal ratings of positive pictures were consistent between genders and across the age range. Prior research has also documented gender differences in valence and arousal ratings of emotional pictures; specifically, using the SAM, females rate both negative and positive IAPS pictures as more intensely arousing and extreme in valence than males do (McManis et al., 2001). This suggests that diminished negative-neutral memory enhancement in males versus females likely reflects that the negative pictures did not elicit the same degree of emotional response across the age range in both genders.

We analyzed mood and affect ratings to evaluate whether the results were confounded by age or gender differences in how the task impacted participants' moods. Mood ratings did not change significantly at either Session 1 or 2, and did not differ by age or gender. Participants' positive affect did increase significantly from the beginning to the end of both sessions; this change was slightly larger for older participants at Session 1. At present, we do not have data to address why older participants' felt more positive at the end of Session 1. The pattern of increased positive affect at the end of each session likely reflects that the last 5 pictures presented were positive and prompted slightly more positive affect at the end of the session. Overall, the consistency in mood and affect ratings across the age range and between genders indicates that there were not differential task effects on certain participants' affective state or mood. Therefore, we are confident that there were not changes in mood and affect that could have generated age or gender differences in the observed EME effects.

The present findings are robust and align with Vasa and colleagues (2011) finding of consistent EME for both adults and adolescents. However, results from other studies of EME in middle childhood have varied. Cordon and colleagues (2012) reported that 7- to 9-year-olds and adults had equivalent memory for aversive stimuli, but adults also remembered more neutral items than the children. Thus, the EME effect was larger for children than for adults. Leventon and colleagues (2014) did not find evidence of EME effects on recognition memory for 5- to 8-year-olds. This result merits special consideration, as the present study and Leventon and colleagues (2014) employed similar stimuli and laboratory environments. However, there was little overlap in participants' age: the top of the Leventon and colleagues (2014) range was 8 years, which was the bottom of our range. This raises the possibility that EME effects on recognition memory emerge during middle childhood, and do not appear in younger children.

The difference between Leventon and colleagues (2014) findings and the present results could reflect a transition to adult-like EME effects that occurs in middle childhood, around 8 years of age. Indeed, Leventon and colleagues found age-specific changes in the neural response to emotional versus neutral pictures. Specifically, for younger participants (5-7.5 years), there was not a significant difference in the event-related potentials (ERPs) triggered by emotional and neutral pictures. In contrast, there were significant differences between the ERPs for emotional versus neutral pictures in older participants (7.5-8.9 years)—even though there were not significant differences in their memory for emotional and neutral pictures. These age differences in the neural response to emotional stimuli could foreshadow the emergence of EME effects in middle childhood.

An additional difference between Leventon and colleagues (2014) and the present study was the delay between memory encoding and test: 24 hours versus 2 weeks, respectively. The duration of study-test delay is critical for EME, because emotion is believed to impact memory in two ways: attention mediation and preferential consolidation. The former is a relatively fast-acting process, whereas the latter requires time for consolidation to occur before its effects are apparent (e.g., LaBar & Cabeza, 2006; Talmi & McGarry, 2012; Talmi, 2013). It is possible that in the age range tested by Leventon and colleagues (2014) the effects of emotion on attention were not adult-like, and the 24-hour delay was not long enough for preferential consolidation of the emotional stimuli to unfold. Thus, one explanation for the mixed results from studies of EME in children could be that the effects of emotion on attention during encoding are different from adults, and that preferential consolidation of emotional information requires longer periods (i.e., >24 hours) to unfold in children.

Adult studies have utilized behavioral and neuroimaging studies, along with pharmacological manipulations, to identify the mechanisms that generate behavioral EME effects. This line of research has elucidated many of the cognitive and neural mechanisms that generate EME in adults, including attention mediation and preferential consolidation. Broadly, emotion captures attention, and thereby facilitates preferential encoding of the emotional information, relative to neutral. In addition, emotional arousal triggers a cascade of neurobiological events that boost consolidation of emotional information, relative to neutral (see, e.g., Roozendaal & McGaugh, 2011; Talmi, 2013 for reviews). Delineating the mechanisms that drive EME effects, such as attention mediation and preferential consolidation, provides insight into what factors modulate EME, and, in turn, improves understanding of *how* emotion impacts memory. These mechanisms have been systematically investigated in adults, but not across development. Thus, at present, we do not have a robust developmental account of how emotion modulates subsequent memory across development.

We tested EME in a manner that should eliminate most sources of developmental difference: encoding was incidental, mnemonic strategies were not necessary, and participants did not need to report details about their memory or provide judgments of memory strength. This contribution is important, but leaves open questions about the development of EME. There remains a need to examine developmental change in EME for other types of memory, including recollection and recall. Ideally, future studies of EME across development will use multiple measures of emotion elicitation. Specifically, behavioral outcome measures can be bolstered with measures of physiological response and overt attention that directly index emotion processing and attention modulation, respectively (e.g., Leventon et al., 2014; Bauer et al., 2016). Finally, there is a need for developmental studies that systematically probe the mechanisms thought to generate EME effects, to determine whether the contributions of these mechanisms to EME effects are developmentally continuous. For instance, the relative magnitude of emotion effects on attention could be compared between children and adults.

Our results should be interpreted in the context of three limitations of the present study. First, we tested recognition memory for IAPS pictures. Whereas IAPS provide a well-controlled stimulus set, it is unlikely that they elicit emotion either of the same kind or magnitude as that experienced in contexts outside the laboratory. This limitation could be addressed in future studies by using dynamic stimuli, such as film clips or story passages. Second, our stimuli were not appropriate for, and our paradigm was too demanding to include, participants younger than 8 years old. Ideally, future studies of EME across development will be designed so younger participants can be included, as it is plausible that age differences in EME effects on recognition memory occur prior to middle childhood (e.g., Leventon et al., 2014). On the flip side, using pictures that are appropriate for children as young as 8 years old precluded the use of many pictures that adults consider to be more intensely emotionally arousing, such as erotica and violent imagery. Thus, it is likely that some of the age-related change we observed in EME in males reflects an attenuated emotional response in the older participants. Third, we utilized a cross-sectional design that cannot address whether EME effects change within an individual as they develop. In short, the present work should be complemented by studies that utilize a variety of stimuli and paradigms, include younger participants, and examine whether EME effects shift within individuals across development.

In conclusion, the findings of the present research extend and enrich the EME literature. First, we conducted a direct comparison of EME effects for both positive and negative stimuli across a wide range of ages, using the same stimulus set, paradigm, and methodology. Second, our large sample allowed us to evaluate both age and gender differences in EME, as well as possible interactions between these factors. Third, we identified gender differences in developmental trajectory of EME that emerge in early adulthood. We found that EME is present and robust for both genders in middle childhood, but that by early adulthood the magnitude of this enhancement remains stable for females, while it decreases for males. We propose that future work should assess the extent to which this finding might have resulted from age and/or gender differences in how effectively our stimuli elicited emotion, in order to determine whether there are in fact gender differences in the mechanisms of EME that emerge across development. Our results provide compelling evidence that emotion consistently enhances recognition memory from middle childhood through adulthood for both genders, but that there are small but significant gender differences in the developmental trajectory of EME.

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Table 1. *Memory performance by emotion condition, across participants (Panel A) and within-subjects correlations between age, participant ratings of picture valence and arousal, and magnitude of EME (Panel B).*

Panel A.

	Negative		Neutral		Positive	
	d'	*C*	*d'*	*C*	*d'*	*C*
Mean	1.92	0.16	1.33	0.43	1.48	0.18
St. Dev.	0.68	0.46	0.65	0.50	0.65	0.47
Min.	0.04	-1.04	-1.04	-0.88	-0.52	-1.04
Max.	3.79	1.19	3.46	1.62	3.15	1.40

Note. $N = 206$.

Panel B.

	Negative		Neutral		Positive	
	Valence	Arousal	Valence	Arousal	Valence	Arousal
Age	-.11	-.11	-.10	$-.26^{**}$	-.09	$-.25^{**}$
Negative-neutral *d'* difference	.06	-.05	.06	-.06	.02	.02
Positive-neutral *d'* difference	-.07	$.15^{*}$	.06	.03	$.12^{+}$	.11

Notes. $N = 204$. $^{+}$ Indicates uncorrected $p < .1$; * Indicates uncorrected $p < .05$; ** Indicates uncorrected $p < .001$

Table 2. *Self-assessment manikin (SAM) ratings of picture valence and arousal.*

Rating	Picture Valence	*M*	*SD*	*Min.*	*Max.*
Arousal	Negative	3.1	0.7	1.3	4.9
	Neutral	1.8	0.8	1.0	3.7
	Positive	2.8	0.8	1.0	4.8
Valence	Negative	2.0	0.5	1.0	4.1
	Neutral	3.1	0.3	1.9	5.0
	Positive	4.0	0.4	3.1	5.0

Note. N = 204.

Table 3. *Results of Welch's two sample t-tests comparing participants' SAM ratings of pictures valence and arousal by emotion.*

Rating	Comparison	*M* Difference	*t*	*df*s	*p*
Valence	Negative-neutral	-1.1	-26.9	344.6	< .0001
	Positive-neutral	0.9	24.4	389.1	< .0001
	Negative-positive	-2.0	-44.5	384.9	< .0001
Arousal	Negative-neutral	1.4	19.6	402.0	< .0001
	Positive-neutral	1.0	13.4	389.7	< .0001
	Negative-positive	0.4	4.9	401.4	< .0001

Table 4. *Descriptive statistics for mood and positive and negative affect (PANAS) ratings.*

Panel A. Mood ratings.

	N	*M*	*SD*	*Min.*	*Max.*
Pre-encoding	119	4.1	0.7	2.0	5.0
Post-encoding	114	4.3	0.8	2.0	5.0
Pre-recognition	123	4.1	0.9	1.0	5.0
Post-recognition	115	4.0	1.0	1.0	5.0
Rating change: Encoding	110	0.1	0.8	-2.0	2.0
Rating change: Recognition	114	-0.1	0.8	-2.0	2.0

Panel B. PANAS ratings.

	N	*M*	*SD*	*Min.*	*Max.*
Positive change, Encoding	151	3.3	5.3	-11.0	18.0
Negative change, Encoding	151	0.2	2.9	-10.0	7.0
Positive change, Recognition	149	3.1	4.8	-8.0	17.0
Negative change, Recognition	148	0.1	2.3	-6.0	8.0

Note. Positive mean values indicate higher scores at the beginning of the session (first administration) than at the end (second administration).

Table 5. *Results of regression models of the relationship between age, gender, and emotion effects on memory performance (Panel A) and memory bias (Panel B).*

Panel A.

	Negative-neutral *d'* difference			Positive-neutral *d'* difference		
	β (S.E.)	*t*	*p*	*β (S.E.)*	*t*	*p*
Age	-.01(.09)	-0.10	.92	-.02	-0.21	.83
Gender	.07(.14)	0.96	.33	.02	0.12	.90
Age x Gender	-.26(.14)	-1.88	.06	-.20	-1.46	.14

Panel B.

	Negative-neutral *C* difference			Positive-neutral *C* difference		
	β (S.E.)	*t*	*p*	*β (S.E.)*	*t*	*p*
Age	.02(.10)	0.24	.81	-.02(.10)	-0.21	.83
Gender	-.05(.14)	-0.75	.46	.01(.14)	0.12	.90
Age x Gender	.02(.14)	0.18	.86	-.20(.14)	-1.46	.14

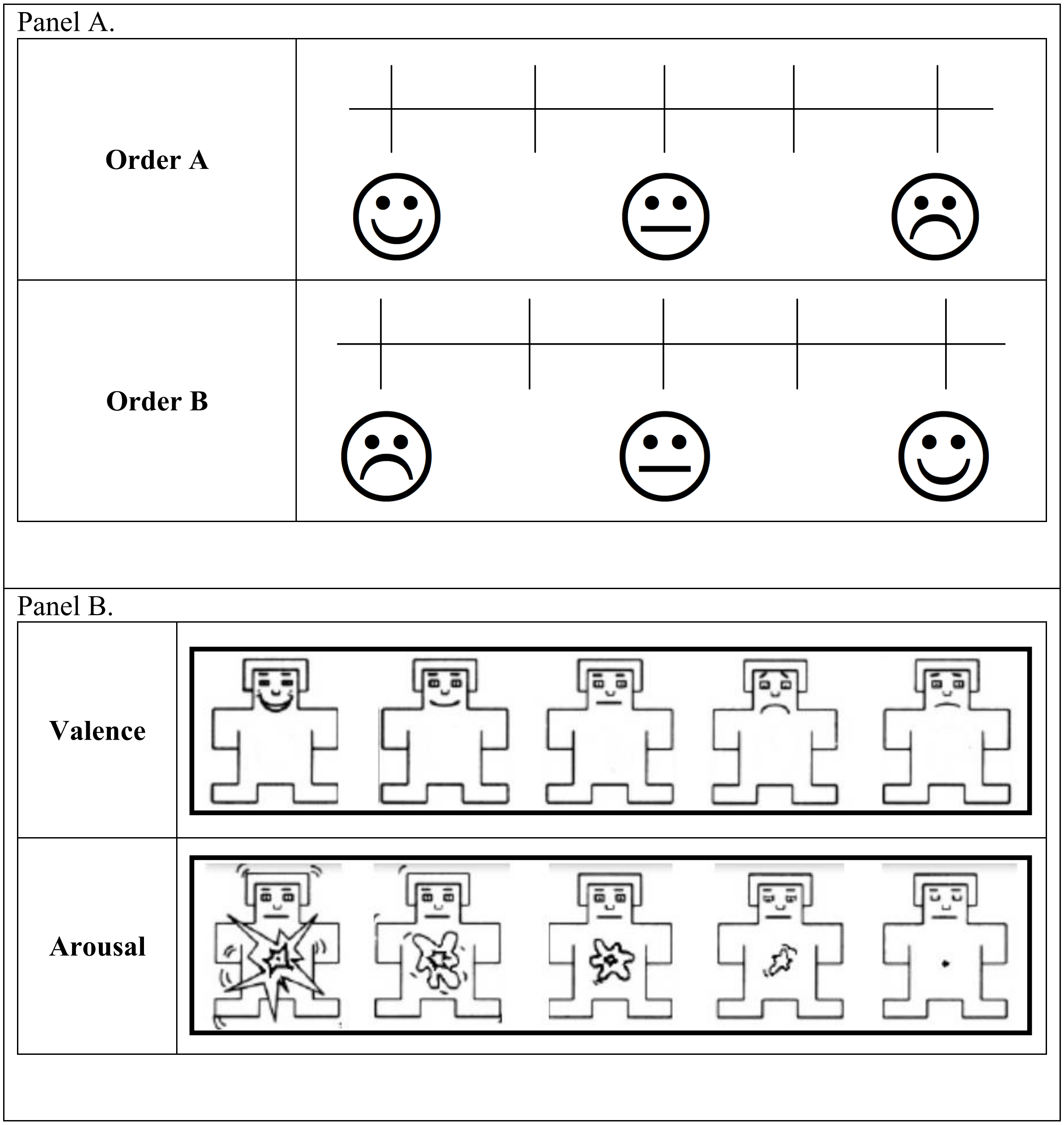


Figure 1. Mood (Panel A) and Self-Assessment Manikin (SAM) (Panel B) rating scales.

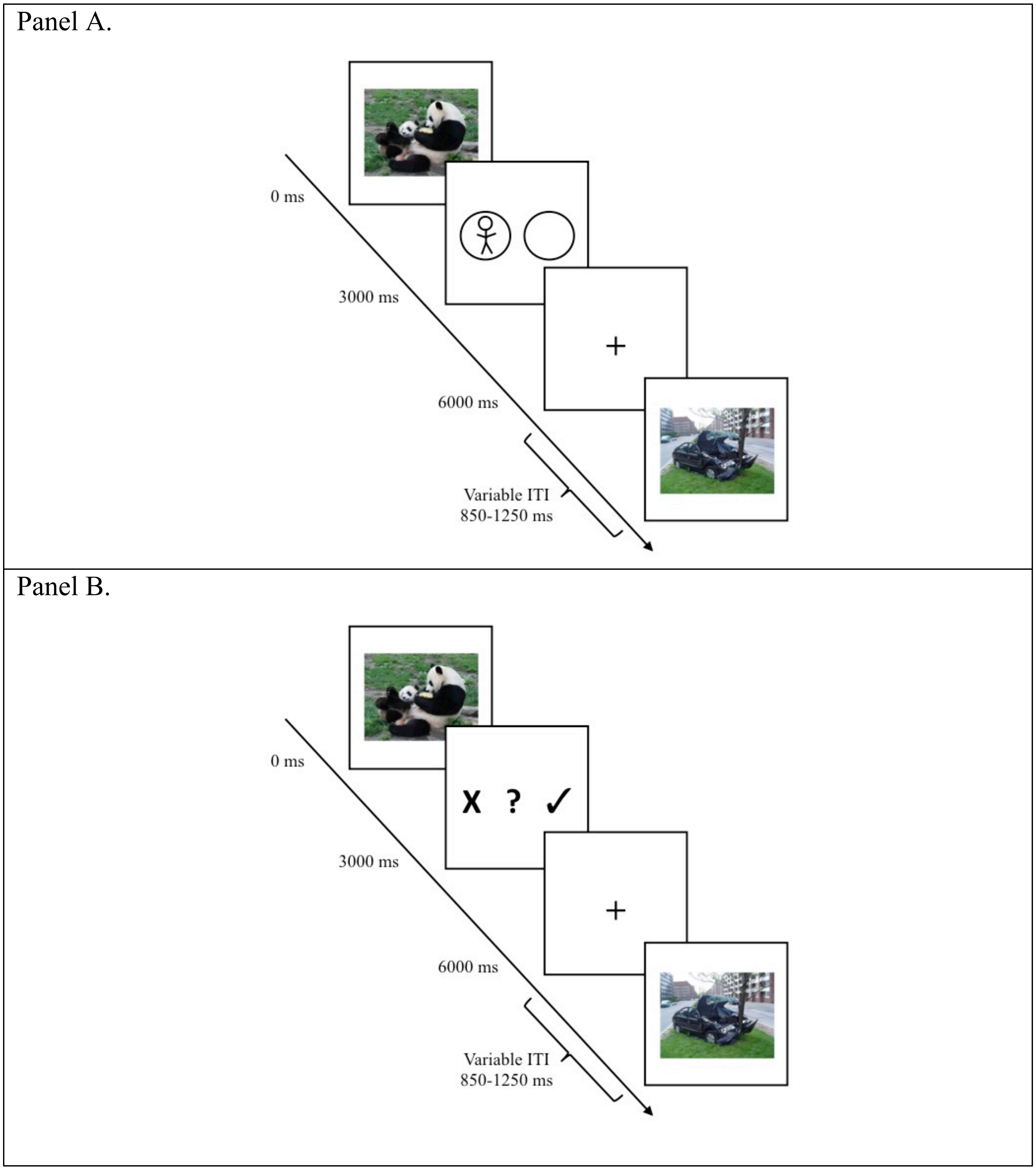
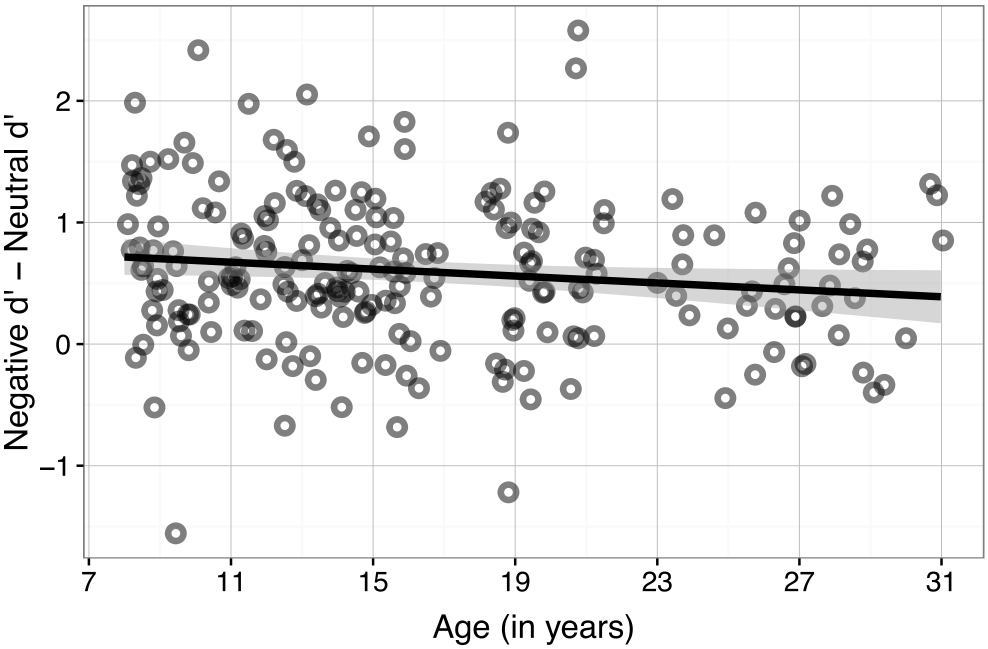


Figure 2. Trial structure during encoding (Panel A) and recognition (Panel B) sessions.

Panel A. *Difference in memory performance (d') for negative versus neutral pictures.*



Panel B. *Difference in memory performance (d') for positive versus neutral pictures.*

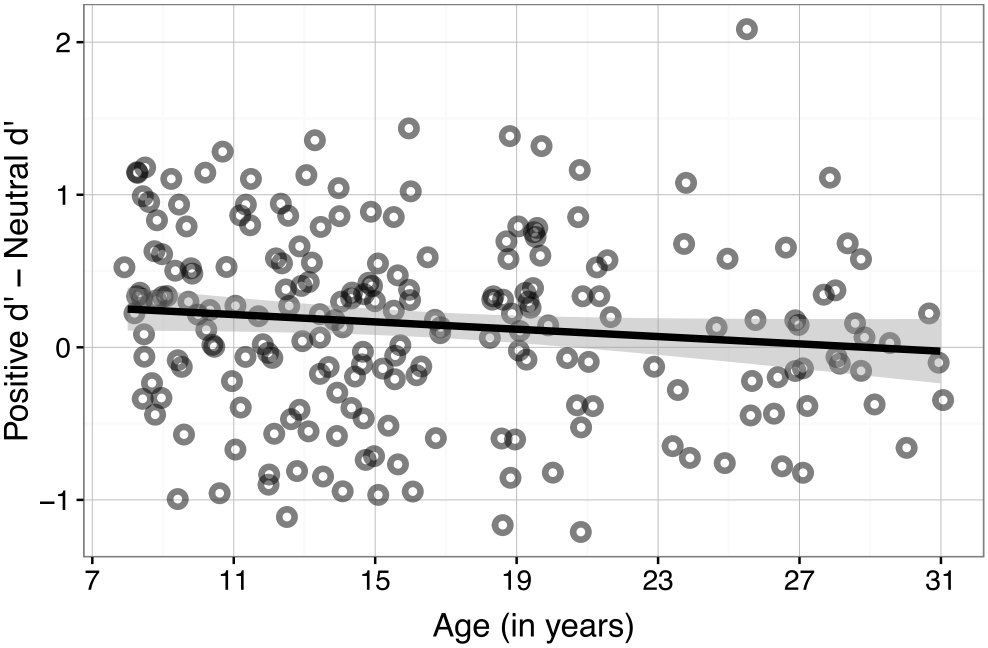
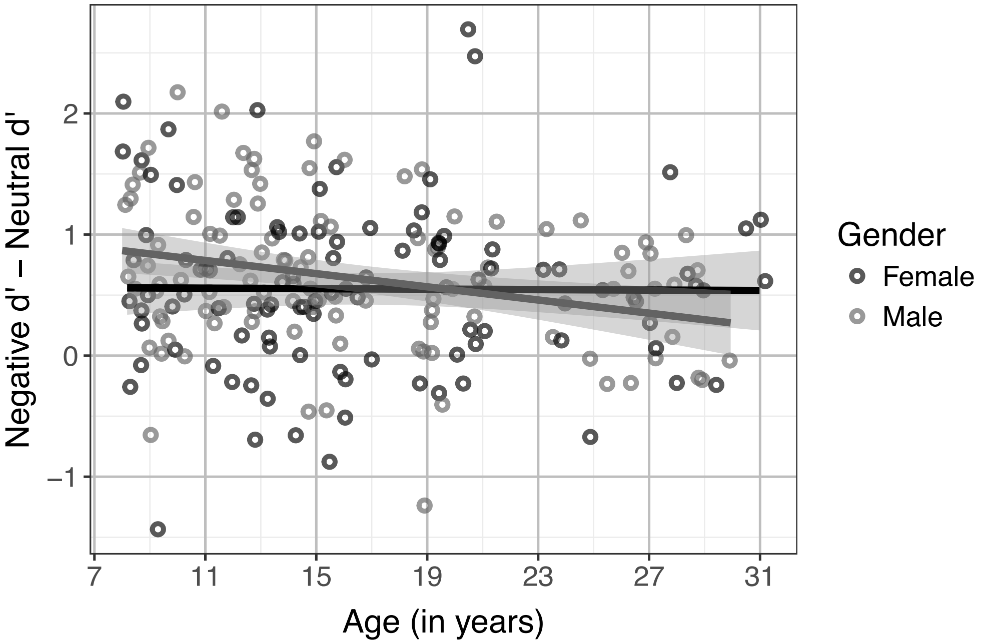


Figure 3. Magnitude of emotional memory enhancement for individuals aged 8 to 30. Shaded areas show 95% confidence intervals around the regression lines.

Panel A. *Difference in memory performance (d') for negative versus neutral pictures.*



Panel B. *Difference in memory performance (d') for positive versus neutral pictures.*

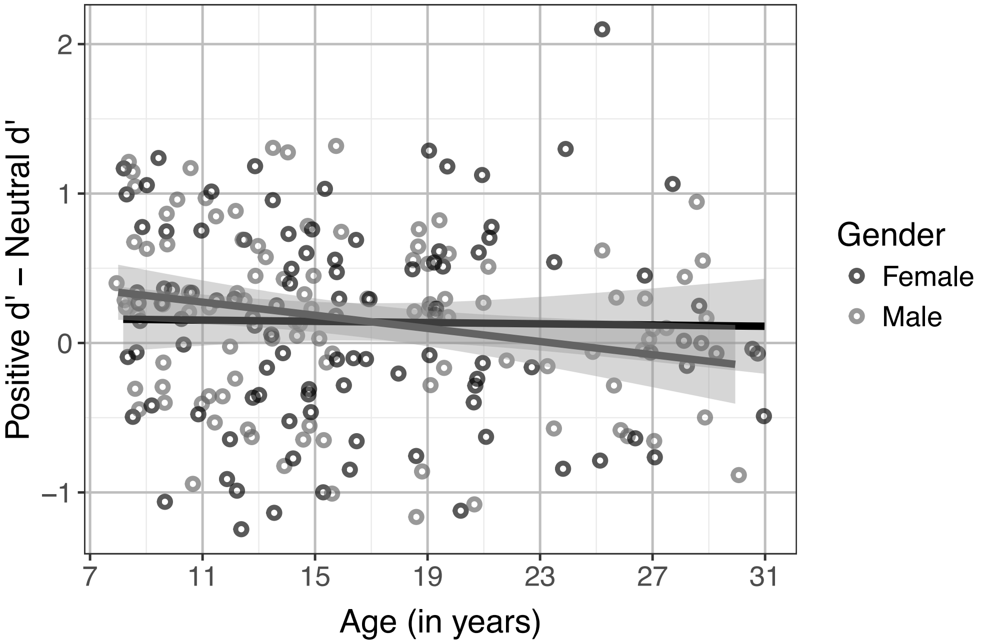


Figure 4. Magnitude of emotional memory enhancement for females and males aged 8 to 30. Shaded areas show 95% confidence intervals around the regression lines.

Paper 2

Emotion effects on event-related potentials are consistent from childhood through adulthood

Anaïs F. Stenson, Jacqueline S. Leventon, and Patricia J. Bauer

Abstract

Emotion has powerful effects on memory encoding processes. These emotional memory enhancement (EME) effects have been studied extensively in adults, but much less is known about EME across development. To map the developmental trajectory of EME effects, we examined behavioral responses and event-related potentials (ERPs) while 8- to 30-year-old participants viewed positive, negative, and neutral pictures. Two weeks later, we tested old/new recognition. We assessed: a) the impact of emotion on neural activity during encoding, as measured with event-related potentials (ERPs) in three temporal windows that have previously been shown to be modulated by emotion (150-300ms, 400-1000ms, and 1000-2000ms), and b) differences in the neural activity elicited during encoding by emotional and neutral pictures that were later correctly recognized. When all trials were analyzed, regardless of subsequent memory performance, emotion did not modulate ERPs in the early (150-300ms) window, but did modulate ERPs in both later windows (400-1000ms and 1000-2000ms). There were not significant relations between the impact of emotion on these ERPs and participants' age or gender. Analysis of the ERPs for trials that were later remembered revealed a similar pattern: emotion consistently modulated ERPs regardless of participant age or gender. These EME effects on both ERPs and memory were consistent across the age range and for both genders. These results suggest that emotion effects on recognition memory are apparent by middle childhood and that they are observed through early adulthood.

Keywords: memory, recognition memory, development, emotion, event-related potentials, gender

Introduction

Emotion has powerful, well-documented effects on cognitive processes, including memory (for reviews see, e.g., Banich et al., 2009; Kensinger & Schacter, 2008; Pessoa, 2008; Roozendaal & McGaugh, 2011; Yiend, 2010). There has been substantial progress in understanding emotion effects on memory in adults. In contrast, there has been less research on in children, particularly as they transition from middle childhood into adolescence, and then into early adulthood (for reviews see, e.g., Carver, 2014; Hamann & Stevens, 2014). As Del Piero, Margolin and Saxbe (2016) propose, it is particularly important to document emotion effects on cognition before, during, and after adolescence, as it is a phase of dramatically increased risk for negative health outcomes related to emotion processing and response, particularly mental illness (for a review see, e.g., Paus, Keshavan, & Giedd, 2008). The psychological tumult of adolescence has been linked to the profound neuroendocrine changes associated with puberty and associated brain development in areas that facilitate emotion processing and response, such as the amygdala, hippocampus, and medial prefrontal cortex (e.g., Gee et al., 2013; Gogtay et al., 2004; Østby et al., 2009; Satterthwaite et al., 2014; for reviews see, e.g., Del Piero, Saxbe, & Margolin, 2016; Heller & Casey, 2015; Scherf, Smyth, & Delgado, 2013). Thus, identifying changes in basic emotion processing and emotional effects on memory across this age range could elucidate how developmental change in these cognitive processes relates to mental health outcomes. At present, however, more is known about developmental differences in emotion processing than about developmental change in emotional memory enhancement (EME). The present study addressed the gap between the adult and developmental emotional memory enhancement (EME) literatures by examining the developmental trajectory of emotion effects on recognition memory from middle childhood through early adulthood using both behavioral and neural measures of emotional processing and memory.

A large body of literature connects emotional memory enhancement effects to increased amygdala activity in response to emotional versus neutral stimuli (e.g., Dolcos, LaBar, & Cabeza, 2004; Kensinger, Garoff-Eaton, & Schacter, 2006; Kensinger & Corkin, 2003; Lane, Chua, & Dolan, 1999). Multiple studies have documented age-related changes in the amygdala, which plays a central role in emotion. Results from several functional magnetic resonance imaging (fMRI) studies suggest that amygdala response to emotional and neutral faces is elevated in adolescents relative to both children and adults (Guyer et al., 2008; Hare et al., 2008; Passarotti, Sweeney, & Pavuluri, 2009). Studies have also documented changes in amygdala connectivity to other brain areas implicated in emotion and memory. Critically, Guyer et al. (2008) found greater amygdala-hippocampal connectivity in adults relative to adolescents while they viewed pictures of fearful versus neutral faces. In contrast, Gee et al. (2013) reported declines in amygdala-prefrontal connectivity, along with reduced amygdala reactivity to fearful versus neutral faces, between childhood and young adulthood; however, no age-related change was found in amygdala-hippocampal connectivity. These results suggest that the neural processing of emotional information and the connectivity between brain structures implicated in EME continue to develop across adolescence, but do not provide a unified account of amygdala-hippocampal connectivity changes. Interactions between the amygdala and hippocampus play a primary role in EME, therefore, developmental changes in their connectivity could generate developmental in EME (reviewed by, e.g., Roozendaal & McGaugh, 2011).

Relatedly, the amygdala is densely populated with receptors for the gonadal hormones, including estrogen and testosterone, which surge during adolescence and have been hypothesized to impact amygdala activity (e.g., Ladouceur, 2012; Scherf et al., 2013). Indeed, one study has documented gender differences in amygdala activation during emotion processing tasks in adolescents (e.g., Schneider et al., 2011), however, others have not (e.g., McClure et al., 2004). At present, there is not a clear picture of whether neuroendocrine and neural developments between middle childhood and adulthood contribute to gender-specific changes in emotion processing and memory. However, together these factors suggest that EME effects could change between middle childhood and adulthood, and that the trajectory of any such changes might be gender-specific.

Several studies report gender differences in EME, including enhanced memory for negative stimuli in women versus men and gender differences in the patterns of brain activity elicited by emotional stimuli that are later remembered (e.g., Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004; Canli, Desmond, Zhao, & Gabrieli, 2002; Gasbarri et al., 2006; Glaser, Mendrek, Germain, Lakis, & Lavoie, 2012). Although these gender differences have been widely referenced (e.g., Altemus, 2006; Andreano & Cahill, 2009; Cahill, 2006; Hamann, 2012), multiple studies of EME have not found gender differences in either neural processing, memory performance, or both (e.g., Anderson, Wais, & Gabrieli, 2006; Cordon, Melinder, Goodman, & Edelstein, 2012; Hurlemann et al., 2005; Kensinger, Garoff-Eaton, & Schacter, 2007; Spalek et al., 2015; Talmi, Anderson, Riggs, Caplan, & Moscovitch, 2008; Waring & Kensinger, 2011). Few developmental data exist that inform this question. Bauer, Stevens, Jackson, and San Souci (2012) observed gender differences in neural activity during emotional autobiographical memory recall. However, since the study compared neural activity elicited by successfully remembered negative, neutral, and positive autobiographical memories, there was not a direct comparison of relative EME effects between genders. In contrast, Cordon et al. (2013) documented equivalent emotion ratings and recognition memory for emotional pictures between genders, but did not measure neural processes. These inconsistencies in findings of gender differences, and the absence of developmental data, warrant further inquiry into the magnitude and etiology of gender differences in the emotional memory enhancement effect. One approach to that inquiry is to study the effect across development and between genders, as in the present work.

To delineate the developmental trajectory of emotion effects on ERPs and memory, it is critical to conduct the same studies with children and adults. For the most part, however, the developmental and adult literatures on emotion effects on memory have utilized different methods and stimuli thereby obfuscating the source of any observed differences. Adult studies of EME typically use standardized stimulus sets (e.g., the International Affective Picture System (IAPS); Lang, Bradley, & Cuthbert, 2008), control conditions during encoding and testing, and then compare memory for emotional and neutral stimuli. Typically, more emotional items are remembered than neutral (see, e.g., Kensinger & Schacter, 2008; Murphy & Isaacowitz, 2008; Talmi, 2013 for reviews). The widespread use of standardized stimuli and testing parameters facilitates direct comparisons of EME effects between subjects and across studies. In contrast, developmental studies of EME often investigate children’s memories for naturally-occurring emotional events (see, e.g., Goodman, Quas, & Ogle, 2010, for a review). Because the goal of these studies is not to examine EME effects, they do not utilize systematic manipulation of emotion; Rather than examining the memory differential between emotional and neutral, these studies were designed to ascertain whether and how children remember emotional events. These studies have shown that children recall emotional events in greater detail than neutral events (e.g., Ackil, Van Abbema, & Bauer, 2003; Bauer et al., 2017; Fivush, Hazzard, McDermott Sales, Sarfati, & Brown, 2003). However, because the goal of these studies is to examine retrospective reports of personal experiences, they are not designed to: a) make direct comparisons of EME between subjects and b) produce results that are directly comparable with those from the adult EME literature.

A few developmental studies have examined EME using stimuli and paradigms that parallel adult EME studies, however, they have produced a mixed pattern of results that does not yield clear account of EME across development. Cordon et al. (2012) showed 7- to 9-year-olds and young adults negative and neutral pictures and measured recognition memory one week later; the adults remembered more neutral pictures than the children, but memory performance for negative was equivalent. Leventon, Stevens, and Bauer (2014) showed 5- to 8-year-olds negative, neutral, and positive pictures and did not observe EME effects on recognition memory. Vasa et al. (2011) showed 12-17 year old adolescents and adults negative, neutral, and positive IAPS pictures before conducting a free recall task; there were robust EME effects for both groups. These studies each tested different age ranges and used different paradigms; therefore, it is difficult to offer a robust interpretation of their mixed results.

Interpretation of developmental differences in behavioral EME can be facilitated by inclusion of other measures of emotion processing and memory encoding. Studies using event-related potentials (ERPs) suggest that both time course of emotion processing and the neural response to emotional versus neutral stimuli shift across childhood (e.g., Hajcak & Dennis, 2009; Leventon, Stevens, & Bauer, 2014). Hajcak and Dennis (2009) examined ERPs following presentation of emotional and neutral pictures in 5- to 8-year-old children and found no evidence for an ERP signature of emotion processing, called the Early Posterior Negativity (EPN). The EPN is a negative deflection in the neural response to emotional versus neutral stimuli that appears over posterior cortex approximately 150-300 ms after stimulus onset (e.g., Leite et al., 2012; Schupp et al., 2006; Schupp, Junghöfer, Weike, & Hamm, 2003). In contrast, Hajcak and Dennis (2009) did observe the Late Positive Potential (LPP), another ERP signature of emotional processing. Similarly, Leventon, Stevens, and Bauer (2014) found that emotion enhanced the LPP in both older (7.6-8.9 years old) and younger (5.5-7.5 years old) children, however, the effect appeared by 800–1200ms in the older children, but not until 1600–2000ms in the younger children. The LPP is a positive deflection that manifests over central-parietal cortex for emotionally arousing relative to neutral stimuli; it is typically maximal from 500 to 1500 ms after stimulus onset (e.g., Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak & Dennis, 2009; Herbert, Junghofer, & Kissler, 2008; Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp et al., 2006; Weinberg & Hajcak, 2010). The LPP is typically larger for items that are later remembered (e.g., Dolcos &

Cabeza, 2002). Results from Hajcak and Dennis (2009) and Leventon et al. (2014) both indicate that emotion effects on ERPs develop throughout middle childhood, and that the neural response to emotion might accelerate across childhood.

Currently, the lack of closely parallel studies of EME across development impedes our understanding of how emotion processing and EME effects change across the lifespan. It has been suggested that the prevalence of disorders that involve maladaptive emotion processing make it important to understand how emotion processing and EME manifest across development, especially during adolescence, when gonadal hormone levels, gender differences in brain development, and mental illnesses all surge (e.g., Del Piero et al., 2016). To date, the developmental trajectory of EME effects in both brain and behavior is not fully articulated, and we do not know if that trajectory is gender-specific. The present research addresses this gap by documenting how emotion processing impacts brain, behavior, and memory from middle childhood through adulthood. We examined EME of recognition memory in from middle childhood, prior to the onset of adolescence, through young adulthood (ages 8-30 years). To facilitate comparison of performance across this age range, the same stimuli, paradigm, and analyses were used for all participants. We assessed, a) the impact of emotion on neural activity, measured as ERPs, in three temporal windows, the EPN (150-300ms), an early LPP (400-1000ms), and a late LPP (1000-2000ms), b) the neural indices of subsequent memory for emotional versus neutral stimuli in the LPP window, and c) the effect of emotion on recognition memory performance. This study design allows for direct comparison of emotion effects on neural processes at encoding and on recognition memory performance across a wide age range and between genders.

We hypothesized that EME effects would emerge gradually across the tested age range, and that there might be gender differences in the trajectory of that emergence. Based on prior literature, we predicted emotion effects on the EPN in older, but not younger, participants, whereas we predicted significant emotional modulation of the LPP for all participants. The variable findings of gender differences, or lack thereof, for both the EPN and LPP components precluded formulation of a robust hypothesis regarding gender differences in the ERP data. Thus, we sought to determine whether EME effects on recognition memory—measured both with memory performance and ERPs—change between middle childhood and early adulthood, if gender was related to memory performance, and if any observed developmental changes would be gender-specific.

Method

Data were collected at a large, private Southeastern university. Initially, 150 children (73 female), ages 8 to 16, and 88 adults (45 female), ages 18 to 30, enrolled in the study (total *N* = 238). Of those participants, both sessions were completed and both behavioral and ERP data were usable for 119 children (59 female), and 76 adults (39 female). All analyses reported herein include these participants' data (final *N* = 195). Participants self-reported, or parents reported, their race as follows: 33 African-American, 25 Asian, 120 Caucasian, 13 multi-racial. Four did not report their race. Participants also self-reported ethnicity: 11 Hispanic or Latino and 178 not Hispanic or Latino. Six participants did not report their ethnicity. Children were recruited from a database of families that had previously expressed interest in study participation through the university's Child Study Center. Although detailed data on socioeconomic status were not collected, the pool is comprised primarily of families from educated middle- to upper-middle-class SES. Guardian report of highest educational achievement in the household indicated that 5% had completed some college, 7% completed a technical or associate's degree, 23% completed a college degree, 8% completed some graduate school, and 55% completed a post-graduate degree; 2% did not provide this data. Information about education was not systematically collected from adult participants. Prior to testing the children, their guardians provided written informed consent. The children received a gift card to a major retail chain for their participation. Adult participants were recruited through either the university psychology subject pool or via advertisements posted on the university campus. They provided written informed consent and received either course credit or a gift card to a major retail chain for their participation. All procedures were reviewed and approved by the university's IRB.

Materials

157 child-appropriate pictures (57 negative, 50 neutral, and 50 positive) were selected from the International Affective Picture System (IAPS; Lang et al., 2008) and a lab-collected set of similar pictures. To control for previously reported biases in affective processing of pictures containing humans (Proverbio, Adorni, Zani, & Trestianu, 2009), 50% of the pictures in each emotion condition included humans and 50% did not. The same pictures were used for all participants, regardless of age. This set of pictures was used to create eight presentation orders that were used for both child and adult participants. Before children came to the lab, thumbnails of all 157 pictures were sent via email to the guardian to approve presentation of the images (procedure approved by Lang, personal communication). If the guardian requested that specific pictures be removed, they were replaced with alternate pictures of the same valence. Regardless of

any such replacements, every participant saw 50 negative, 50 neutral, and 50 positive pictures.

The study consisted of two sessions separated by approximately 14 days (M = 14.15(*1.01*), *Range* = 11-20). During Session 1, participants viewed the stimuli and engaged in a behavioral task to ensure attention to the pictures. Before starting the picture viewing and again after viewing was complete, all children rated their mood, using a 5-point emoticon scale (see Figure 1, Panel A), and all participants aged 11 years or older completed the Positive and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988). During Session 2, participants viewed all pictures from Session 1, along with new pictures, and completed a recognition memory task. Like Session 1, participants provided mood and/or PANAS ratings both before and after the picture task. At the end of Session 2, participants provided subjective ratings of valence and arousal for a subset of the pictures using the modified Self-Assessment Manikin shown in Figure 1, Panel B (SAM; Bradley & Lang, 1994). Picture presentation in both Sessions 1 and 2 was controlled using Advanced Neuro Technology eevoke™ software. All pictures were presented in full color at 30.5 cm (h) × 23 cm (w) in size, subtending a visual angle of approximately 15.6° (h) × 20.6° (w).

Electrophysiological (EEG) data in Sessions 1 and 2 was recorded using an elastic-lycra 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 3) arranged according to the International 10-5 system, an adaptation of the International 10-20 system (Jasper, 1958). Impedances were generally under 5k**Ω**. Using an ASA amplifier (A.N.T. Software B.V., Enschede, The Netherlands) the EEG data were sampled continuously at 256 Hz and amplified 20,000 times.

Session 1.

After consent procedures, participants were oriented to the task and EEG capping procedure. Application of the cap typically took 20-40 minutes, during which time participants completed the pre-session mood and/or PANAS ratings. The experimenter then explained the importance of remaining still and relaxed throughout the EEG recording. Before recording, three neutral pictures, which did not appear in the testing phase, were presented as practice trials to establish that participants understood the task.

EEG data were then collected as participants viewed 90 pictures (30 of each valence) presented in a pseudo-randomized order. No more than two images of the same valence preceded one another. The images and presentation order were counterbalanced across participants. Each picture was presented for 3000ms and immediately followed by a decision screen lasting for 3000ms that prompted participants to indicate if the prior picture contained a human. A fixation-cross ('+') was onscreen during the 850 to 1250ms inter-stimulus interval.

During picture presentation, participants used a game controller to indicate if each picture contained a human. The position of the response options was counterbalanced across participants. Five additional positive images were included at the end of each presentation to conclude on a positive note; These trials were not included in analyses. A trial schematic is presented in Figure 2, Panel A. The picture presentation and EEG recording lasted approximately 9 minutes. Participants then completed the post-session mood and/or PANAS ratings prior to having the EEG cap removed. Altogether, Session 1 typically lasted between 1hr and 1hr30m.

Session 2.

Participants were fitted with an EEG cap while they completed the pre-session mood and/or PANAS ratings. Prior to EEG recording, participants were asked to remain still and relaxed throughout the EEG recording. Participants were then instructed to look carefully at pictures presented on the monitor, some of which were shown during Session 1 (i.e., were ‘old’) and some of which were new, and do their best to determine if each picture was old or new. They then indicated whether they thought each picture was ‘old,’ ‘maybe old,’ or ‘new’ via a button press on a game controller. The position of the response options was counterbalanced across participants. Participants completed three practice trials (same images as Session 1 practice) to ensure that they understood the task. Once participants affirmed that they understood the instructions, picture presentation and data recording began.

Participants viewed 150 pictures (50 negative, 50 neutral, and 50 positive) while EEG data and button-press responses were recorded. These included the 90 pictures from Session 1 (30 per valence) and 60 new pictures (20 per valence), which the participant had not seen before. Like Session 1, the order of picture presentation was pseudo-randomized so that no more than two images of the same valence preceded one another. The eight presentation orders were counterbalanced so that across participants all pictures were used equally in the old and new conditions. Five positive images were added to the end of the session to conclude on a positive note; These trials were not included in any analyses. Each picture was presented for 3000ms, followed by the 'old'/'maybe old'/'new' decision screen for 3000ms. A fixation-cross ('+') was onscreen during the 850 to 1250ms inter-stimulus interval. A trial schematic is presented in Figure 2, Panel B. The recognition task lasted approximately 18 minutes for all participants.

Following the recognition task, participants completed the post-session mood and/or PANAS ratings prior to having the EEG cap removed. Participants then provided subjective valence and arousal ratings for 45 images (15 from each emotion condition) using the modified SAM, shown in Figure 1, Panel B. The SAM was abbreviated from the full 9-point version of the scale to reduce participant burden for the children (Leventon et al., 2014). The modified SAM consisted of one 5-point scale for valence (1 = very unpleasant, 3 = neutral, and 5 = very pleasant), and another for arousal (1 = very low arousal, 5 = very high arousal). Altogether, Session 2 typically lasted between 1hr20m and 1hr45m.

Data reduction.

EEG data.

Mean value (DC bias) was removed from the EEG data before initial 0.1Hz highpass filtering (infinite impulse response function Butterworth filter, roll-off = 24dB/octave, half-amplitude cutoff = -6dB) using EEGLAB 13.4.4 (Delorme and Maekig, 2004) and ERPLAB 4.0.3.1 (www.erplab.org) operating in Matlab 2014b (MathWorks, Natick, MA, USA). Independent component analysis (ICA) was applied after highpass filtering to identify and remove artifacts resulting from eyeblinks, heartbeat, muscle activity, channel noise, and 60Hz noise using both experimenter examination of the continuous EEG data and the “automatic EEG artifacts detector with joint use of spatial and temporal features” (ADJUST) algorithm (Mognon, Jovicich, Bruzzone, & Buiatti, 2011). After ICA, a 40Hz lowpass filter (infinite impulse response function Butterworth filter, roll-off = 24dB/octave, half-amplitude cutoff = -6dB) was applied to the EEG data before re-referencing to mathematically linked mastoids. EEG data was segmented into 2750ms epochs beginning 250ms before picture onset and ending 2500ms after picture onset. A 250ms pre-stimulus window was used to correct for baseline activity in each epoch. Epochs in which EEG amplitude changed more than ±150mV were excluded from analyses.

Event-related potentials.

The EEG epochs were classified according to picture valence (negative, neutral, or positive) and subsequent memory performance (via back-sorting trials based on performance during Session 2). The encoding trials were classified according to whether or not the picture was correctly remembered at Session 2: encoding trials that were associated with pictures that were later correctly identified as ‘old’ or ‘maybe old’ (during Session 2) were classified as ‘hits,’ whereas encoding trials for those pictures that were later incorrectly identified as ‘new’ (during Session 2) were classified as a ‘misses’.

Emotion effects on the ERPs were examined in three time windows: 150-300ms, 400-1000ms, and 1000-2000ms. The 150-300ms window often includes the EPN component, thus ERPs in an occipital-parietal cluster (electrodes: P7, P3, O1, P8, P4, O2, Pz, POz, Oz; see Figure 3, Panel A) were analyzed by emotion condition. The 400-1000ms and 1000-2000ms windows typically contain the LPP, thus data from a central-parietal cluster (electrodes: Cz, C3, C4, CP1, CP2, CP5, CP6; see Figure 3, Panel B) were also analyzed by emotion condition. Participants were included in analyses of emotion effects on ERPs if at least 10 trials per valence condition were usable ($M_{Negative}$ = 29.2(*2.6*), $M_{Neutral}$ = 29.2(*2.6*), $M_{Positive}$ = 29.3(*2.4*)). Subsequent memory (Dm) effects (i.e., ERPs for hit trials only) were analyzed in the 400-1000ms and 1000-2000ms windows for the central-parietal cluster defined above. Fewer participants (*N* = 170) met the criterion of at least 10 hit trials per valence condition ($M_{Negative}$ = 23.4(*3.9*), $M_{Neutral}$ = 18.4(*4.6*), $M_{Positive}$ = 21.3(*4.4*)).

Analytic approach: Memory data.

Following prior research, we evaluated participants' discrimination between old and new images by calculating *d',* a discriminability index (e.g., Banks, 1970, Snodgrass & Corwin, 1988, Macmillan & Creelman, 2005; Wixted, 2007). We calculated *d'* by first calculating *z* scores for hit (HR) and false alarm (FA) rates, and then subtracting *z*(FA) from *z*(HR). Thus, for each participant *d'* = *z*(HR) - *z*(FA). This *d'* value indexes how well participants distinguished old items from new items. Hit and FA rates of 1 or 0 were corrected in accordance with Macmillan and Kaplan's (1985) recommendation: rates of 0 were replaced with 0.5 / *n* and rates of 1 were replaced with (*n* – 0.5) / *n,* where *n* is the total possible number of hits or false alarms. We quantified the degree of EME within-subjects by computing difference scores in *d'* for each emotion condition relative to neutral (e.g., negative *d'* – neutral *d'*).

Analytic approach: ERP data.

We analyzed the mean amplitude of the EPN and LPP components. Mean amplitude characterizes the magnitude and direction of the ERP within specific windows. To isolate emotion effects on these ERPs, we calculated the mean amplitude difference for both negative versus neutral trials and positive versus neutral trials (i.e., $\text{MeanAmp.}_{\text{Neg}}$ - $\text{MeanAmp.}_{\text{Neut}}$ and $\text{MeanAmp.}_{\text{Pos}}$ - $\text{MeanAmp.}_{\text{Neut}}$). These difference scores were the dependent variable in all ERP analyses. This approach enabled us to treat age as a continuous variable for all analyses, rather than collapsing age into groups to use a more conventional analysis of variance for statistical analysis of the ERPs.

Results

Previously reported analyses (Stenson, Leventon, & Bauer, 2017) of the mood ratings and PANAS results indicated that there were not meaningful age or gender differences in task effects on mood and/or affect, or on memory bias (*C*). Therefore, analyses of these data are not reported here.

All analyses were conducted in R 3.3.1 (R Core Team, 2016). The normality of the distributions of all dependent variables was evaluated with Shapiro-Wilk normality tests; the results indicated non-normal distributions. Therefore, the significance of all *t*-tests and Pearson correlations were evaluated against the distribution of 5000 bootstrapped resamples using the 'boot' package; these resamples were also used to generate confidence intervals (Canty & Ripley, 2016). Test statistics evaluated for significance against a bootstrapped null distribution are indicated by the addition of '*' after the statistic abbreviation (e.g., *t**). The impact of emotion on dependent variables was tested with one-tailed, one-sample *t*-tests, in which the mean amplitude difference was compared against 0.

The distributions of the dependent variables across the age range were heteroscedastic. Specifically, residuals varied more for younger versus older participants. This precluded the use of ordinary least squares regression models to analyze the relations between age, gender, and the dependent variables. Therefore, we used weighted least-squares regression models, in which the residuals were weighted as a function of participant age (1/Age) to correct for the impact of heteroscedasticity. For these linear models, the β-weights and standard errors for each predictor were generated from 5000 bootstrapped case-based resamples in the 'car' package (Fox et al., 2012). The β weights and standard errors for each predictor are shown in Table 4. The mean amplitude differences, overall and by gender, for each ERP component are reported in Table 3.

Memory Performance Data

Behavioral results are summarized in Table 1. Because this analysis includes a subset of the participants included in the previously reported behavioral study, the behavioral results reported herein differ slightly. Memory performance was elevated for negative and positive relative to neutral pictures. This pattern of emotional memory enhancement (EME) diminished slightly, but significantly, across the tested age range. The negative correlation between age and the negative-neutral *d'* difference approached statistical significance (without corrections for multiple comparisons), *r*(193) = -.13, *p* = .07. There was a significant negative correlation between age the positive-neutral *d'* difference, *r*(193) = -.14, *p* = .03.

ERPs for All Trials

Early posterior negativity (EPN).

Negative versus neutral.

The mean amplitude difference following negative versus neutral pictures was not significantly less than 0, *t**(194) = -0.69, *p* = 0.32, 95% C.I. [-Inf., 0.96], *d* = -0.05, indicating that negative emotion did not modulate this ERP. Age was not significantly correlated with the negative-neutral mean amplitude difference, *r**(193) = .14, *p* = .15, [0.0, 0.28]. There were not significant gender differences in the mean amplitude difference, *t(*178.62*)* = .018, *p* = .494[-3.73, 3.78], *d* = 0.30. A regression which included age, gender, and their interaction as predictors indicated that the mean amplitude difference was marginally less for males than females ($\beta_{Male} = -.28, t = -1.71,\ p = .09, 95\%$ CI $[-.57, -.02]$), but that neither age nor the interaction of age and gender were significant predictors. Overall, the model did not account for a significant proportion of the variance in the negative-neutral EPN difference, *F*(3, 191) = 2.29, *p* = .08, R^2 = .03.

Positive versus neutral.

The mean amplitude difference following positive versus neutral pictures was not significantly different than 0, *M* = -1.05(0.96), *t**(194) = -1.06, *p* = .22, 95% C.I. [-Inf, 0.55], *d* = 0.08. The correlation between age and the magnitude of the positive-neutral difference was significant before correction for multiple comparisons, *r**(193) = .19, *p* = .05, 95% C.I. [.05, .32]. There were not significant gender differences in the mean amplitude difference, *t*(179.74) = -0.01, *p* = .49, [-3.78, 3.73], *d* = 0.18. Results of a regression indicated that neither age, gender, nor their interaction independently predicted mean amplitude difference (see Table 4), but that they jointly explained a small but significant proportion of the variance in the positive-neutral EPN difference, *F*(3,191) = 3.01, R^2 = .04, *p* = .03.

Late positive potential, 400-1000ms (early LPP).

Negative versus neutral.

The negative-neutral mean amplitude difference was significantly greater than 0, *t**(194) = 3.73, *p* = .004, 95% CI [2.66, Inf.], *d* = 0.27. The positive correlation between age and the negative-neutral difference approached significance, *r**(193) = .16, *p* = .09, [.03, .30]. There were not significant gender differences in the mean amplitude difference, $t^*(193) = -.01$, $p = .50$, [-5.15, 5.09], $d = 0.19$. Together, age, gender, and their interaction explained a significant proportion of the variance in mean amplitude difference, $F(3,191) = 2.78$, $p = .03$, $R^2 = .04$, however, neither predictor was independently significant (see Table 3).

Positive versus neutral.

The mean amplitude difference was significantly greater than 0 in the early LPP window, $t^*(194) = 6.90$, $p < .0001$, 95% CI [5.71, Inf.], $d = 0.49$. The correlation between age and mean amplitude difference was not significant, $r^*(193) = .12$, $p = .20$, [-0.02, 0.25]. There were not significant gender differences in mean amplitude, $t^*(193) = -0.01$, $p = .50$, [-4.04, 4.00], $d = 0.23$. Together, age, gender, and their interaction were not significant predictors of the positive-neutral ERP difference, $F(3,191) = 2.40$, $p = .07$, $R^2 = .04$ (see Table 3).

Late positive potential, 1000-2000ms (late LPP).

Negative versus neutral.

The mean amplitude difference was significantly greater than 0, $t^*(194) = 4.83$, $p = .001$, 95% CI [3.73, Inf.], $d = 0.35$. Age was not significantly correlated with the negative-neutral difference, $r^*(193) = .06$, $p = .41$, [-.08, .19]. There was not a significant gender difference, $t^*(193) = 0.004$, $p = .50$, [-4.70, 4.72], $d = 0.19$. Together, neither age, gender, nor their interaction predicted the magnitude of the negative-neutral differences in the late LPP window, $F(3,191) = 1.82$, $p = .14$, $R^2 = .03$ (see Table 3).

Positive versus neutral.

The mean amplitude difference was significantly greater than 0, $t^*(194) = 7.16$, $p < .0001$, 95% CI [5.01, Inf.], $d = 0.51$. Age was not significantly correlated with the magnitude of this difference, $r^*(193) = .08$, $p = .33$, [-.06, .22]. There were not significant gender differences in mean amplitude, $t^*(193) = -0.02$, $p = .49$, [-3.65, 3.59], $d = 0.28$. Although neither age nor gender independently predicted a significant proportion of the variance in the positive-neutral ERP difference, together they did account for a small but statistically significant proportion of the variance in mean amplitude difference, $F(3,191) = 2.59$, $p = .05$, $R^2 = .04$ (see Table 3).

Summary of emotion effects on ERPs.

These results indicate that emotion did not modulate ERPs in the early window (EPN), but did in both the early and late LPP windows. Across all three ERP windows, neither age, gender, nor their interaction predicted a significant proportion of the emotional-neutral mean amplitude difference. However, these predictors jointly accounted for a small but significant proportion of the variance in, a) the negative-neutral mean amplitude difference in the EPN window, and b) the positive-neutral mean amplitude difference in the late LPP window. Overall, these results indicate that emotion modulated ERPs in both LPP windows, but that age and gender have little or no impact on those effects.

ERPs for Correctly Remembered ('Hit') Trials

The ERPs in both LPP windows were compared for only those pictures that were later correctly remembered (during the Session 2 recognition memory test), in order to examine the impact of emotion on the ERP response when subsequent memory performance was equivalent across emotion conditions. The ERPs for pictures that were correctly remembered were compared using emotional-neutral difference scores, as in the proceeding analyses of all encoding trials (e.g., $\text{MeanAmp.}_{\text{NegativeHits}} - \text{MeanAmp.}_{\text{NeutralHits}}$

= MeanAmp.$_{\text{Negative - Neutral}}$ Hit Difference). A minimum threshold of 10 trials per emotion condition was set, which reduced the number of participants included in these analyses from 195 to 170.

Late positive potential, 400-1000ms (early LPP).

Negative versus neutral.

The mean amplitude difference was significantly greater than 0, $t^*(169) = 3.50$, $p = .01$, 95% CI [1.49, Inf.], $d = 0.27$. Age was not significantly correlated with the magnitude of this difference, $r^*(168) = .18$, $p = .07$, [.04, .33]. There were not significant gender differences in either mean amplitude variance, $F(88, 80) = 1.15$, $p = .52$, or mean amplitude, $t^*(168) = -0.02$, $p = .50$, [-3.26, 3.20], $d = -0.002$. Although neither age, gender, nor their interaction independently predicted a significant proportion of the variance in the negative-neutral ERP difference, together they did account for statistically significant proportion of the variance, $F(3,166) = 3.22$, $p = .02$, $R^2 = .06$ (see Table 3).

Positive versus neutral.

The mean amplitude difference was significantly greater than 0, $t^*(169) = 5.275$, $p = .000$, 95% CI [2.645, Inf.], $d = 0.406$. Age was not significantly correlated with the magnitude of this difference, $r^*(168) = .1595$, $p = .118$, [0.010, 0.302]. There were not significant gender differences in either mean amplitude variance, $F(88, 80) = 0.831$, $p = .396$, or mean amplitude, $t^*(1, 168) = -0.011$, $p = .490$, [-1.785, 2.892], $d = 0.243$. Neither age, gender, nor their interaction predicted a significant proportion of the variance in the positive-neutral mean amplitude difference, $F(3,166) = 2.012$, $p = .114$, $R^2 = .035$ (see Table 3).

Late positive potential, 1000-2000ms (late LPP).

Negative versus neutral.

The mean amplitude difference was significantly greater than 0, $t^*(169) = 5.10$, $p = .004$, 95% CI [2.71, Inf.], $d = 0.39$. Age was not significantly correlated with the magnitude of this difference, $r^*(168) = .07$, $p = .39$, [-.08, .22]. There were not significant gender differences in either mean amplitude variance, $F(88, 80) = 0.85$, $p = .45$, or mean amplitude, $t^*(1, 168) = 0.01$, $p = .49$, [-3.11, 3.15], $d = 0.18$. Neither age, gender, nor their interaction predicted a significant proportion of the variance in the negative-neutral mean amplitude difference, $F(3,166) = 1.21$, $p = .31$, $R^2 = .02$ (see Table 3).

Positive versus neutral.

The mean amplitude difference was significantly greater than 0, $t^*(169) = 6.01$, $p < .0001$, 95% CI [3.24, Inf.], $d = 0.46$. Age was not significantly correlated with the magnitude of this difference, $r^*(168) = .06$, $p = .42$, [-.09, .21]. There were not significant gender differences in either mean amplitude variance, $F(88, 80) = 1.40$, $p = .13$, or mean amplitude, $t^*(1, 168) = 0.01$, $p = .50$, [-2.98, 2.97], $d = 0.23$. Neither age, gender, nor their interaction predicted a significant proportion of the variance in the positive-neutral mean amplitude difference, $F(3,166) = 1.34$, $p = .27$, $R^2 = .02$ (see Table 3).

Summary of emotion effects on 'hit' ERPs.

Even when controlling for subsequent memory performance, emotion significantly modulated ERPs in both and early and late LPP window. There were no relations between age, gender, and the magnitude of the emotion effect in either window. This result demonstrates that the overall emotion effects on ERPs do not simply reflect the fact that more emotional than neutral pictures were later remembered. Instead, there is an emotion effect on ERPs that is distinct from successful memory encoding.

Discussion

We investigated the extent to which emotion enhances memory and modulates neural activity in 8- to 30-year old females and males, thereby enabling examination of whether emotion processing or EME effects change before, during, or after adolescence, as well as between genders. We found that the impact of emotion on ERPs and memory was consistent across the age range, and between genders. We also observed that emotion effects on ERPs were robust even when the emotional-neutral memory performance difference was accounted for by comparing only ‘hit’ trials. These results suggest that emotion effects on recognition memory are apparent by middle childhood and are observed through early adulthood. Most notably, to our knowledge this is the first study to investigate emotion effects on ERPs and recognition memory, using the same stimuli and methodology, across this swath of development. Our results provide compelling evidence for consistency in emotion effects on ERPs and recognition memory across this phase of development.

We tested EME in a manner that eliminates most sources of developmental difference in memory processes: encoding was incidental, mnemonic strategies were not necessary, and participants did not need to report details about their memory or provide judgments of memory strength. In addition, we utilized a design that enabled us to compare memory performance between emotion conditions within-subjects and treat age as a continuous variable, thereby affording greater power to detect differences linked to age. Specifically, we did not focus on main effects of emotion, as prior studies have typically done (e.g., Hajcak & Dennis, 2009; Leventon et al., 2014). Instead, we evaluated individual differences in the degree to which emotion modulated EME and ERP response within-subjects by examining the effects of age and gender on the negative-neutral and positive-neutral difference scores for each dependent variable. This approach to quantifying the impact of emotion on both memory and ERPs allowed us to treat age as a continuous variable for all analyses, thereby maximizing statistical power and facilitating the detection of age-related change that might emerge gradually across development.

We found enhanced memory performance for both negative and positive pictures, relative to neutral. This EME effect was consistent across the tested age range for females and males alike. Emotion effects were also apparent in the later ERP (400-1000ms and 1000-2000ms) windows, as evidenced by more positive-going ERPs for negative and positive versus neutral pictures (see Figure 4, Panels A and B). This emotion-enhancement of both early and late LPP was consistent across the age range and between genders. Interestingly, these emotion effects on the LPP remain even when comparing the ERPs for hit trials only—that is, the emotion effect on the LPP was not simply reflecting that more emotional than neutral images were successfully encoded in memory (see Figure 5, Panels A and B). When EME effects for this hit-only analysis were compared across the age range and between genders, we found no evidence of age or gender differences. In contrast, there were not significant emotion effects on an early ERP (150-300ms) for participants, regardless of age or gender (see Figure 4, Panels A and B). The consistency of these emotion effects on ERPs for both genders and across the age range indicates that emotion effects on neural processing and recognition memory are consistent in across middle childhood, adolescence, and early adulthood.

Our results align with numerous studies that report emotion effects on the LPP (see Olofsson et al., 2008, for a review). In conjunction with prior developmental ERP studies, we found consistent emotional modulation of the LPP across the age range (e.g., Hajcak & Dennis, 2009). However, our results diverge from prior ERP studies that report emotion effects on the EPN. Hajcak and Dennis (2009) also did not find emotion effects on the EPN, but their sample only included children, and so they interpret the null effect as evidence for a developmental trajectory for the EPN, such that it is apparent in adults but not children. We did not find evidence for emotion EPN effects in either children or adults. It is possible that our EPN results reflect the fact that, because many participants were children, the stimulus set did not include the extremely high arousal pictures (e.g., images of mutilation or erotica) that are often included in studies with adults, and which have been found to elicit the most extreme effects on ERP amplitude, relative to other stimuli that are emotionally evocative but less arousing (e.g., Kaestner & Polich, 2011; Schupp et al., 2007; Schupp, Junghöfer, Weike, & Hamm, 2003b; Weinberg & Hajcak, 2010).

Prior ERP studies have reported that the magnitude of the LPP is larger for pictures that are later remembered (Dolcos & Cabeza, 2002). Our ERP results also indicate that emotion effects on both the early and late LPP persist even when only the ERPs associated with pictures that were later correctly remembered (i.e., hits; based on Session 2 performance) are compared. This suggests that emotion enhancement of the LPP does not primarily reflect more successful encoding of the emotional versus neutral pictures. Indeed, prior studies have linked emotion effects on the LPP to the dedication of more attentional resources to emotional versus neutral stimuli (for reviews see, e.g., Hajcak, MacNamara, & Olvet, 2010; Olofsson et al., 2008). However, we are not aware of prior research that has shown that emotion enhancement of the LPP when directly comparing between subsequently remembered emotional and neutral trials.

These results help to fill a critical gap in the literature to date; namely, the dearth of studies that examine emotion processing and EME with consistent approach across a broad development range. The present findings of equivalent EME for negative pictures across the age range aligns with Vasa et al.'s finding that adolescents and adults alike remember more emotional than neutral pictures. However, results from other studies of EME, with slightly younger children, have varied. Cordon et al. (2012) reported that 7- to 9-year-olds and adults had equivalent memory for negative pictures, however, the adults remembered more neutral items. Thus, the EME effect was actually larger for children than for adults. In contrast, Leventon et al. (2014) did not observe EME effects on recognition memory for 5- to 8-year-olds. This raises the possibility that EME effects on recognition memory emerge during middle childhood and are adult-like by adolescence. Broadly, recognition memory capacity improves between the ages of 6 and 8 years, at which point it stabilizes at adult-like levels (e.g., Ghetti & Angelini, 2008). It is thus difficult to ascertain whether the atypical EME effects reported by Cordon et al. (2012) and Leventon et al. (2014) resulted from the young participants' immature recognition memory capacities, or from a developmental difference in EME. Notably, however, Leventon et al. (2014) compared overall memory performance between younger (5.5-7.5

years) and older (7.6-8.9 years) participants, and found that while older children demonstrated better recognition overall, they still did not display EME effects.

This result merits special consideration, as the present study and Leventon and colleagues (2014) employed similar stimuli and laboratory environments. However, there was little overlap in participants' age: the top of the Leventon and colleagues (2014) age range was 8 years, which was the bottom of our age range. The difference between Leventon et al.'s (2014) findings and the present results could reflect a transition to adult-like EME effects that occurs in middle childhood, around 8 years of age. Indeed, although Leventon and colleagues (2014) did not find behavioral EME effects, they did report age-specific changes in the neural response to emotional versus neutral pictures. Specifically, for younger participants (5-7.5 years), there was not a significant difference in the ERPs triggered by emotional and neutral pictures. In contrast, there were significant differences between the ERPs elicited by emotional versus neutral pictures in older participants (7.5-8.9 years)—even though there were not significant differences in their memory for emotional and neutral pictures. These age differences in the neural response to emotional stimuli could foreshadow the emergence of the adult-like EME effects that the present study documented in both brain and behavior.

Interpretation of the mixed findings regarding EME across development is complicated by differences in the paradigms and stimulus sets used with children versus adults. In conjunction with Leventon and colleagues' (2014) finding that adult-like emotion effects on ERPs emerge in middle childhood, prior to the development of emotion effects on memory, our results suggest that the emotion effects on ERPs and recognition memory emerge during childhood and are observed from late childhood through early adulthood. This result is striking in that many other studies report that adolescents demonstrate a) different emotion processing responses than adults and, sometimes, children, and b) developmental changes in connectivity between regions implicated in emotion and EME, particularly the amygdala. A critical difference between the present study and most of the literature on emotion processing in adolescence lies in the type of stimuli used. Specifically, our stimuli were pictures of scenes, some of which included faces, whereas several other studies have presented only emotional and neutral faces (e.g., Guyer et al., 2008; Nelson et al., 2003). Given that adolescence is a time of heightened sensitivity to socially-relevant cues, such as facial displays of emotion, it is likely that the relative proportions of socially-relevant information in a task could impact both task performance and associated neural activity (for reviews see, e.g., Blakemore & Mills, 2014; Casey, 2014, 2015; Del Piero et al., 2016).

Our findings also extend Spalek and colleagues (2015) finding of equivalent EME effects on recognition memory for both genders by showing that there also are not gender differences earlier in development. This is striking given that adolescence is a period when gender differences would be expected to emerge and—perhaps—peak due to dramatic increases in levels of gonadal hormones, which are argued to modulate EME effects. Whereas some prior research has documented gender differences in EME, these studies differ in several important ways. First, many of these studies have tested other types of memory, particularly the ability to verbally recall information (see Andreano & Cahill, 2009, for a review). Of the studies that have found gender differences in recognition memory performance, some have used complex stimuli, like short stories or films (e.g., Cahill et al., 2001; Gasbarri et al., 2006). Second, most have tested small (<25 participants/gender) samples (e.g., Cahill et al., 2001; Canli et al., 2002; Gasbarri et al., 2006; Glaser et al., 2012). In short, at present the balance of evidence indicates that EME for recognition memory is a common effect between genders.

The present research makes an important contribution to the literature, but some limitations are worth noting. There remains a need to examine developmental change in EME for other types of memory, including recollection and recall. This is particularly important for further assessing the existence of gender differences in EME. In addition, including children as young as 8 in the present study precluded the use of stimuli that might elicit particularly strong emotional processing, such as erotic or graphically violent images. This might have compromised our ability to assess the EPN. An additional limitation of the present study was that ensuring the task was feasible for children as young as 8 to complete necessitated limiting the duration of each study session and, therefore, limiting the total number of trials. This, in turn, precluded sufficient numbers of trials for comparison the ERPs associated with all possible memory outcomes (hit, miss, false alarm, and correct rejections). In addition, the comparatively low minimum trial threshold (10 per emotion condition) for the subsequent memory ERP analysis is not ideal from the perspective of the signal-to-noise ratio required for clean ERP analyses. It is also worth nothing that we tested emotion effects on ERPs and recognition memory in a laboratory context, and using a standardized stimulus set to elicit emotion. These conditions likely do not mimic all aspects of emotion processing, and, in turn, its effects on memory, that occur in naturalistic contexts. Ideally, future studies will include novel methods to elicit emotion effects.

These findings extend and enrich the EME and ERP literatures. First, we conducted a direct comparison of EME effects for both positive and negative stimuli across a wide range of ages, using the same stimulus set, paradigm, and methodology. Second, our large sample allowed us to evaluate both age and gender differences in EME, as well as possible interactions between these factors. Third, we found that EME for recognition memory is present and robust for both genders from middle childhood through early adulthood. Finally, we documented developmental consistency in emotion effects on ERPs for both genders. Our results provide compelling evidence that emotion consistently modulates neural processes and enhances recognition memory from middle childhood through adulthood for both genders.

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Table 1. *Behavioral memory performance.*

Panel A. *Emotional memory enhancement (Mean(SD)), overall and by gender*

	Female	Male	All
Negative *d'* – Neutral *d'*	0.54(*0.68*)	0.68(*0.59*)	0.61(*0.64*)
Positive *d'*– Neutral *d'*	0.14(*0.63*)	0.16(*0.57*)	0.15(*0.60*)

Panel B. *Emotional memory enhancement and correlation to age*

	t (194)	*p*	*d*	*r*
Negative *d'* – Neutral *d'*	13.293	< .0001	0.954	-.129 $^{+}$
Positive *d'*– Neutral *d'*	3.528	.0003	0.253	-.138 *

Note. * Indicates uncorrected p <= .05, $^{+}$ indicates uncorrected p < .10.

Table 2. *Mean amplitude for EPN and LPP Components, overall and by gender.*

	Females	Males	All
EPN: All Negative v. Neutral	1.37(*1.52*)	-2.64(*1.13*)	-0.63(*0.96*)
EPN: All Positive v. Neutral	0.16*(1.52)*	-2.27*(1.15)*	1.05*(0.96)*
Early LPP: All Negative v. Neutral	6.6(*1.79*)	3.05 (*1.9*0)	4.83(*1.31*)
Early LPP: All Positive v. Neutral	8.62(*1.43*)	5.31(*1.46*)	6.98(1.03)
Late LPP: All Negative v. Neutral	7.31(*1.51*)	4.09*(1.86)*	5.71(*1.20*)
Late LPP: All Positive v. Neutral	8.32(*1.33*)	4.73(*1.25*)	6.54(*0.92*)
Early LPP: Negative v. Neutral Hits	4.29(*1.16*)	1.31(*1.14*)	2.87(*0.82*)
Early LPP: Positive v. Neutral Hits	4.98(*0.97*)	2.64(*1.12*)	3.86(*0.74*)
Late LPP: Negative v. Neutral Hits	4.93(*1.05*)	3.03(*1.20*)	4.02(*0.80*)
Late LPP: Positive v. Neutral Hits	5.53(*1.12*)	3.32(*0.99*)	4.48(*0.76*)

Table 3. *Regression table: Age and gender as predictors of the emotional-neutral ERP difference.*

	β Age	SE β Age	β Gender	SE β Gender	β Age x Gender	SE β Age x Gender
EPN: All Negative v. Neutral (OPP)	.093	.143	-.288 $^{+}$	.144	.074	.167
EPN: All Positive v. Neutral (OPP)	.140	.140	-.160	.143	.109	.167
Early LPP: All Negative v. Neutral	.104	.101	-.175	.142	.179	.144
Early LPP: All Positive v. Neutral	.043	.117	-.212	.139	.191	.161
Late LPP: All Negative v. Neutral	.013	.131	-.179	.144	.213	.174
Late LPP: All Positive v. Neutral	.017	.125	-.267 $^{+}$	.145	.181	.161
Early LPP: Negative v. Neutral Hits	.118	.141	-.241	.152	.164	.171
Early LPP: Positive v. Neutral Hits	.107	.127	-.219	.151	.104	.182
Late LPP: Negative v. Neutral Hits	-.002	.139	-.165	.155	.166	.199
Late LPP: Positive v. Neutral Hits	.024	.112	-.212	.149	.132	.170

Notes. All βs and β S.E.s were generated from 5000 bootstrapped resamples. $^{+}$Indicates uncorrected $p \leq .10$.

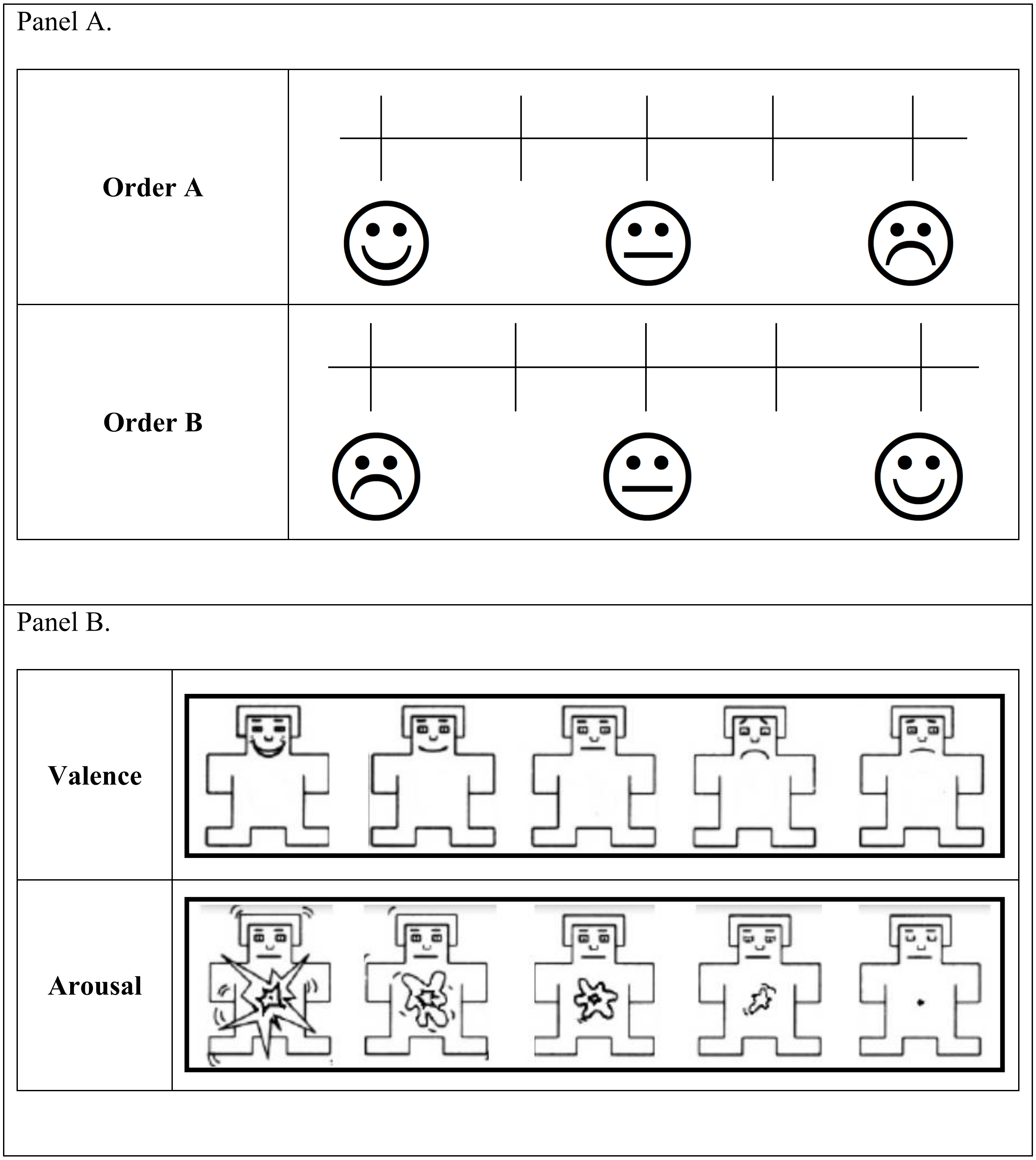


Figure 1. Mood (Panel A) and Self-Assessment Manikin (SAM; Panel B) rating scales.

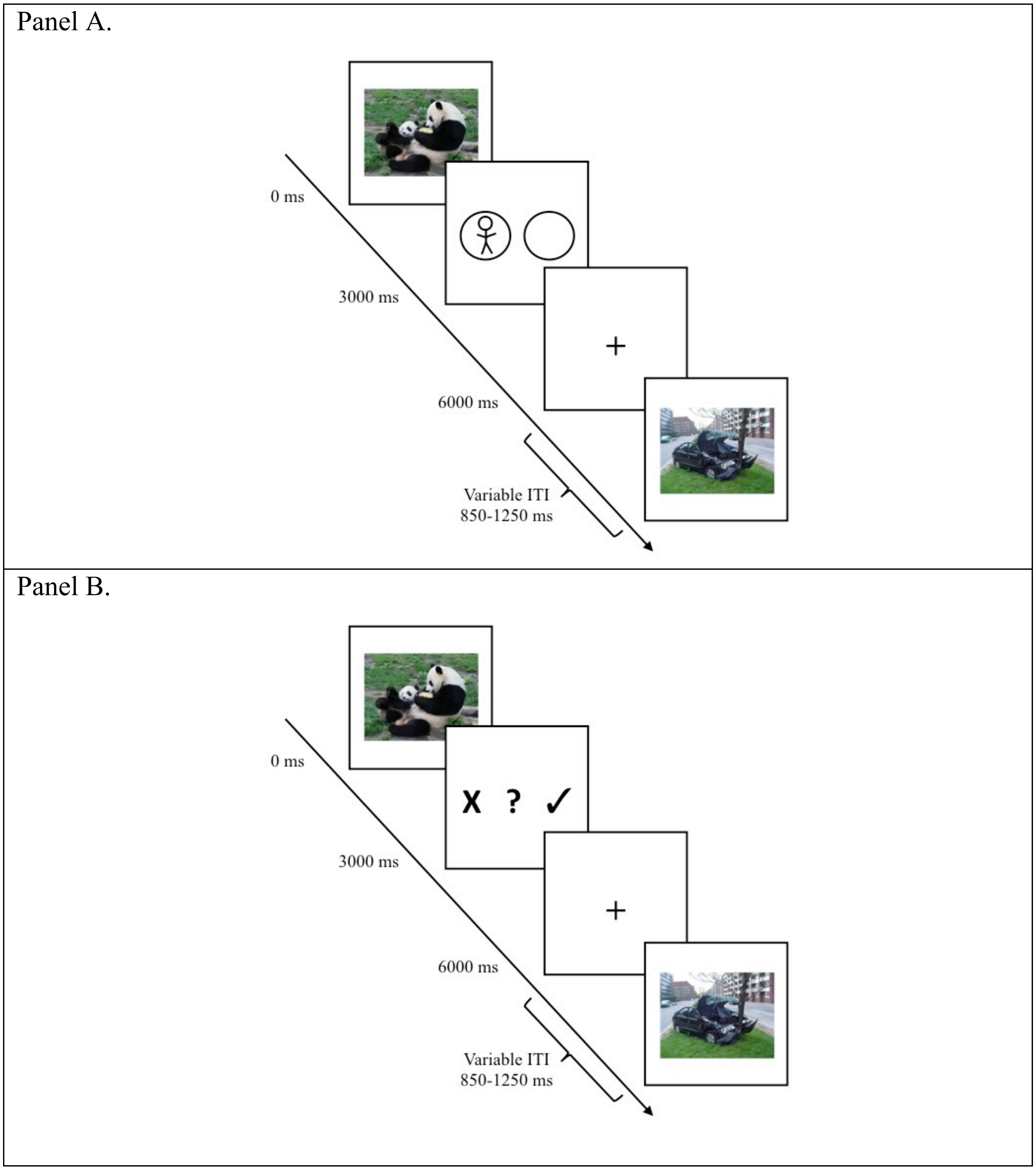
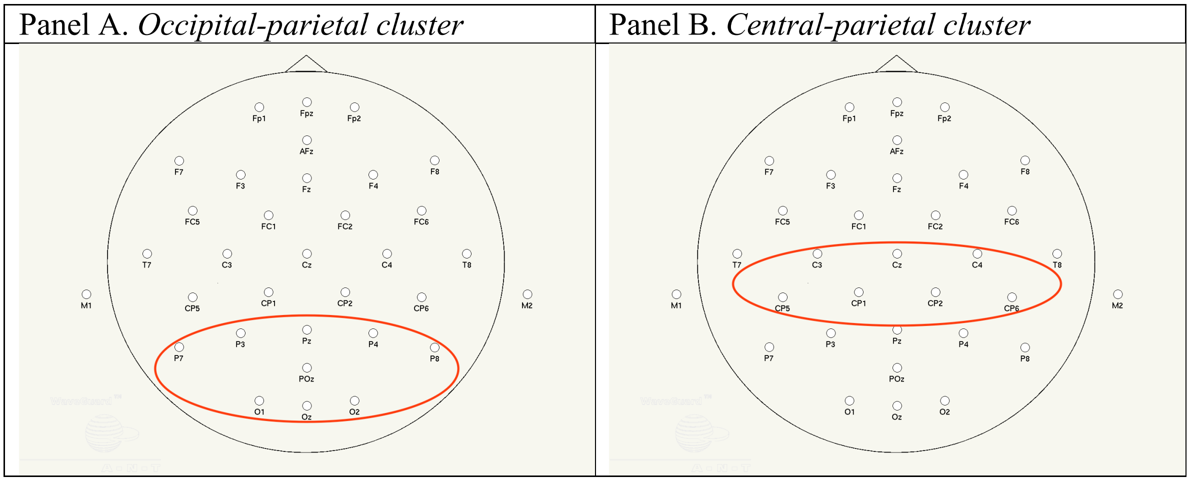
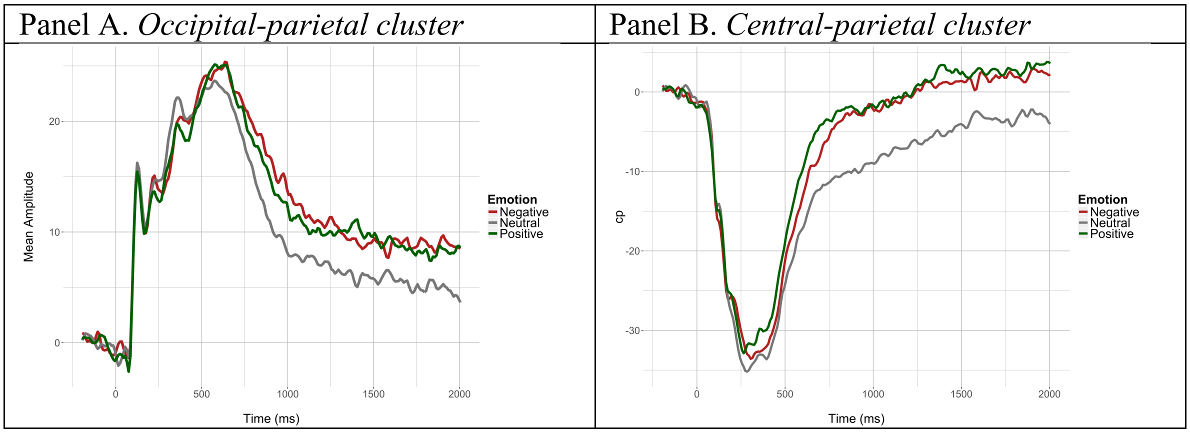


Figure 2. Trial Schematics for Session 1 (Panel A) and Session 2 (Panel B).


Panel A. *Occipital-parietal cluster*

Panel B. *Central-parietal cluster*

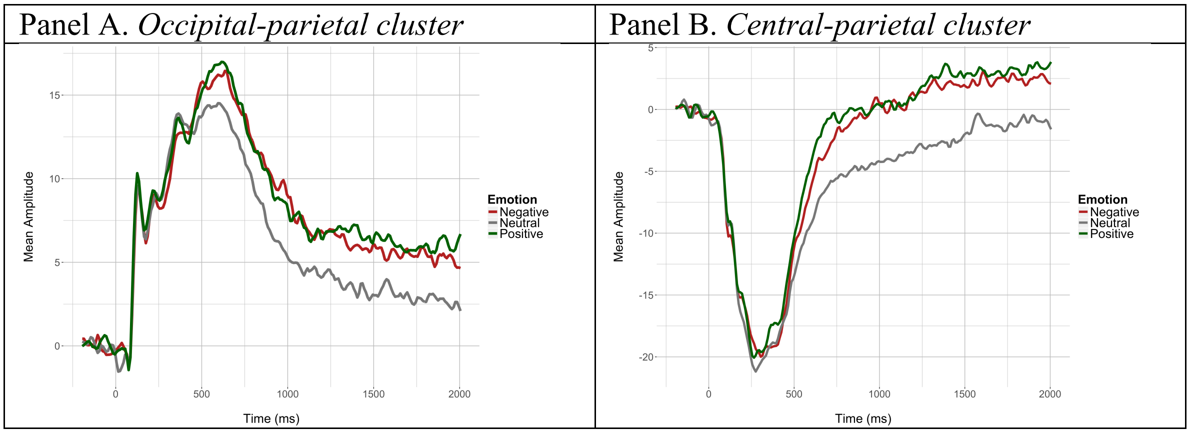
Figure 3. Electrode clusters examined in ERP analyses.



Panel A. *Occipital-parietal cluster*

Panel B. *Central-parietal cluster*

Figure 4. ERP responses to all negative, neutral, and positive pictures.



Panel A. *Occipital-parietal cluster*

Panel B. *Central-parietal cluster*

Figure 5. ERP responses to subsequently remembered negative, neutral, and positive pictures.

Paper 3

Emotion modulates the neural correlates of recognition memory from childhood through adulthood

Anaïs F. Stenson and Patricia J. Bauer

Abstract

Emotion has powerful effects on memory processes. These emotional memory enhancement (EME) effects have been studied extensively in adults, but much less is known about EME across development. Children as young as 7 respond to emotion during tests of recognition memory, yet adult-like emotion EME effects on memory processes might not emerge until middle childhood (Leventon, Stevens, & Bauer, 2014). Eight- to 30-year-old participants viewed positive, negative, and neutral pictures and then completed an old/new recognition task, during which event-related potentials (ERPs) were recorded, two weeks later. We tested for age differences in: a) the difference in ERPs for correctly classified old and new pictures in an early, mid-frontal ERP component previously shown to be modulated by old/new item status in adults, but not children (e.g., Friedman, de Chastelaine, Nessler, & Malcolm, 2010) and, b) emotion effects on a later, central-parietal ERP component that is sensitive to both old/new item status and emotion (e.g., Schaefer, Pottage, & Rickart, 2011). We report consistent old/new effects on both the early midfrontal and later central-parietal ERP components across the tested age range. Emotion effects on the later ERP component were also found to be equivalent for participants across the age range. These results suggest that emotion effects on recognition memory processes are apparent by middle childhood and are then observed through early adulthood.

Keywords: memory, recognition memory, development, emotion, event-related potentials

Introduction

Memory for emotional events is often uniquely powerful, vivid, and long lasting (for reviews, see, e.g., Banich et al., 2009; Buchanan, 2007; Kensinger & Schacter, 2008). There has been substantial progress towards understanding emotion effects on memory in adults. In contrast, there has been less research across development, particularly as children transition from middle childhood into adolescence, and as adolescents transition into mature adults (for reviews see, e.g., Carver, 2014; Hamann & Stevens, 2014). The study of emotion effects on memory has primarily been pursued using two approaches: the first compares memory for emotional and neutral stimuli in the laboratory, and the second examines memory for events from individuals' lives (autobiographical memories). Studies with adults have used both methods extensively, whereas studies with children have predominately examined emotional memory enhancement (EME) effects with autobiographical memories (e.g., Ackil, Van Abbema, & Bauer, 2003; Bauer, Stevens, Jackson, & Souci, 2012; Fivush, Hazzard, McDermott Sales, Sarfati, & Brown, 2003). Many adult EME studies—and a handful of developmental EME studies—have also utilized measures of neural activity, including event-related potentials (ERPs), to elucidate the neural processes underlying EME effects. Together, these studies have demonstrated that emotion impacts memory processes during encoding (for a review see, e.g., Talmi, 2013), consolidation (for a review see, e.g., Roozendaal & McGaugh, 2011), and recognition or retrieval (for a review see, e.g., Buchanan, 2007). However, to date these EME effects have been primarily studied in adults; thus, at present the developmental trajectory of EME effects prior to adulthood is largely unknown. We addressed this gap in the existing literature by examining emotion effects on memory as measured in a) a recognition memory paradigm; and b) with ERPs, to examine the neural correlates. We conducted the study across a wide developmental period, with participants aged 8- to 30-years-old.

Over the first three decades of life, individuals move through childhood, adolescence, emerging adulthood, and, finally, into adulthood. Along the way, there are dramatic changes in the individual's physiology, cognitive capacities, social environment, and behavioral repertoire (e.g., Blakemore & Mills, 2014; Casey, 2015; Larson, Richards, Moneta, Holmbeck, & Duckett, 1996; Steinberg, 2008; Suleiman, Galván, Harden, & Dahl, 2016). Developments in the subjective experience of emotional events and in memory for them are inextricably related to these changes (Del Piero et al., 2016; Heller & Casey, 2015; Larson et al., 2002; Leventon & Bauer, 2016; Silk et al., 2009). It is particularly important to understand developmental change in the processing of emotional events and experiences, given its relations with well-being and mental health (e.g., Dahl & Gunnar, 2009; Larson et al., 2002; Silk, Steinberg, & Morris, 2003). At present, however, there is a paucity of research on EME across development. As a consequence, it is not clear whether—and how—EME effects change between childhood and adulthood. Adult studies of EME typically use standardized stimulus sets (e.g., the International Affective Picture System (IAPS); Lang, Bradley, & Cuthbert, 2008), control conditions during encoding and testing, and then compare memory for emotional and neutral stimuli. The widespread use of standardized stimuli and testing parameters facilitates direct comparisons of EME effects between subjects and across studies. These studies consistently find that emotional stimuli are remembered more often than neutral stimuli (for reviews see, e.g., Kensinger & Schacter, 2008; Murphy & Isaacowitz, 2008; Talmi, 2013).

In contrast to the approach taken in many adult EME studies, most developmental studies of EME have investigated children's autobiographical memories, thus precluding experimental manipulation of emotion (e.g., Bauer, Stark, Ackil, Larkina, Merrill, & Fivush, 2017; Ackil, Van Abbema, & Bauer, 2003; Bauer, Stevens, Jackson, & Souci, 2012; Fivush, Hazzard, McDermott Sales, Sarfati, & Brown, 2003; although see Cordon, Melinder, Goodman, and Edelstein, 2012; Van Bergen, Wall, & Salmon, 2015; Vasa et al., 2012 for exceptions). These studies have shown that children recall emotional events over longer periods of time (e.g., Bauer et al., 2017) and in greater detail than neutral events. However, because these studies examine retrospective reports of personal experiences that vary across individuals, they: a) complicate direct comparison of EME between subjects and b) produce results that are not directly comparable with those from the adult EME literature. In order to map EME effects across development, we need parallel studies of EME across the lifespan—particularly before, during, and after adolescence, when critical outcomes related to emotion processing, including mental health, are increasingly salient.

Mapping EME effects across development will entail not only studies of overt memory behavior but also studies of neural responses to emotional events and experiences. Studies of EME in adults frequently employ ERPs during memory tests to elucidate the neural response to items as a function of emotion and status in memory (i.e., if old and new items are correctly classified). ERPs are an ideal tool for examining these processes, because they enable dissociation of neural activity both over time and across the cortex (e.g., Rugg & Curran, 2007). In addition, ERPs are well suited for use with a large developmental sample.

A bevy of adult studies indicate that ERPs are differentially responsive to correctly classified old and new items. Typically, ERP amplitudes are more positive for correctly identified old items versus new items (for reviews see, e.g., Friedman & Johnson, 2000; Rugg & Curran, 2007). Moreover, these studies have demonstrated that temporally and topographically distinct ERPs are modulated by memory and emotion (for reviews see, e.g., Friedman & Johnson, 2000; Rugg & Curran, 2007). Specifically, an early old/new effect (~300-500ms after stimulus onset) recorded at midfrontal sites indexes the status of an event in memory, but is not sensitive to emotion (Duarte et al., 2004; Johansson et al., 2004; Weymar et al., 2009). A later old/new effect (~400-1000ms after stimulus onset) recorded from central and parietal sites is sensitive to both memory and emotion (Johansson et al., 2004; Weymar et al., 2009; Weymar, Löw, Schwabe, & Hamm, 2010). That is, the magnitude of this late old/new ERP difference is larger for correctly remembered emotional relative to correctly remembered neutral stimuli. This finding indicates that, for adults, emotion modulates memory processes for emotional stimuli over and above those that differentiate old from new stimuli. In short, studies of EME in adults demonstrate that a) memory processes are indexed by the early midfrontal and late central-parietal old/new ERP components, and b) enhancement of old/new ERP effects for emotional stimuli is observed in the late central-parietal component.

At present, there is not a developmental literature that directly aligns with the adult ERP literature on EME for recognition memory. Yet some developmental studies have utilized ERPs to examine recognition memory processes—albeit without including emotional stimuli—in a manner that closely parallels the adult literature. The results of these studies provide a platform from which to make predictions about how EME effects on recognition memory processes, as measured with ERPs, might shift across development. Several developmental studies have found that the early midfrontal old/new effects that are consistently documented in adults are not sensitive to memory processes in children (e.g., Czernochowski, Mecklinger, & Johansson, 2009; Friedman, de Chastelaine, Nessler, & Malcolm, 2010; Sprondel, Kipp, & Mecklinger, 2011). One exception is Mecklinger, Brunneman, and Kipp (2010), who tested 8- to 10-year-old children's memory for emotionally neutral pictures, and found that their ERPs were sensitive to correctly recognized old versus new items in a speeded response task, but not in a non-speeded task. A second exception is Haese and Czernochowski (2016), who observed the early old/new ERP component in older (10-year-old) but not younger (7-year-old) children during a recognition memory task. Together, the results from this literature suggest that the canonical early midfrontal old/new effect seen in adults emerges between middle childhood and adolescence. Prior to that time, it seems to appear only under unique testing conditions, such as when there are constraints on response time. This profile, coupled with the observation that the early midfrontal old/new effect is not sensitive to emotion in adults, makes it unlikely that emotion would modulate this ERP component differentially across development.

In contrast to the findings of developmental change in the early midfrontal old/new effect, the late central-parietal old/new ERP component has been consistently documented in children (Czernochowski et al., 2009; Friedman et al., 2010; Haese & Czernochowski, 2016; Sprondel et al., 2011). This ERP is apparent from ~400-1000ms after stimulus onset and is larger for old than new items or events. Critically, at present, our knowledge of whether it is modulated by emotion in children is extremely limited. To our knowledge, there is only one study that has addressed the question (though see Cordon et al., 2001, for a relevant behavioral study). Leventon, Stevens, and Bauer (2014) showed younger (5-7) and older (7-9) children negative, neutral, and positive pictures from a developmentally appropriate subset of the IAPS; recognition memory performance was then tested the next day. There was no behavioral evidence of EME effects on memory performance for either the younger or older children—memory for negative, neutral and positive pictures was not statistically different. Interestingly, though, ERPs recorded during the recognition memory test revealed that emotion modulated the neural response to correctly recognized old pictures. Specifically, correctly identified old negative pictures elicited significantly more positive-going ERPs than correctly identified new negative pictures at posterior sites starting approximately 400ms after picture presentation. The timing and location of this emotion effect corresponds to the late central-parietal old/new effect that has been documented in adult studies (e.g., Johansson et al., 2004; Schaefer, Pottage, & Rickart, 2011; Weymar et al., 2009, 2010). Yet it also differed from the canonical adult effect in that ERPs for neutral and positive pictures did not differ between old and new items. This contrasts with multiple adult studies that have found that the late central-parietal old/new ERP effect is modulated by positive as well as negative emotion, relative to neutral. These findings suggest that emotion effects on recognition memory emerge during middle childhood, and that ERPs are sensitive to changes in these effects prior to their behavioral debut. Still, our knowledge of EME for recognition memory across development is extremely limited.

In light of the paucity of research on EME effects in ERPs in development, and of the tremendous amount of social, emotional, physiological, and cognitive development that unfolds between middle childhood and adulthood, it is necessary to examine potential changes in EME effects across developmental. That is, there remains a need to assess EME prior to adulthood in a manner that a) parallels the large body of EME research in adults, and b) enables direct comparisons of EME effects across the age range.

In the present study, we used ERPs to examine developmental change in emotion effects on memory recognition. In order to parallel a common approach in the adult literature, we used a developmentally appropriate version of the widely used IAPS, controlled conditions during encoding and testing, and then compared recognition memory for emotional and neutral stimuli. In order to directly compare participants' performance and ERPs across a wide swath of development, we included participants from 8-30 years in the study. This age range enables us to examine participants before, during, and after adolescence; in addition, it includes emerging and slightly older adults, thereby permitting assessment of whether EME changes across this window. We tested emotion effects on memory in a manner that eliminates most sources of developmental difference in memory processes: encoding was incidental, mnemonic strategies were not necessary, and participants did not need to report details about their memory or provide judgments of memory strength. In addition, we utilized a design that enabled us to compare memory performance between emotion conditions within-subjects and treat age as a continuous variable, thereby affording greater power to detect differences linked to age. Specifically, we did not focus on main effects of emotion, as prior studies have typically done (e.g., Leventon, Stevens, & Bauer, 2014; Schaefer et al., 2011; Weymar et al., 2009). Instead, we evaluated individual differences in the degree to which emotion modulated EME and ERP responses within-subjects by examining the effects of age on the negative-neutral and positive-neutral difference scores for each dependent variable. This approach to quantifying the impact of emotion on both memory and ERPs allowed us to treat age as a continuous variable, thereby maximizing statistical power and facilitating the detection of age-related change that might emerge gradually across development.

To accomplish the goals of the study, we used a subset of the data collected in Stenson, Leventon, and Bauer (2017). The prior report was of behavioral performance alone (no ERP results were reported). In the sample, there were no age-related differences in overt, behavioral recognition memory. Across the age range, there were consistent EME effects on recognition memory performance. This consistency in behavior is ideal for present purposes, because when behavioral performance differs substantially with age, it can be difficult to interpret differences in the neural activity measured during task performance (Casey, Davidson, & Rosen, 2002). In contrast, parallel behavioral performance across an age range affords a perfect platform from which to determine whether the underlying natural processes differ in spite of consistent behavior.

Based on the adult literature, which indicates that memory status (i.e., old versus new) modulates ERPs in both the early (~300-500ms) midfrontal and late (~400-100ms) central-parietal ERP components, we expected to observe these old/new effects in the adults in the present study. In contrast, based on prior findings that the early old/new ERP is attenuated in children, we did not expect to observe early (300-500ms) midfrontal old/new effects in children (Friedman et al., 2010; Haese & Czernochowski, 2016; Mecklinger, Brunnemann, & Kipp, 2011). We predicted that old/new effects on the late (400-800ms) central parietal component would be significant for children as well as adults, as this effect has been documented in both children and adults (e.g., Haese & Czernochowski, 2016; Mecklinger, Brunnemann, & Kipp, 2011).

The central question of the present research was whether emotion would modulate ERPs in similar ways in children and adults. Based on the tremendous amount of development that unfolds between the ages of 8 and 30, as well as the evidence of age-related (in 5- to 8-year-olds) change in emotion effects on ERPs during a recognition memory test documented by Leventon and colleagues (2014), we anticipated that there could be age-related changes in the emotion effects on ERPs for correctly identified old and new pictures. Based on adult ERP studies that indicate emotion does not modulate this early old/new effect, in conjunction with the fact that this component is often not found at all in children, we did not expect emotion effects on this component for any participants, regardless of age. However, we did anticipate finding emotion effects on the late central-parietal component in adults; specifically, we expected that the old/new effect would be more pronounced for the emotional old/new contrast than for neutral. We hypothesized that this emotion effect would likely be consistent across the tested age range, because a) old/new effects in this late component have been found to be similar in children and adults, and b) Leventon and colleagues (2014) documented emotion effects on late parietal ERPs in younger children.

Finally, because several studies have reported gender differences in both behavioral and neural measures of EME, we anticipated that there could be gender differences in either the early or late old/new ERP components (e.g., Canli, Desmond, Zhao, & Gabrieli, 2002; Glaser, Mendrek, Germain, Lakis, & Lavoie, 2012). However, multiple studies of EME have not found gender differences in either neural processing, memory performance, or both (Cordon, Melinder, Goodman, & Edelstein, 2012; Kensinger, Garoff-Eaton, & Schacter, 2007; Spalek et al., 2015; Talmi, Anderson, Riggs, Caplan, & Moscovitch, 2008). These inconsistencies in findings of gender differences, and the absence of developmental data, warrant further inquiry into the magnitude and etiology of gender differences in the emotional memory enhancement effect. Thus, a secondary aim of this study was to assess if emotion effects on memory retrieval differed between genders at any point in the tested age range.

Method

Data were collected at a large, private Southeastern university. Altogether, 151 children (75 females), ages 8 to 16, and 88 young adults (45 females), ages 18 to 30, enrolled in the study (total *N* = 239). Twelve children (five females) and four adults (one female) were lost to attrition between Sessions 1 and 2. Sixteen children (5 females) and five adults (4 females) were excluded from analyses due to technical errors, failure to perform the task, or experimenter error. Ultimately, 127 children (65 females) and 79 adults (40 females) were included in the study (final *N* = 206). Of those participants, both behavioral and ERP data were usable for 74 children (42 female), and 51 adults (31 female). All analyses reported herein include these participants' data (final *N* = 125). Self- or parent-reported race and ethnicity was collected from all participants. Thirteen participants identified their race as Asian, 16 as African-American/Black, 88 as Caucasian/White, 6 as multi-racial, and 2 did not report this information. Four participants identified their ethnicity as Hispanic or Latino, 119 did not identify as Hispanic or Latino, and 2 did not disclose this information. Children were recruited from a database of families that had previously expressed interest in study participation through the university's Child Study Center. Although detailed data on socioeconomic status were not collected, the pool is comprised primarily of families from educated middle- to upper-middle-class SES. Guardian report of highest educational achievement in the household indicated that 8% completed some college, 3% completed a technical or associate's degree, 22% completed a college degree, 11% completed some graduate school, and 56% completed a post-graduate degree. Information about education was not systematically collected from adult participants. Prior to testing the children, their guardians provided written informed consent. The children received a gift card to a major retail chain for their participation. Adult participants were recruited through either the university psychology subject pool or via advertisements posted on the university campus. They provided written informed consent and received either course credit or a gift card to a major retail chain for their participation. All procedures were reviewed and approved by the university's IRB.

Materials

157 child-appropriate pictures (57 negative, 50 neutral, and 50 positive) were selected from the International Affective Picture System (IAPS; Lang et al. 2008) and a lab-collected set of similar pictures. To control for previously reported biases in affective processing of pictures containing humans (Proverbio et al., 2009), 50% of the pictures in

each emotion condition included humans and 50% did not. The same pictures were used for all participants, regardless of age. This set of pictures was used to create eight presentation orders that were used for both child and adult participants. Before children came to the lab, thumbnails of all 157 pictures were sent via email to the guardian to approve presentation of the images (procedure approved by Lang, personal communication). If the guardian requested that specific pictures be removed, they were replaced with alternate pictures of the same valence. Regardless of any such replacements, every participant saw 50 negative, 50 neutral, and 50 positive pictures.

The study consisted of two sessions separated by approximately 14 days (*M* = 14.1 (*0.84*), *Range* = 11-19). During Session 1, participants viewed the stimuli and engaged in a behavioral task to ensure attention to the pictures. Before starting the picture viewing and again after viewing was complete, children rated their mood, using a 5-point emoticon scale (see Figure 1, Panel A), and all participants aged 11 years or older completed the Positive and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988). During Session 2, participants viewed all pictures from Session 1, along with new pictures, and completed a recognition memory task. Like Session 1, participants provided mood and/or PANAS ratings both before and after the picture task. At the end of Session 2, participants provided subjective ratings of valence and arousal for a subset of the pictures using the modified Self-Assessment Manikin shown in Figure 1, Panel B (SAM; Bradley & Lang, 1994). Picture presentation in both Sessions 1 and 2 was controlled using Advanced Neuro Technology eevoke™ software. All pictures were presented in full color at 30.5 cm (h) × 23 cm (w) in size, subtending a visual angle of approximately 15.6° (h) × 20.6° (w).

Electrophysiological (EEG) data in Sessions 1 and 2 was recorded using an elastic-lycra Advanced Neuro Technology (A.N.T.) Waveguard EEG cap with 32 shielded Ag/AgCl electrodes (A.N.T. Software B.V., Enschede, The Netherlands; Fig. 3) arranged according to the International 10-5 system, an adaptation of the International 10-20 system (Jasper, 1958). Impedances were generally under 5k**Ω**. Using an ASA amplifier (A.N.T. Software B.V., Enschede, The Netherlands) the EEG data were sampled continuously at 256 Hz and amplified 20,000 times.

Session 1.

After consent procedures, participants were oriented to the task and EEG capping procedure. Application of the cap typically took 20-40 minutes, during which time participants completed the pre-session mood and/or PANAS ratings. The experimenter then explained the importance of remaining still and relaxed throughout the EEG recording. Before recording, three neutral pictures, which did not appear in the testing phase, were presented as practice trials to establish that participants understood the task.

EEG data were then collected as participants viewed 90 pictures (30 of each valence) presented in a pseudo-randomized order. No more than two images of the same valence preceded one another. The images and presentation order were counterbalanced across participants. Each picture was presented for 3000ms and immediately followed by a decision screen lasting for 3000ms that prompted participants to indicate if the prior picture contained a human. A fixation-cross ('+') was onscreen during the 850 to 1250ms inter-stimulus interval.

During picture presentation, participants used a game controller to indicate if each picture contained a human. The position of the response options was counterbalanced across participants. Five additional positive images were included at the end of each presentation to conclude on a positive note; these trials were not included in analyses. A trial schematic is presented in Figure 2, Panel A. The picture presentation and EEG recording lasted approximately 9 minutes. Participants then completed the post-session mood and/or PANAS ratings prior to having the EEG cap removed. Altogether, Session 1 typically lasted between 1hr and 1hr30m.

Session 2.

Participants were fitted with an EEG cap while they completed the pre-session mood and/or PANAS ratings. Prior to EEG recording, participants were asked to remain still and relaxed throughout the EEG recording. Participants were then instructed to look carefully at pictures presented on the monitor, some of which were shown during Session 1 (i.e., were ‘old’) and some of which were new, and do their best to determine if each picture was old or new. They then indicated whether they thought each picture was ‘old’, ‘maybe old’, or ‘new’ via a button press on a game controller. The position of the response options was counterbalanced across participants. Participants completed three practice trials (same images as Session 1 practice) to ensure that they understood the task. Once participants affirmed that they understood the instructions, picture presentation and data recording began.

Participants viewed 150 pictures (50 negative, 50 neutral, and 50 positive) while EEG data and button-press responses were recorded. These included the 90 pictures from Session 1 (30 per valence) and 60 new pictures (20 per valence), which the participant had not seen before. Like Session 1, the order of picture presentation was pseudo-randomized so that no more than two images of the same valence preceded one another.

The eight presentation orders were counterbalanced so that across participants all pictures were used equally in the old and new conditions. Five positive images were added to the end of the session to conclude on a positive note; These trials were not included in any analyses. Each picture was presented for 3000ms, followed by the 'old'/'maybe old'/'new' decision screen for 3000ms. A fixation-cross ('+') was onscreen during the 850 to 1250ms inter-stimulus interval. A trial schematic is presented in Figure 2, Panel B. The recognition task lasted approximately 18 minutes for all participants.

Following the recognition task, participants completed the post-session mood and/or PANAS ratings prior to having the EEG cap removed. Participants then provided subjective valence and arousal ratings for 45 images (15 from each emotion condition) using the modified SAM, shown in Figure 1, Panel B. The SAM was abbreviated from the full 9-point version of the scale to reduce participant burden for the children (Leventon et al., 2014). The modified SAM consisted of one 5-point scale for valence (1 = very unpleasant, 3 = neutral, and 5 = very pleasant), and another for arousal (1 = very low arousal, 5 = very high arousal). Altogether, Session 2 typically lasted between 1hr20m and 1hr45m.

Data reduction.

EEG data.

Mean value (DC bias) was removed from the EEG data before initial 0.1Hz highpass filtering (infinite impulse response function Butterworth filter, roll-off = 24dB/octave, half-amplitude cutoff = -6dB) using EEGLAB 13.4.4 (Delorme and Maekig, 2004) and ERPLAB 4.0.3.1 (www.erplab.org) operating in Matlab 2014b (MathWorks, Natick, MA, USA). Independent component analysis (ICA) was applied after highpass filtering to identify and remove artifacts resulting from eyeblinks, heartbeat, muscle activity, channel noise, and 60Hz noise using both experimenter examination of the continuous EEG data and the "automatic EEG artifacts detector with joint use of spatial and temporal features" (ADJUST) algorithm (Mognon, Jovicich, Bruzzone, & Buiatti, 2011). After ICA, a 40Hz lowpass filter (infinite impulse response function Butterworth filter, roll-off = 24dB/octave, half-amplitude cutoff = -6dB) was applied to the EEG data before re-referencing to mathematically linked mastoids. EEG data was segmented into 2750ms epochs beginning 250ms before picture onset and ending 2500ms after picture onset. A 250ms pre-stimulus window was used to correct for baseline activity in each epoch. Epochs in which EEG amplitude changed more than ±150μV were excluded from analyses.

Event-related potentials.

The EEG epochs were classified according to subsequent memory performance and picture valence (negative, neutral, or positive). When participants correctly identified a picture as 'old' or 'maybe old' the epoch was classified as a 'hit' (H), whereas when participants incorrectly identified a picture as 'new' the epoch was classified as a 'miss' (M). When participants identified new pictures as new, the epoch was classified as 'correct new' (CN), whereas new items incorrectly identified as old were classified as 'false alarms' (FAs). Participants were included in ERP analyses if they had at least 10 usable trials per condition ($M_{AllHits}$ = 62.1(*10.9*), $M_{AllCorrectNew}$ = 48.5(*6.1*), $M_{Neg.Hits}$ = 23.1(*3.7*), $M_{Neg.CorrectNew}$ = 16.5(*2.4*), $M_{Neut.Hits}$ = 18.0(*4.5*), $M_{Neut.CorrectNew}$ = 16.4(*2.4*), $M_{Pos.Hits}$ = 21.0(*4.5*), $M_{Pos.CorrectNew}$ = 15.6(*2.6*)).

Analytic approach: Memory data.

Following prior research, we evaluated participants' discrimination between old and new images by calculating *d',* a discriminability index (e.g., Banks, 1970, Snodgrass & Corwin, 1988, Macmillan & Creelman, 2005; Wixted, 2007). We calculated *d'* by first calculating *z* scores for hit (HR) and false alarm (FA) rates, and then subtracting *z*(FA) from *z*(HR). Thus, for each participant *d'* = *z*(HR) - *z*(FA). This *d'* value indexes how well participants distinguished old items from new items. Hit and FA rates of 1 or 0 were corrected in accordance with Macmillan and Kaplan's (1985) recommendation: rates of 0 were replaced with 0.5 / *n* and rates of 1 were replaced with (*n* – 0.5) / *n,* where *n* is the total possible number of hits or false alarms. We quantified the degree of EME within-subjects by computing difference scores in *d'* for each emotion condition relative to neutral (e.g., negative *d'* – neutral *d'*).

Analytic approach: ERP data.

We analyzed the mean amplitude (MA) of the early (300-500ms) midfrontal and late (400-800ms) central-parietal old-new ERP components. We defined the electrode clusters used in all analyses based on prior literature, rather than visual inspection of the waveforms, in order to avoid the 'implicit multiple comparisons' problem articulated by Luck (2014). Following prior research, the midfrontal cluster included electrodes FC1, FC2, and Fz (see Figure 3, Panel A; e.g., Friedman, de Chastelaine, Nessler, & Malcolm, 2010; Haese & Czernochowski, 2016); as shown in Figure 3, Panel B, the central-parietal cluster included electrodes Cz, CP1, CP2, and Pz (e.g., Weymar, Löw, Melzig, & Hamm, 2009; Weymar, Löw, Schwabe, & Hamm, 2010).

Mean amplitude characterizes the magnitude and direction of the ERP within specific windows. To isolate the effects of memory status and/or emotion effects, for each ERP of interest we calculated the MA difference for a) hit versus correct new (CN) trials (i.e., $MA_{Hit} - MA_{CN}$) and b) hit versus CN trials for each emotion condition (i.e., negative $MA_{Hit} - MA_{CN}$, neutral $MA_{Hit} - MA_{CN}$, and positive $MA_{Hit} - MA_{CN}$). These difference scores were the dependent variable in all ERP analyses. This approach enabled us to treat age as a continuous variable for all analyses, rather than collapsing age into groups to use a more conventional analysis of variance for statistical analysis of the ERPs.

Results

Previously reported analyses (Stenson, Leventon, & Bauer, 2017) of the mood ratings and PANAS results indicated that there were not meaningful age or gender differences in task effects on mood and/or affect, or on memory bias (*C*). Therefore, analyses of these data are not reported here. All analyses were conducted in R 3.3.1 (R Core Team, 2016).

Behavioral results for the participants who met all ERP inclusion criteria are summarized in Table 1. Memory performance was elevated for negative and positive relative to neutral pictures. This pattern of emotional memory enhancement (EME) was consistent across the tested age range. There were not significant correlations between age and either the negative-neutral *d'* difference, *r*(123) = -.13, *p* = .16, or the positive-neutral *d'* difference, *r*(123) = -.10, *p* = .29. There was a significant gender difference in the mean negative-neutral *d'* difference, *t*(106.81) = -2.98, *p* = .004, *d* = 0.55; the difference was larger for males, *M* = 0.79(*0.65*), than for females, *M* = 0.44(0.62). In contrast, the mean positive-neutral *d'* difference did not differ significantly between genders, *t*(119.44) = 1.64, *p* = .10, *d* = 0.28; on average, the difference was larger for males, M = 0.21(*0.57*), than for females, M = 0.03(*0.67*). Together, these findings indicate that negative emotionality had a greater enhancing effect on memory for males versus females. In contrast, the impact of positive emotion on memory was statistically equivalent for both genders. The EME effects for both negative and positive relative to neutral were consistent across the age range.

In the present study, the paradigm did not yield sufficient trials for each of the three possible behavioral ratings of memory: 'definitely old,' 'maybe old,' and 'new.' In addition, there was significant inter-participant variability in relative rate of use of each memory classification. Together, these factors necessitated that we collapse 'definitely old' and 'maybe old' responses to old items into a single category ('hits').

Midfrontal Old/New Effect

We examined differences in the mean amplitude of ERPs from 300-500ms in a frontal-central cluster between a) hit and correct new trials, and b) hit and correct new negative, neutral and positive trials. Consistent with prior studies, ERP amplitudes were larger for younger participants (see Picton & Taylor, 2007, for a review). For all analyses, ERP values more than four standard deviations from the mean were removed. Preliminary analyses (ANOVA with factors item status (hit or correct new) and gender) did not indicate any significant main effects of gender, $F(1, 123) = 0.88$, $p = .35$, GES = .001, or interactions between gender and item status, $F(1, 123) = 0.00$, $p = .97$, GES < .001; therefore, gender is not considered further. In contrast, the main effect of item status was significant, $F(1, 123) = 9.55$, $p = .002$, GES = .007. The mean amplitude for hit trials (M = -9.1, SE = 0.57) was significantly more positive than for correct new trials (M = -9.52, SE = 0.58). We calculated this hit-correct new amplitude difference for within-subjects and then tested the average hit-correct new difference (*M* = 0.36, *SE* = 0.12) against the null hypothesis (*M* = 0) using a one-sample *t*-test (one-tailed) that indicated the difference was significant, *t*(123) = 2.98, *p* = .003 , *d* = 0.27. This difference was not, however, significantly correlated with age, *r* = -.06, *t*(122) = -0.67, *p* = .50. Thus, the hit-correct new mean amplitude difference was consistent across the age range and between genders, suggesting that, at least as tested in the present paradigm, the midfrontal old/new effect for recognition memory is consistent between middle childhood and adulthood.

After verifying that we replicated prior reports of a midfrontal old/new effect, we examined the relations between item status (hit or correct new) and emotion condition (negative, neutral, or positive). We first calculated amplitude differences between hit and correct new trials for each participant within each emotion condition (i.e., negative hit - negative correct new, neutral hit - neutral correct new and positive hit - positive correct new). To assess the magnitude of the old/new difference for each emotion condition, we compared the difference scores to zero with one-sample *t*-tests (one-tailed). See Table 2 for details. None of the comparisons was significant, and the old-new effect was small for each emotion condition: negative *d* = 0.17, positive *d* = 0.11, and neutral, *d* = 0.08. Thus, in the present study the midfrontal old/new effect was not sensitive to emotion. We then tested for correlations between age and the old-new MA difference for negative, neutral, and positive pictures; as both Figure 1, Panels A-C, and the results in Table 2 indicate, age was not correlated with the magnitude of the old/new ERP difference for any emotion condition.

Central-Parietal Old/New Effect

We examined differences in the mean amplitude of ERPs from 400-800ms in a central-parietal cluster between a) hit and correct new trials, and b) hit and correct new negative, neutral and positive trials. For all analyses, ERP values more than four standard deviations from the mean were removed. Preliminary analyses (ANOVA with factors item status (hit or correct new) and gender) indicated a significant main effect of item status, $F(1, 123) = 20.47$, $p < .0001$, $GES = .004$, but did not indicate any significant main effects of gender, $F(1, 23) = 0.16$, $p = .69$, $GES = .001$, or interactions between gender and item status, $F(1, 123) = 1.78$, $p = .18$, $GES < .001$, therefore, gender is not considered further.

The mean amplitude for hit trials ($M = 2.06$ $SE = 0.32$) was significantly greater for hit versus correct new trials ($M = 1.57$, $SE = 0.34$). We calculated hit-correct new amplitude differences within-subjects and then tested the average hit-correct new difference ($M = 0.50$, $SE = 0.10$) against the null hypothesis ($M = 0$) with a one-sample *t*-test (one-tailed) that indicated the difference was significant and robust, $t(124) = 4.82$, $p < .0001$, $d = 0.43$. This difference was not significantly correlated with age, $r = -.07$, $t(123) = -0.80$, $p = .43$. Thus, the hit-correct new amplitude difference was significant, and this effect of item status was consistent across the age range.

After verifying that old versus new items impacted parietal ERPs, we examined the relations between item status and emotion condition. We first calculated mean amplitude differences between old and new pictures for each participant within each emotion condition (i.e., negative old v. negative new, neutral old v. neutral new, and positive old v. positive new). To assess the magnitude of the old/new difference for each emotion, we compared the difference to zero with one-sample *t*-tests (one-tailed). See

Table 3 for details. These tests indicate that the old-new effect was significant for negative, *d* = 0.40, and positive, *d* = 0.27, trials, but not neutral, *d* = -.05, trials. These results demonstrated that emotion impacted ERPs in the central-parietal cluster from 400-800ms. Specifically, ERPs for hit trials were more positive than for correct new trials; this effect was largest for negative trials, followed by positive trials, but the hit-correct new difference was not significant for neutral trials. We tested for correlations between age and the old-new MA difference for negative, neutral, and positive pictures; as both Figure 2, Panels A-C, and the results in Table 3 indicate, age was not correlated with the magnitude of the old/new ERP difference for any emotion condition.

Discussion

In the present investigation, we tested recognition memory for negative, neutral, and positive pictures and the associated ERP correlates of correctly identified old and new pictures. Currently, the EME literature is based on research in adults, and the developmental trajectory of EME is largely unknown. Thus, our primary goal was to characterize EME effects on recognition memory across window of development when physiological, social, and environmental factors related to emotion undergo dramatic change: between middle childhood through adulthood. To address the questions of a) whether early old/new effects are present in middle childhood, and b) if emotion modulates the neural correlates of successful recognition memory consistently from middle childhood through adulthood, we employed a recognition memory paradigm and examined behavioral memory performance and ERPs in 8- to 30-year-olds. Therefore, we tested recognition memory performance for emotional versus neutral stimuli across this age range, and examined emotion effects on two ERPs: the early (300-500ms) and late

(~400-1000ms) old/new components. We predicted that memory would be better for emotional versus neutral stimuli across the age range, and that this behavioral effect would be reflected by an enhanced late old/new ERP component for emotional versus neutral trials. We did not anticipate emotion effects on the early old/new ERP, but we expected that age differences in overall old/new ERP effects were most likely to appear in this earlier time window. We first briefly discuss the behavioral results, followed by discussion of the ERP results.

Behavioral results demonstrated that EME for both negative and positive versus neutral was robust and consistent across the age range. These results indicate that both negative and positive emotion consistently enhance recognition memory performance, relative to neutral, between middle childhood and adulthood. Interestingly, the magnitude of EME for negative versus neutral, but not positive versus neutral, pictures was significantly greater for males versus females. Unfortunately, the sample sizes for each gender were not equal ($N_{Female} = 73$, $N_{Male} = 52$); The fact that so many males were excluded from the final analyses complicates interpretation of this gender difference, particularly because this result diverges from the results of the prior behavioral study, from which the participants in the current study are a subset. In that study, we found that EME effects for negative versus neutral were generally consistent between genders, but that the magnitude of the effect decreased slightly with age for males, but not for females.

It is intriguing that males' behavioral performance indicates a greater EME effect for negative versus neutral pictures, as there were not significant gender differences in the effects of emotion on ERPs. This pattern is somewhat counter-intuitive: presumably, males' larger negative-neutral behavioral EME should be paralleled by larger negative-neutral ERP difference. However, to our knowledge there are not studies that have directly examined whether the effects of emotion on these ERP components scales with the individual participants' behavioral EME. Rather, studies that have examined both EME effects on both behavior and ERPs have focused on group-level effects (e.g., Johansson, Mecklinger, & Treese, 2004; Leventon, Stevens, & Bauer, 2014; Schaefer, Pottage, & Rickart, 2011; Weymar, Löw, Melzig, & Hamm, 2009). We note that there were relatively few males participants who met all criteria for inclusion in the present analyses; The proportion of males from the behavioral study who were included in the present analyses (~44%) was lower than for females (60%).

Analyses of the ERP data indicated that we replicated the well-established early (300-500ms) midfrontal old/new effect: ERPs following hits were more positive-going than those following correct new responses. This effect was not statistically different between genders. It also was not sensitive to emotion condition, mirroring results from prior studies (Johansson et al., 2004; Weymar et al., 2011). Based on prior studies that did not find early old/new effects in children, we anticipated that there could be age differences in this effect. However, we found that the effect was consistent across the tested age range, and not significantly correlated with participant age. The absence of an age difference in the early midfrontal old/new effect aligns with the consensus that item memory capacity reaches adult-like levels at approximately 8-10 years of age (Y. M. Cycowicz et al., 2001; Ghetti & Angelini, 2008). However, it is interesting in the context of some findings from prior ERP studies of children's item memory that have not found early old/new effects in children (Czernochowski et al., 2009; Friedman et al., 2010; Mecklinger et al., 2011).

We believe there are two likely reasons why we found that old/new effects on this early midfrontal ERP were consistent in participants aged 8-30 years. First, we tested recognition memory in a manner that did not require participants to utilize strategy, engage in recall, or make source memory judgments. In contrast, most prior studies that have examined this ERP effect in children have utilized more demanding memory tasks. For instance, some have examined episodic memory retrieval processes in the context of source memory tasks (e.g., Cycowicz & Friedman, 2003; Cycowicz, Friedman, & Duff, 2003) and others have used utilized a continuous recognition memory paradigms, which require participants to assess the how recently they have seen each item (Czernochowski et al., 2009; Friedman et al., 2010). We suggest that the absence of early old/new effects in children reported by prior studies reflects use of paradigms that require children to engage in more demanding memory processes, such as source judgments or continuous recognition tasks. We propose that, by employing a paradigm in which all 'old' items were encoded in a single session, and then memory for those items is later tested, we eliminated demands that might explain the absence of early old/new ERP effects in children that has been documented in prior studies.

Another possible explanation for our findings of old-new effects in children as young as 8 years, in contrast to prior studies that have not found this effect in middle childhood, is suggested by the results of a recent study. Namely, the window between 8- and 10-years of age might be when, for most children, recognition processes for item memory reach maturity. Haese and Czernochowski, (2016) compared early frontal (300-500ms) and late (500-700ms) old/new ERP effects in 7- and 10-year-old children who had encoded pictures while completing either incidental or intentional encoding tasks, and then viewed identical or perceptually modified pictures while completing a recognition memory test in which they classified the pictures as “same,” “different,” or “new.” The authors report that there was no evidence for the early mid-frontal old/new effect in 7-year-olds in any of the task conditions; in contrast, the old/new effect was apparent in 10-year-olds during the intentional encoding task when ERPs for identical old versus new items were compared. This finding mirrors the results of multiple behavioral studies that report age-related differences in recognition memory performance during middle childhood, with performance differences between 6 and 10 years of age (Cycowicz et al., 2001; Ghetti & Angelini, 2008; Mandler & Robinson, 1978). It is likely that, in a similar fashion, the neural processes measured by ERPs also undergo substantial change in middle childhood, making relatively small differences in the age of participants critical.

We found that the late (400-800ms) centroparietal old/new effect was sensitive to item status, and that this was specific to the negative and positive conditions. Specifically, the old/new ERP effect was apparent only when negative or positive hits and correct new trials were compared. In contrast, there were not significant differences in the ERPs associated with neutral hit and correct new trials. The main effect of emotion and item status on this ERP component was consistent for participants across the age range. There was not a significant relation between age and the magnitude of the old/new ERP difference. This pattern of results replicates findings from multiple adult ERP studies of recognition memory for emotional and neutral events (e.g., Johansson et al., 2004; Schaefer et al., 2011; Weymar et al., 2009; Weymar, Löw, Schwabe, & Hamm, 2010). This result provides evidence that emotion effects on recognition memory processes, at least as tested in the present study, are consistent between middle childhood and adulthood.

This result replicates and extends a prior study from our lab, which documented an emotional enhancement of the old/new effect for a topographically and temporally similar ERP effect in 7.5-8.9 year olds (Leventon et al., 2014). One notable difference between that study and the present results is that the Leventon and colleagues (2014) report that this emotion effect was specific to negative stimuli. In contrast, we report significant emotion effects for negative and positive stimuli alike, relative to neutral. It is also worth noting that Leventon and colleagues did not find that evidence for emotion effects on the late old-new ERP component in younger participants (5-7.5 years). In contrast, there were significant differences between the ERPs for emotional versus neutral pictures in older participants (7.5-8.9 years)—even though there were not significant differences in their memory for emotional and neutral pictures. These age differences in the neural response to emotional stimuli could foreshadow the emergence of the adult-like EME effects that the present study documented in both brain and behavior. The present results indicate that emotion impacted ERPs similarly across the tested age range. Presumably, had the study included even younger participants, we might have observed diminished emotion effects for those participants.

This research makes an important contribution to the literature, but some limitations are worth noting. First, ensuring the task was feasible for children as young as 8 to complete necessitated limiting the duration of each study session and, therefore, limiting the total number of trials. This, in turn, precluded sufficient numbers of trials for comparison the ERPs associated with all possible memory outcomes (hit, miss, false alarm, and correct rejections). In addition, the comparatively low minimum trial threshold (10 per emotion condition) for the subsequent memory ERP analysis is not ideal from the perspective of the signal-to-noise ratio required for clean ERP analyses. Related to this issue of trial counts, we had to exclude a higher proportion of male participants' data from the final analysis, relative to females. Thus, our final analyses included more females than males. Another limitation was that our paradigm did not use one of the more commonly employed memory response options (e.g., remember/know or a continuous confidence rating scale). Instead, we instructed participants to classify items as 'old,' 'maybe old,' or 'new,' complicating our ability to directly compare our participants' use of the high ('old') and low ('maybe old') confidence memory options. And, the low trial counts overall necessitated that we collapse all trials judged old (i.e., both 'old' and 'maybe old) into a single bin. Therefore, we could not address impacts of participants' confidence in their memory on ERPs, as prior studies have done (e.g., Schaefer et al., 2011; Weymar et al., 2009, 2010). It is also worth nothing that we tested emotion effects on ERPs and recognition memory in a laboratory context, and using a standardized stimulus set to elicit emotion. These conditions likely do not mimic all aspects of emotion processing, and, in turn, its effects on memory, that occur in naturalistic contexts. Moreover, including children as young as 8 in the present study precluded the use of stimuli that might elicit particularly strong emotional processing, such as erotic or graphically violent images. Future studies should include novel methods to elicit comparable emotion effects in participants of different ages.

Ideally, future studies will examine the interaction of emotion, memory confidence judgments, and memory performance across development, in order to provide more information about whether shifts in emotion effects on memory are related to changes in memory confidence judgments. There also remains a need to examine developmental change in EME for other types of memory, including recollection and recall. Our findings suggest that any age-related change in emotion effects on recognition memory must come from other sources, such as development in recall strategy and performance, and autobiographical memory capacity (e.g., Bauer et al., 2017; Fivush, Hazzard, McDermott Sales, Sarfati, & Brown, 2003). This is particularly important for further assessing the existence of gender differences in EME, as gender differences in these types of memory are well-established (for reviews see, e.g., Andreano & Cahill, 2009; Fivush, 2011).

In conclusion, the findings of the current research extend and enrich the EME and ERP literatures. First, we conducted a direct comparison of EME effects on recognition memory performance for both positive and negative stimuli across a wide range of ages, using the same stimulus set, paradigm, and methodology. Second, we found that emotion effects on recognition memory performance are present and robust from middle childhood through early adulthood. Finally, we documented developmental consistency in emotion effects on ERPs, specifically the early mid-frontal and late central-parietal old/new components, during a recognition memory task. Our results largely mirror those of previous studies of emotion effects on recognition memory processes at retrieval while extending them by demonstrating that emotion effects on episodic memory retrieval are consistent from middle childhood through adulthood. Our findings expand the memory development literature by demonstrating that, at least as tested in the present paradigm, emotion effects on recognition memory are consistent from middle childhood through adulthood; this consistency is apparent in both behavioral and neural processes. In short, our results provide compelling evidence that emotion consistently modulates neural processes and enhances recognition memory performance from middle childhood through adulthood.

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Table 1. *Behavioral memory performance.*

	M(SD)	*Min.*	*Max.*
Negative Hits	23.94(*3.72*)	11	30
Neutral Hits	18.62(*4.68*)	10	30
Positive Hits	21.52(*4.32*)	12	30
Negative Misses	5.74(*3.51*)	0	16
Neutral Misses	11.05(*4.55*)	0	20
Positive Misses	8.23(*4.21*)	0	17
Negative-neutral *d*’	0.59(0.65)	-1.60	2.33
Positive-neutral *d*’	0.10(0.63)	-1.11	2.10

Note. Total *N* = 125; total possible hits = 30; total possible misses = 30.

Table 2. *Mean amplitude differences (hit – correct new) and correlation with age by emotion condition from 300-500ms in frontal-central cluster.*

Emotion	*M(SE)*	*t*	*df (t)*	*p (t)*	*d*	r_{age}	*df* (r_{age})	*p* (r_{age})
Negative	0.47(*0.24*)	1.93	123	.06	0.17	-.06	122	.53
Neutral	0.20(*0.22*)	0.91	124	.36	0.08	-.06	123	.50
Positive	0.28(*0.24*)	1.17	124	.25	0.11	-.04	123	.69

Table 3. *Difference in ERP mean amplitude for old versus new pictures.*

Emotion	$M(SE)$	t	df (t)	p (t)	r_{age}	df (r_{age})	p (r_{age})
Negative	0.80(*0.18*)	4.46	124	< .0001	-.03	123	.71
Neutral	-0.11(*0.20*)	-0.53	124	.60	-.01	123	.93
Positive	0.56(*0.18*)	3.03	124	.003	-.11	123	.24

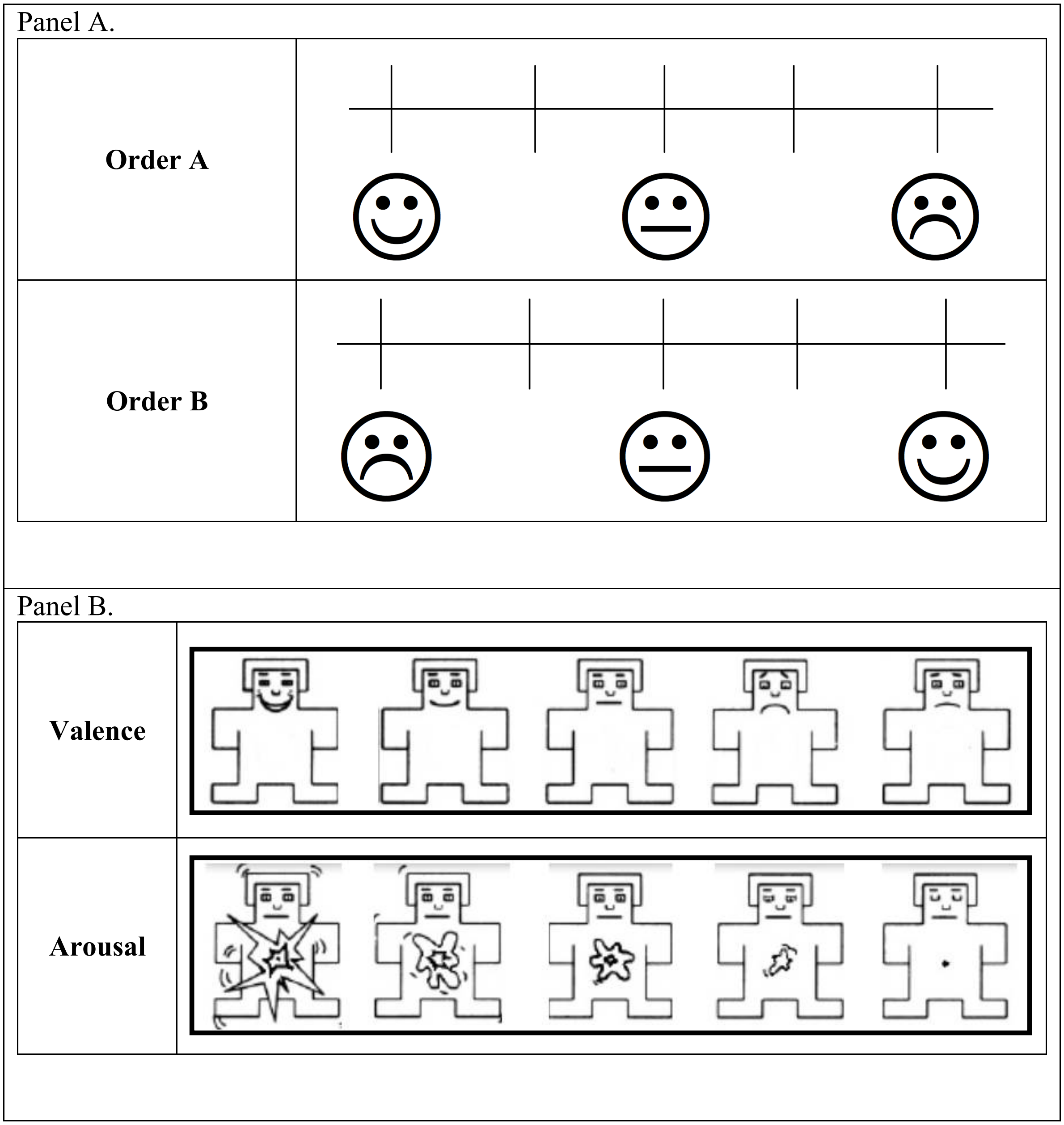


Figure 1. Mood (Panel A) and Self-Assessment Manikin (SAM) (Panel B) rating scales.

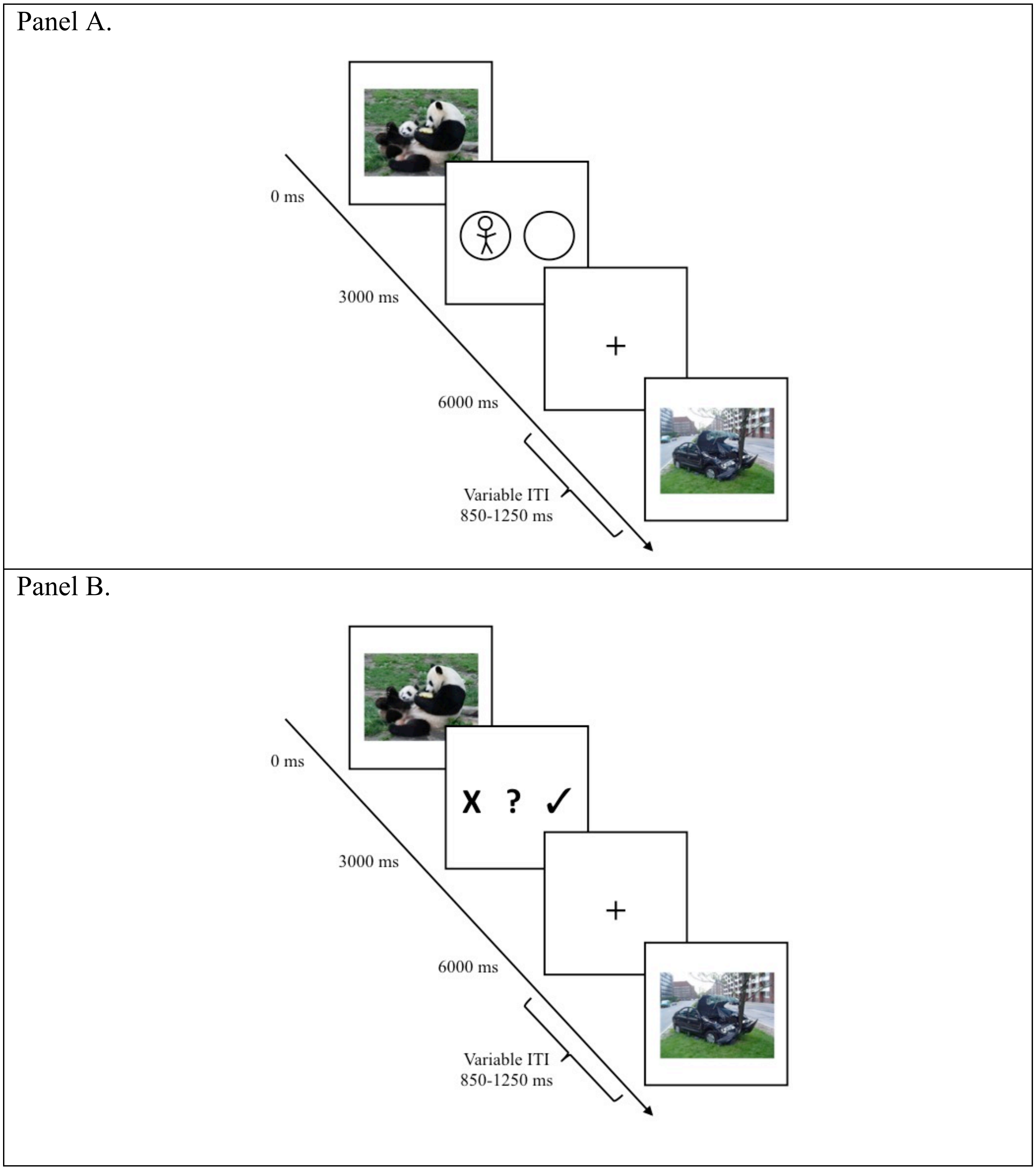
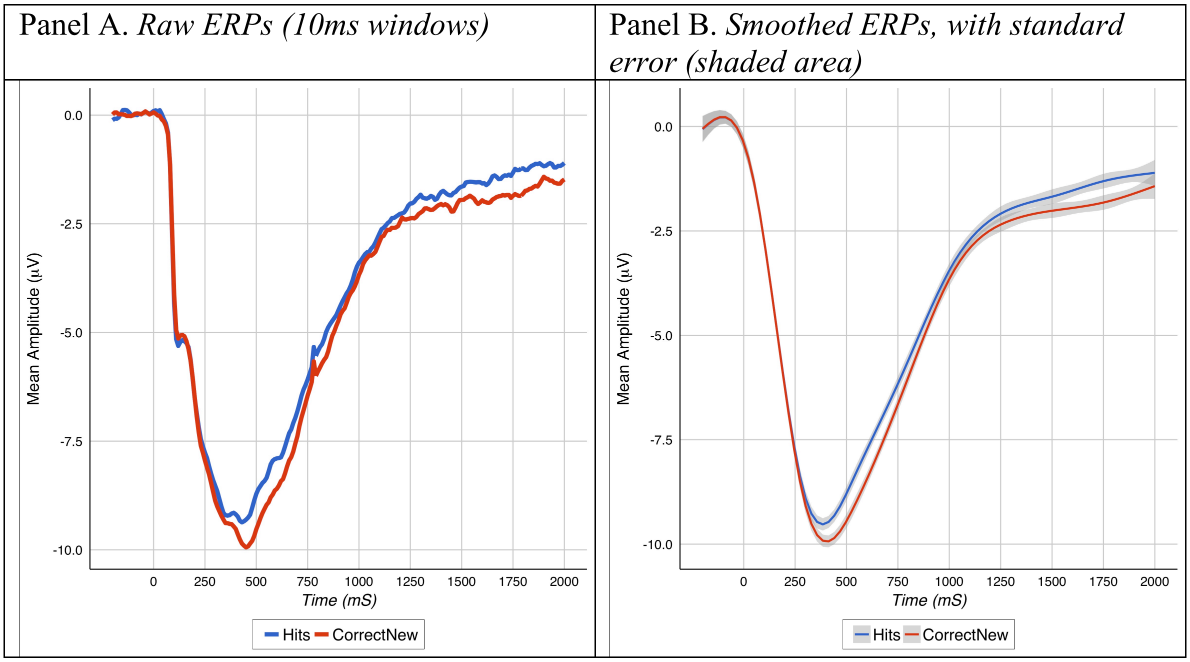


Figure 2. Trial structure for encoding (Panel A) and recognition (Panel B).

Panel A. *Mid-frontal cluster*

Panel B. *Central-parietal cluster*

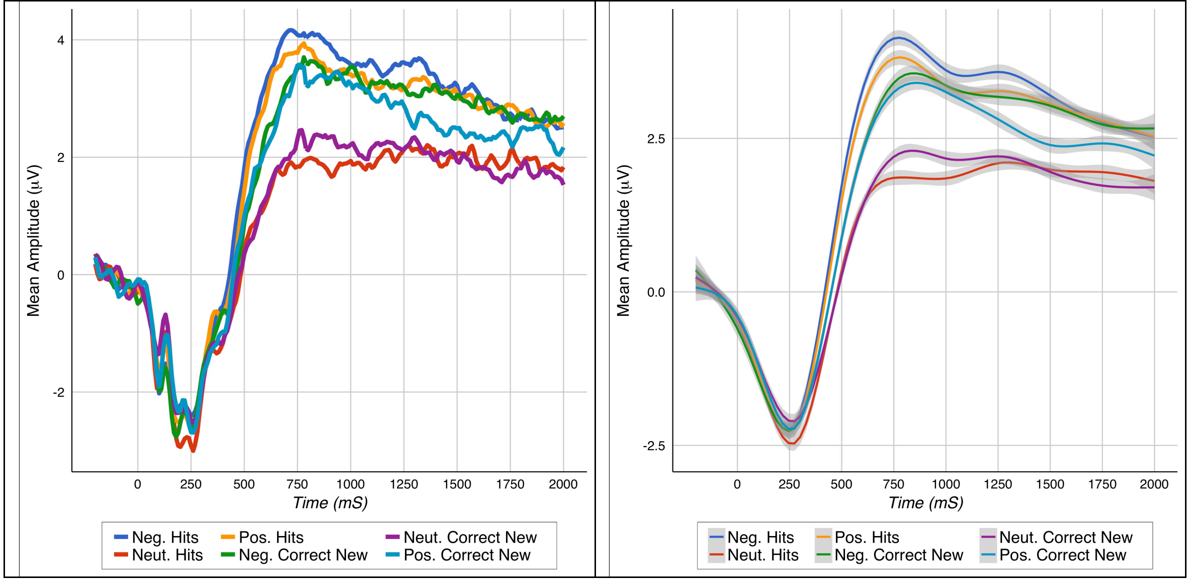
Figure 3. Electrode clusters examined in ERP analyses.



Panel A. *Raw ERPs (10ms windows)*

Panel B. *Smoothed ERPs, with standard error (shaded area)*

Figure 4. Frontal-central cluster for all hit and correct new trials.



Panel A. *Raw ERPs (10ms windows)*

Panel B. *Smoothed ERPs, with standard error*

Figure 5. Central-parietal cluster for all hit and correct new trials by emotion condition.

General Discussion

The overarching goal of this dissertation was to add to our understanding of emotion effects on memory between middle childhood and adulthood. To that end, in this dissertation three papers addressed separate but related questions, in the context of a behavioral and ERP study. Each of three papers examined one aspect of emotion effects on memory in the developmental window between middle childhood and adulthood, in order to determine if there was developmental change or consistency: Paper 1 examined the consistency of emotion effects on recognition memory performance, Paper 2 addressed the effects of emotion at encoding, and Paper 3 examined the retrieval of emotional and neutral memory. Findings from the three papers reported herein thus address the developmental trajectory of emotion effects on encoding and recognition memory between middle childhood and adulthood.

Findings from Paper 1 indicate that, as measured through overt behavior, emotion effects on recognition memory are largely consistent from middle childhood through adulthood (8-30 years). Specifically, recognition memory performance was enhanced for both negative and positive versus neutral pictures, though the effect was larger for negative pictures. The magnitude of this memory enhancement for negative pictures was impacted by age and gender: for females, EME for negative was consistent across the age range, whereas for males the enhancement diminished in older participants. We also examined whether key aspects of the paradigm, including emotion elicitation and the impact of the task on participants' mood and affective state, changed with age or between genders. For the most part, we found that they did not, however, there were gender differences in participants' valence ratings of the pictures: on average, female participants rated negative pictures as more negative, and positive pictures as more positive, relative to neutral pictures, than did male participants. There were also gender differences in participants' arousal ratings for negative versus neutral pictures. Specifically, the average increase in arousal rating for negative pictures was larger for females. There were not age differences in valence ratings, however, participant age was a significant predictor of arousal ratings for negative, but not positive, versus neutral pictures, such that the negative-neutral arousal rating difference was larger for older participants; this result reflects the tendency of younger participants to rate neutral pictures as more arousing than older participants. The fact that females rated the negative and neutral pictures as more emotionally arousing than did males, but that there were not overall gender differences in the magnitude of EME, mirrors the results of a recent, well-powered study (Spalek et al., 2015). These findings imply that a) small gender differences in subjective ratings emotion elicitation do not produce gender differences in EME; b) emotion effects on recognition memory are apparent by middle childhood and remain consistent through early adulthood for females; and c) for males, EME for positive emotion is consistent, whereas EME for negative emotion diminishes slightly across this age range.

Findings from Paper 2 indicate that emotion effects on ERP indices of memory encoding are consistent from middle childhood through adulthood (8-30 years). Specifically, emotion enhanced the late positive potential (LPP) similarly for participants across the age range, and subsequent memory analyses also revealed consistency across development and between genders. This emotion effect on the LPP was apparent both overall (for all pictures, regardless of whether they were later remembered) and when examining only pictures that were later correctly remembered (during the Session 2 memory test). Together, these ERP results indicate that: a) emotion effects on neural activity, at least as measured in this study, were consistent in both female and male participants ranging in age from 8-30 years old; and b) these emotion effects were present and consistent across participants even when comparing ERPs for pictures that were later remembered. It is also noteworthy that the emotion effect on neural activity was maintained even when controlling for subsequent memory performance (i.e., when only correctly remembered emotional and neutral trials were analyzed). Although these findings contribute to our understanding of EME across development, their interpretation is somewhat constrained by limitations of the study, which included having to collapse across the high and low confidence 'old' response options, not having sufficient trials to analyze ERPs across other memory outcomes (i.e., hits, misses, false alarms, and correct rejections), and the possibility that the stimuli were not sufficiently emotionally arousing to elicit an early emotion effect ERPs—the Early Posterior Negativity—that has been documented several in prior studies (for a review, see Olofsson, Nordin, Sequeira, & Polich, 2008). In spite of these limitations, however, the results of this study provide novel evidence that emotion has consistent effects on recognition memory encoding processes between middle childhood and adulthood.

Findings from Paper 3 indicate that there is developmental consistency in two ERP indices of recognition memory, and in the impact of emotion on those indices. Specifically, we found that, across the tested age range and for both genders, a) an early mid-frontal ERP component was selectively modulated according to whether correctly recognized pictures were old or new; and b) emotion selectively enhanced the central-parietal old-new ERP effect, such that ERP amplitudes were more positive for correctly recognized emotional, but not neutral, pictures. To our knowledge, these results are the second to indicate that ERP correlates of correct recognition memory (the mid-frontal old-new effect) are present and adult-like in middle childhood (Haese & Czernochowski, 2016). In addition, these results extend prior research, which has repeatedly documented emotion effects on ERP old-new effects in adults (e.g., Schaefer, Pottage, & Rickart, 2011; Weymar, Löw, Melzig, & Hamm, 2009; Weymar, Löw, Schwabe, & Hamm, 2010), and, in one instance, found this emotion effect in middle childhood, albeit for negative but not positive events (Leventon et al., 2014). We interpret these results with some caution, however, because a large proportion of participants were excluded from these analyses due to not meeting minimum trial count criteria. This problem was exacerbated for male versus female participants. Perhaps relatedly, there were gender differences in behavioral EME effects that presented an opposite pattern of gender differences from what was found in Paper 1. Specifically, in Paper 1 we reported that the impact of negative versus neutral emotion on memory declined with age for males, but not for females. In contrast, in Paper 3 we found that, across the age range, the negative-neutral EME effect was significantly larger for males than for females. Ideally, future studies will investigate emotion effects on recognition memory with samples that include equal numbers of females and males, and will assess whether, when behavioral performance is equivalent for both genders, emotion effects on ERPs will still be equivalence. In spite of the limitations of this study, these results provide novel evidence that emotion consistently modulates neural processes and enhances recognition memory performance from middle childhood through adulthood.

Together, the results of these papers suggest that, at least as tested in the present studies, EME effects on recognition memory are consistent from middle childhood through adulthood. This result is striking when we reflect on how different 8- and 30-year-olds are: across this age range, there are dramatic changes in the individual's physiology, cognitive capacities, social environment, and behavioral repertoire (e.g., Blakemore & Mills, 2014; Casey, 2015; Larson, Richards, Moneta, Holmbeck, & Duckett, 1996; Steinberg, 2008; Suleiman, Galván, Harden, & Dahl, 2016).

The results of these studies are also striking in that they indicate no overall gender differences in EME effects on recognition memory as measured with behavior, ERP at encoding, and ERP at retrieval. We did find the females and males had slightly different "developmental profiles" for the impact of negative emotion, relative to neutral, on behavioral measures of EME. Specifically, EME for negative versus neutral stimuli decreased across the age range for males, but was consistent for females. As detailed in Paper 1, we believe this change reflected the diminished salience of the emotional pictures used in this study (i.e., cupcakes, cute puppies, fireworks, and smiling babies) for older males. This hypothesis is supported by studies that use similar picture stimuli (from IAPS) to elicit emotion in adult males and find that emotion effects are largest for highly arousing positive images, such as erotica (e.g., Weymar et al., 2009; for a review, see Olofsson et al., 2008). In future research, it is important to test this empirically, by using different stimulus sets (i.e., one similar to that used in the present study, and another that includes images rated as highly arousing by adult males) to examine how EME effects might change for adult males, relative to females and younger males, as a function of the stimuli.

On the whole, the results of the present studies indicate that EME effects on recognition memory are generally similar for females and males. This finding corroborates the results of a recent, well-powered study of EME on memory, which found equivalent emotion effects on recognition memory for females and males (Spalek et al., 2015). I propose that together, the results reported herein and by Spalek and colleagues (2015), constitute compelling evidence that EME for recognition memory is not gender-specific. Here it is important to note that recognition memory is less impacted by social and cultural learning than some other types of memory, including free recall and autobiographical memory. For instance, there is evidence that how parents talk to their children about both autobiographical memories, and emotional events, depends on the child's gender (for a review see, e.g., Fivush, 2011). Thus, we anticipate that there is likely to be gender-specific developmental change in EME effects on performance in free recall and autobiographical memory tasks.

The results of these three studies indicate that EME effects on recognition memory are consistent across development. Although the absence of age-related change is, at first glance, not exciting, this result provides important context for interpretation of the many other processes that do change across adolescence. Specifically, the present results offer important constraints on interpretation of age-related change in other cognitive processes across adolescence: whatever other changes unfold, they are likely not the result of shifts in emotion effects on recognition memory.

As Heller and Casey (2016) argue, understanding both normative and pathological emotion processes across development is critical, and particularly for adolescence, given that it is the period both when most mental illnesses emerge and when changes in emotion processing might contribute to the risky behaviors that are pervasive in adolescents. Similarly, Del Piero et al. (2016) propose that to achieve a more complete understanding of emotion processing across adolescence, and identify possible relations between emotion processing and the increased prevalence of mental health issues across adolescence, we need more studies that probe basic emotion processing and emotion-cognition interactions across development. The present studies constitute a valuable addition to our knowledge about emotion and its effects on recognition memory during adolescence.

Limitations and Future Direction

The primary limitation of the present research was that it examined EME for only one type of memory: recognition. The results of the present studies suggest that if there are age and/or gender related changes in EME, they are not happening at the level of basic recognition memory. Whereas these results constitute a valuable first step towards examining EME across development in a manner that enables direct comparisons across a wide age range, in the future it will be important to conduct similar studies that probe EME effects on free recall, source memory, emotional trade-off effects, and autobiographical memory across development. A particularly interesting avenue for future research would be to examine emotion effects on memory tasks that depend more heavily on strategy and/or emotion regulation, as these capacities continue to develop across adolescence (McRae et al., 2012; for reviews see Ghetti & Bunge, 2012; Ofen, 2012).

There are, of course, additional limitations of the current studies that we hope will be addressed by future research. First, we used different mood and affect ratings for the children and adults. Ideally, in the future consistent mood and/or affect measures will be collected for all participants. Another limitation of the present studies was that the lower bound for participant age was 8 years. Findings from Leventon and colleagues (2014) suggest that there is development change in EME effects slightly earlier in middle childhood (prior to ~8 years of age). Viewed together, these findings suggest developmental change in EME likely occurs in early- and middle-childhood, and therefore that is the critical window in which to examine EME for recognition memory. A third limitation of the present studies is that, while the IAPS provide a well-controlled stimulus set that has been widely used in adult EME studies, it is unlikely that they elicit emotion either of the same kind or magnitude as that experienced in contexts outside the laboratory environment. In addition, the IAPS do not specifically manipulate certain characteristics that have been shown to be particularly salient to adolescents, such as risk and reward (for a review, see Casey, 2015). A final limitation to note is that we utilized a cross-sectional design that cannot address whether EME effects change within an individual as they develop. Ideally, future studies will examine EME within individuals as they develop. In short, the present work should be complemented by studies that utilize a variety of stimuli and paradigms, include younger participants, and examine whether EME effects shift within individuals across development.

Conclusions

The findings of these three papers extend and enrich the EME literature. First, we conducted a direct comparison of EME effects for both positive and negative stimuli across a wide swath of development, using the same stimulus set, paradigm, and methodology. Second, we utilized both behavioral performance and ERPs to provide both overt and covert measures of EME effects. Third, we evaluated both age and gender in relation to EME. We found that EME is apparent in children as young as 8 years, and that EME effects were consistent between this age and 30 years. Our results provide compelling evidence that emotion consistently enhances recognition memory from middle childhood through adulthood for both genders.

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