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Samantha A. Mandel 4/20/11

Emotion processing: An electrophysiological examination of school-age children

by

Samantha A. Mandel

Dr. Patricia Bauer
Adviser

Department of Psychology

Dr. Patricia Bauer

Adviser

Dr. Stephan Hamann

Committee Member

Dr. Peter Brown

Committee Member

4/20/11

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Samantha A. Mandel

Dr. Patricia Bauer

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a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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In adults, emotional stimuli elicit larger neural activity compared to neutral stimuli, as reflected in event-related potential (ERP) paradigms. This larger response has been evidenced across various studies, and has been coined the late-positive potential (LPP). Although the LPP has been thoroughly demonstrated in adults, experiments concerning this emotional neural response have not been fully investigated within chidhood development. Twenty-one school-age children (ages 5 to 8 years old) viewed a presentation of positive, negative, and neutral images during which ERPs were recorded. The participants subjectively rated a subset of the images in order to ensure that children and adults interpreted the emotional content of the images similarly. Behavioral and electrophysiological results indicated that school-age children demonstrate the LPP observed in adults, albeit at a later time, in both the front and back of the scalp. Furthermore, this LPP response is affected by the positive condition in the front of the scalp and by the negative condition in the back of the scalp; and this topographical difference in emotion processing has yet to be evidenced in the LPP literature. There was differential processing of emotion across time windows, ERP electrodes, and hemisphere as well. Collectively, these findings suggest that school-age chidren's neural responses to positive and negative stimuli are larger than to neutral stimuli, which demonstrates that by school-age years there is a LPP present, even though their brains are not yet fully developed during this age range. Lastly, the findings indicate that there may be a relationship between the way children process emotional stimuli and how that affects their behavior in diverse emotional contexts (e.g., avoiding unpleasant situations).

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Emotion processing: An electrophysiological examination of school-age children

Everyday we come across people, events, and places in emotional contexts. The way we process these emotional encounters can give us insight into why our emotions are a necessary part of life, what are the ways in which emotions can inform us about brain functioning, and how emotions might interact with other subcortical processes (e.g., memory, language). The concept of emotion has many variables that combine to form the two dimensions of what we consider emotion: valence and arousal (LaBar & Cabeza, 2006). Valence has been defined as "a dimension of emotion that varies from unpleasant (negative) to pleasant (positive), with neutral often considered an intermediate value," and arousal is considered "a dimension of emotion that varies from calm to excitement" (LaBar & Cabeza, 2006, p. 54). Processing, reflecting, and expressing emotions are what make us human, which is why it is necessary to understand how emotion is defined in order to understand how the human brain processes emotion. As Hajcak, MacNamara, and Olvet (2010) described in their paper, there is a robust finding that the brain dedicates more attention to emotional stimuli (e.g., positive and negative) more so than neutral stimuli, and this emotional process is the topic of this thesis. This specified emotional response has been documented across the adult literature, but it has not been fully examined in regard to development. Analyzing the neural processing of emotions is important because it will provide researchers with information concerning why humans donate more neural resources to emotional stimuli as opposed to non-emotional stimuli, how this emotional process is beneficial for our survival, and in what ways human emotion processing interacts with other necessary mechanisms.

Empirical evidence from the adult literature has demonstrated that adults dedicate more neural activity to positive and negative stimuli compared to neutral stimuli, which results in a robust and patterned manner called the late positive potential (LPP; Hajcak et al., 2010); however, developmental research on this neural pattern of emotion processing is not as extensive. Therefore studying emotion processing during development can elucidate when the emergence of this temporally efficient adult-like process occurs and how it might go awry (e.g., emotion dysregulation and psychopathologies). How children process emotion at the neural level is of the utmost importance to developmental research since this information will begin to clarify some pertinent questions about the brain's development, such as how a child's developing emotion processes handle the evaluation of emotional stimuli similarly, or differently, from the mature system of an adult. Therefore, it has become evident that more developmental research on emotional processing at the neural level needs to be conducted in order to answer these questions.

Childhood is when humans begin to learn how to respond to their emotions appropriately (Strayer, 1993) and alter their behavior accordingly. In addition childhood is when particular emotional pathologies, such as depression, begin to emerge (Luby & Belden, 2006). Substantial developmental changes occur at the cortical level (Toga, Thompson, & Sowell, 2006), and the fusion of connections between cortical structures permits faster responses over development (Favilla, 2006), so the knowledge of cortical and subcortical development can give a foundation for investigations into development at the neural level. Questions concerning how and when in development emotion is processed in the neural adult-like pattern are theoretically, methodically, and practically pertinent to various areas of interest (e.g., cognition, behavior, social interaction).

Certain behavioral changes have been observed in response to emotional encounters and studies have demonstrated that humans alter their behavior based upon emotional input (Lang, Bradley, & Cuthbert, 1997). For example, positive stimuli generally elicit a pleasant reaction;

therefore individuals will approach and embrace the positive stimuli more often than negative or neutral stimuli. One explanation of this behavior suggests that additional positive encounters might be rewarding to individuals; yet, negative stimuli elicit an avoidant reaction and a person will try to restrict further interactions with the stimuli, seemingly for self-preservation reasons (Bradley & Lang, 1994). Additionally, the more arousing the encounter is, the more likely the respective behaviors occur (Bradley & Lang, 1994).

In conjunction with the intentional behavioral changes, adults display differential automatic physiological responses toward emotional stimuli, such as increased heart and breathing rates (Keil, Bradley, Hauk, Rockstroh, Elbert, & Lang, 2002). Studies have indicated that heart rate decreases and facial muscle movement increases as the valence of a stimulus changes from positive to neutral (Lang, Greenwald, Bradley, & Hamm, 1993). Therefore, there seems to be an automatic response to this type of stimuli, at both the physical and neural level, and these responses cause a change in behavior (e.g., approach towards, or avoidance of, emotional stimuli). Individuals change their behaviors based upon emotion, and this type of observable behavioral change suggests there may be differential subcortical emotion processing that elicits behavioral change. There could be a direct relationship between emotion and behavior, as the documented behavioral changes imply, therefore it is important to explain how the brain is responsible for these behaviors. The present research will attempt to elucidate this relationship during childhood by analyzing whether children process emotion similarly to adults, when the adult-like emotion processing might emerge, and how the neural processing of emotions contributes to behavior based upon emotions.

As previously mentioned, across the literature it has been robustly evidenced that adults process emotional stimuli differently than neutral stimuli, and this effect can be seen across many methodological paradigms (e.g., fMRI, PET). There have been various evolutionary (Lang, Bradley, & Cuthbert, 1997), social (Gross & Muñoz, 1995), and cognitive (Rugg & Curran, 2007) theories as to why this emotional processing phenomenon occurs. However, in order to justify any theories there needs to be thorough developmental research to see how and when this process emerges (Lang, Bradley, & Cuthbert, 1997; Rugg & Curran, 2007). Different methodologies can test how and when this adult emotional processing phenomenon occurs, but because of its temporal resolution, one paradigm in particular is the ideal measurement currently available to answer these questions. This technology is called event-related potentials (ERPs) and it is the most temporally efficient way to directly measure neural activity reflective of emotional processing.

Event-related potentials are time-locked neural responses to a fixed stimulus. This means that a participant's brain activity, in response to particular stimuli, is continuously recorded and the ERPs represent the activity time-locked to the stimulus being presented. The neural responses to each type of stimulus are averaged together across numerous trials, therefore the data allows for comparisons between the neural processing to various stimuli. The dynamics of the organized neural response, as seen in the data produced by ERP technology, have been shown to reflect certain patterns of processing to different stimuli (e.g., semantic anomalies, oddball paradigm). Psychologists who are concerned with emotion processing have capitalized on this technology because it allows them to distinguish different aspects of emotion (e.g., valence and arousal) and translate this temporal information into evaluations of hypotheses concerning possible neural substrates, which may interact with what we generally think of as emotional processing. By utilizing ERP technology, the present investigation will delve into whether the differential emotion processing pattern, called the late positive potential, observed in adults is detected in school-age children (5 to 8 years old). In order to understand how and if these same emotional processing patterns exist in school-age children, it is important to first understand the ways by which this process is observed in adults before we examine how this process develops.

One pattern of emotion processing that has been thoroughly demonstrated in response to visual presentations of pictures is the late positive potential. Although this pattern is similar to the response observed in a different testing paradigm (e.g., oddball), the late positive potential has been hypothesized to be reflective of emotion processing. The robust adult late positive potential (LPP) findings identify this pattern as a positive (e.g., the response is above the horizontal axis, an axis which indicates a baseline of activity) ERP component present after participants view emotional stimuli (e.g., positive and negative compared to neutral), and this positive component has been measured using various stimuli (e.g., words, pictures, faces). Furthermore, this patterned response to emotional stimuli has been observed across extended durations of tine (measured in milliseconds or seconds) and topographical locations on the scalp. Although some studies have found the emotion effect (LPP) to be larger in the right hemisphere compared to the left hemisphere (e.g., Junghöfer, Bradley, Elbert & Lang, 2001), the LPP typically occurs around 300 ms after the stimulus onset, it is sustained for up to several hundred milliseconds, and it is evident primarily over parietal electrodes.

Within the adult literature, researchers have suggested that how participants assess the context and subjective self-relevance of emotional images influence the participants' attention to the stimuli, and therefore emotion processing. This suggests that the level of processing in which participants are engaged while viewing emotional stimuli can modulate the size of the LPP response. To analyze how attention may modulate the LPP, researchers asked one group of participants to find an association between particular stimuli (non-emotional words and emotional pictures) they were viewing, and another group of participants were asked to simply count the different types of stimuli presented during the experiment (Johnston, Miller, & Burleson, 1986). The researchers found that the LPP was larger for the group that was asked to learn the association between the stimuli, which indicates that the LPP can vary based upon the participants' assessments of the task relevance. The modulation of the LPP has been supported by evidence demonstrating that the emotionality of the stimuli, more specifically pictures, has a significant effect on how participants process the image (Johnston, Miller, & Burleson, 1986; Schupp, Junghöfer, Weike, & Hamm, 2003). Since the LPP is affected by an individual's level of attention, researchers can evaluate the necessity of utilizing experimental measures in order to ensure participants attend to the emotional stimuli. This will assist experimenters' speculation concerning why emotions cause a particular pattern of processing and in what other ways can this response be modulated.

The specific valence of the stimulus (e.g., positive vs. negative) is another way in which the LPP can be modulated. One study found that the LPP for aversive stimuli was greater than the LPP was for positive stimuli, suggesting there might be a distinction between the processing within the emotional valences, however, previous studies only found a difference between emotion conditions and the neutral condition (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). In conjunction with evidence regarding the possibility that emotional valence modulates the size of the LPP, there are results implying that the LPP can be modulated by the arousal of stimuli as well. Evidence indicates that the degree of the arousal (e.g., very positive as opposed to positive) affects the size and amplitude of the LPP component (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp, Cuthbert, Bradley, Cacioppo, Ito, & Lang, 2000; Schupp, Stockburger, Codispoti, Junghöfer, Weike, & Hamm, 2007; Versace, Bradley, & Lang, 2010). Interestingly, in each of these studies, the time that the participant had to view each stimulus did not change the patterned LPP response. Collectively, these studies demonstrate that the LPP was larger for more arousing images, it emerged around 300 milliseconds, and it was sustained up to 6 seconds.

In summary, many studies have detected the LPP when adults process emotional stimuli, and the size of this response can vary as a result of the valence and arousal of the stimuli (the primary components of emotion), as well as the adult's level of attention to the stimuli. The LPP is predominantly observed in the parietal electrode clusters toward the back of the scalp; however, there have been some adult studies that have demonstrated the LPP in frontal electrode clusters as well (Schupp et al., 2000). Additionally, there does not seem to be strong hemispheric differences in regards to the expression of the LPP (Carretié & Iglesias, 1995; Schupp et al., 2000), although there have been some studies that have detected right hemisphere dominance for this response (Junghöfer, Bradley, Elbert & Lang, 2001).

Clearly, the LPP is a robust response across the adult ERP literature, however, in order to elucidate when this patterned response might begin to reach the adult level, it is informative to look at the beginning of the developmental spectrum: infancy. ERP experiments have assessed the emotional processing capabilities of infants as young as 7 months old by using emotional faces as stimuli, and researchers found similarities (e.g., sustained positive deflection in the late time window) to the adult LPP (Nelson & De Haan, 1996). However, other studies assessing infants' emotional processing have not found that same positive component evidenced in adults (Hoehl & Striano, 2010). The explanation for the conflicting infant literature may be a result of the age difference (youngest participants in Hoehl & Striano (2010) were 3 months old, whereas youngest were 7 months old in Nelson & De Haan, 1996) and test stimuli implemented (Hoehl and Striano (2010) used only fearful and neutral facial stimuli, whereas Nelson and De Haan (1996) used both happy and fearful faces compared to neutral as their stimuli). It is not clear whether the LPP is present as early in the developmental spectrum as infancy. The observed responses during infancy may not be reflective of emotion processing, therefore infants' responses may not be the emergence of the LPP, as has been suggested (Nelson & De Haan, 1996). The infant literature has demonstrated that there is a differential processing of emotional stimuli, however, the LPP has yet to appear in a robust manner during the beginning of the developmental spectrum. Therefore, research that attempts to elucidate the emergence of the patterned emotion processing viewed in adulthood needs to look at other age ranges throughout the developmental spectrum. Unfortunately, however, there is not a lot of literature assessing children's emotional processing using ERP paradigms. Additionally, many of the adult studies use images that are not appropriate for children (e.g., erotica and mutilation), so choosing stimuli that would elicit similar responses in children as compared to adults is imperative.

It has been recently demonstrated that school-age children show evidence of the LPP, and similar to observations in adults, the size and time of onset of LPP is influenced by emotionally valenced images (Hajcak & Dennis, 2009). The researchers found that there was a LPP present between 500 and 1500 milliseconds following stimulus-onset, and it was largest over occipital-parietal electrode clusters. Furthermore, within each time window (early, middle, and late), there were differences in how positive and negative stimuli were processed compared to neutral stimuli. That is, there were larger responses to the positive images versus the neutral images within the early time window (500 to 1000 msec), there were larger responses to negative images compared to the neutral images during the early and middle time window (1000-1500 msec), and by the late time window (1500-2000 msec) there was no longer any differences in processing by emotion condition.

Dennis and Hajcak (2009) did further research on the LPP finding in school-age children by elaborating on adult evidence of the LPP in frontal electrodes (e.g., Schupp et al., 2000). Their results demonstrated that the LPP was present across the early, middle, and late time windows previously employed (Hajcak & Dennis, 2009), and this response was larger at the posterior electrode clusters. But similarly to adults, there was the same differential processing response of emotional stimuli compared to neutral stimuli (LPP) observed in the frontal electrodes as well. As the researchers looked across the temporal data, the LPP was larger in the posterior sites at the beginning (e.g., early time window: 500-1000 msec), and as time progressed, the LPP became larger in the frontal sites. Additionally, the LPP was dominant in the left hemisphere during the early time window, and then during the middle (1000-1500 msec) and late time window (1500-2000 msec), the right hemisphere produced the more dominant LPP response. As a result of this study (Dennis & Hajcak, 2009), research into the emotion processing of children should assess topographical data, in both the front and back of the scalp, as well as across hemispheres. Since the LPP has been observed in school-age children, more research needs to be conducted to determine the reliability of the presence of this processing pattern across the development spectrum. During the school-age years, children seem to process emotion analogous to adults, albeit at a later time, however, in order to have confidence in this finding it will be useful to add to this emotional processing body of literature.

In sum, the late positive potential is a robust finding as evidenced in the adult emotional processing literature, and possibly the children's literature as well (Hajcak & Dennis, 2009). Because this significant sustained response is evident in adults, it is important to expand the developmental literature to assess how and when children process emotion in accordance with behavioral changes, in addition to delving into the explanations for this ERP component.

In the present investigation, we are looking at school-age children (5-8 years old) to see if this age range demonstrates the similar emotional processing to adults, particularly because this age range is when children are able to understand the task and explicitly reflect upon the emotional stimuli. The ERP research paradigm allows psychologists to evaluate the neural emotional processes, which will elucidate questions concerning the relationship between emotion and behavior in children. Similar to Hajcak and Dennis (2009), we are analyzing whether school-age children differentially process positive, negative, and neutral images (LPP), however, we will extend this literature by including analyses of both the frontal and posterior electrodes in addition to evaluating possible hemispheric differences. This examination of the distribution of the LPP across the scalp in school-age children will provide information concerning when emotions are differentially processed during development, how this differential processing can elicit particular behaviors, and permit speculation in regards to whether emotion might interact with other brain processes (e.g., memory).

Based on the limited ERP emotion processing literature in children (Hajcak & Dennis, 2009; Dennis & Hajcak, 2009), we expect to see adult-like differential emotion processing (LPP) in both the front and back of the scalp, and we speculate that there could be hemisphere dominance for the LPP, particularly in the right hemisphere. This investigation expands the available data on children's ERP responses to emotional stimuli and provides the opportunity to examine the developmental status of emotional processing in school-age children.

Method

Participants

Twenty-one children between the ages of 5 and 8 years old participated in this study (girls: N = 9; *M* = 7.29 years, range = 5.42-8.92 years). The participants were recruited from a family directory provided by the Child Study Center at Emory University. The directory lists families who previously volunteered to participate in research. The children were given a small toy at the end of each session, in addition to a $10 gift certificate, as a token of appreciation for their time and effort. Prior to testing, the researchers received written informed consent from the guardian and verbal assent from the participating child. Data from 3 participants were excluded due to low trial count (see ERP Data Reduction below).

Materials

A set of 164 age-appropriate images (55 positive; 53 neutral; 56 negative) was selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999). Of the 164 selected images, 150 of the images were used as the experimental stimuli. Additionally there were five positive images for the end of the ERP presentation, three neutral images for practice trials, and six negative images that were available as a source of replacement images for objectionable images.

Once the guardians agreed to allow their children participate in the study, thumbnails of the pictures that were to be used in the experiment were sent via email for the guardian to approve of the images. Objectionable pictures were removed from the stimulus set and were replaced with approved pictures from a supplemental set of images. For 4 participants the guardians objected to some of the negative pictures only (*M* = 5.5, range = 2-9).

To generate the image set for the encoding session, the set of 150 experimental stimuli were approximately evenly divided to create two sets of 90 images (30 positive; 30 neutral; 30 negative), each set was randomized twice, creating a total of four sets of encoding images. Participants were randomly assigned to one of the four sets of encoding images. Examples of these images are as follows: positive (e.g., a baby playing, a smiling snowman), neutral (e.g., a sack of potatoes, a boiling teapot), and negative (e.g., a shark chasing swimmers, cockroaches).

Measures

Participants provided subjective valence and arousal ratings on a subset of images viewed during the encoding session using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) after the image presentation in the second session. The SAM allowed for a direct comparison between the adult literature and the present study, allowing us to determine whether the children subjectively viewed the IAPS images similarly to adults. The SAM consists of a 5-point scale for valence and another 5-point scale for arousal. A higher valence score indicates that the participants' view the image as positive, whereas a lower valence score indicates a negative image. For the arousal scale, a high rating indicates the image elicited more arousal than a lower scoring image. An example of the abbreviated, child-appropriate scale is demonstrated in Figure 1 and Figure 2. The children's valence ratings of the images are as follows: positive ($M = 4.29$, $SD = .99$), neutral ($M = 3.33$, $SD = 1.31$), and negative ($M = 2.60$, $SD = 1.38$). The children's arousal ratings of the images are as follows: positive ($M = 3.44$, $SD = 1.67$), neutral ($M = 2.32$, $SD = 1.64$), and negative ($M = 2.72$, $SD = 1.66$). The valence and arousal ratings of the images are displayed in Figure 3. Based on these results, we can conclude that the children rate the valence of the images similarly to adults, although the neutral images elicit a slightly more positive rating. The children's ratings of arousal differed from adults' since adults rate negative images as more arousing than both positive and neutral images, and the arousal of positive images is greater than for neutral. The children in this experiment, on the other hand, rated the negative images as less arousing than positive images and as more arousing than the neutral images.

The researchers gave the participants a mood questionnaire (a 5 point scale; 1 = happy, 5 = unhappy) so the children could indicate their subjective mood before and after the image presentation during both sessions. This measure was utilized to verify that the children's mood did not change as a result of the presentation of the emotional stimuli. The children self-rated their mood similarly before and after the image presentation (Pre: $M = 4.53$, $SD = .81$; Post: $M = 4.47$, $SD = .87$), which indicates that the experimental presentation of emotional images did not influence the participants' mood.

Procedure

The experiment consisted of two sessions: encoding and retrieval. During the encoding session, electrophysiological (ERPs) and psychophysiological (respiration rate, cardiac activity, galvanic skin response) data were collected as participants viewed the set of positive, negative, and neutral images. The psychophysiological data are beyond the focus of this thesis and will not be discussed. The electrophysiological data from the retrieval session are beyond the focus of this thesis as well. The encoding session generally lasted approximately an hour and a half. Assessing emotion processing as the participants encode information allowed the researchers to observe how the neurons respond to emotion at that moment, which can elucidate how the encoding of the emotion relates to behavioral information observed at a later time. After a 24-48 hour delay, the participants returned to the lab for the retrieval session where electrophysiological and behavioral data were collected. After the presentation, the Self-

Assessment Manikin (SAM; Bradley & Lang, 1994) was given to the participant in order to rate the images on valence and arousal. The retrieval session was approximately one hour.

Session 1: Encoding. Each participant was fitted with an Advanced Neuro Technology (ANT) Waveguard EEG cap with 32-shielded electrodes (see Figure 4). The participants were fitted with the appropriate size cap for their head circumference to ensure that the electrodes were properly placed. To determine the placement of the electrodes the 10/5 system, an adaptation of the commonly used International 10/20 system (Jasper, 1958), was employed. Impedances were kept under 10 kΩ, and were generally under 5 kΩ. The sampling rate was set at 256 Hz. Of the 32 electrodes sewn into the elastic cap, two of them were mastoid electrodes. These electrodes are placed directly behind the ear, over the mastoid bone, where there is theoretically no brain activity. The data were first referenced online to the vertex electrode Cz. Then, the data were re-referenced offline to the mathematically-linked mastoids (sites M1 and M2; see Figure 4).

The participants were seated approximately twenty-four inches away from the screen where the images were presented. A dark sheet surrounded the monitor so that the participant could only see the screen. Once the experimenters completed the electrophysiological set up, the presentation began. Participants viewed 95 images as ERPs were recorded (see Materials for more details). Each image of the presentation encompassed the entire monitor screen and was presented in color. Images were presented for 6000 milliseconds, with a 3500-4500 inter-stimulus interval (ISI) between the images. During the ISI, a fixation cross was presented on the center of the screen to keep participants' focus on the screen.

Before the image presentation began, the researchers presented three practice trials to the child to establish that they understood how to complete the task. This practice period was repeated as necessary until children demonstrated that they understood the task instructions. The practice trials consisted of three neutral images that were not presented during the testing phase. Once the participants affirmed they understood the task instructions, the image presentation began.

During the image presentation, children participated in a behavioral task to ensure that the children were attending to the stimuli. Children were asked to use a video game controller to indicate whether each image of the presentation had a human (or any part of the human body) in it or not. The participants were asked to wait until a thick green line outlined the image (three seconds after the image first appeared on the screen), before choosing one of two buttons (the top and bottom buttons on the right hand side of the controller) to determine if there was a human in the image or not (see depiction of presentation in Figure 5). Preliminary data shows that the participants understood the task and were attentive during the image presentation as demonstrated by the proportion of correctly and incorrectly identified human/non-human button presses (Correct: 81.5%; Incorrect: 11.3%; No Response: 7.2%). Participants completed a mood questionnaire, and then the presentation began. The presentation of the images lasted fifteen minutes. An additional five positive images, to which ERP responses were not analyzed, were shown to the participants at the end of the experimental presentation so that the session ended on a positive note. After the presentation was done, the participants were given the mood questionnaire again.

Session 2: Retrieval. Electrophysiological data were collected following a similar protocol outlined in the encoding procedure. The ERP cap was removed from the participant and then participants were asked to sit at a table on the other side of the testing room to complete the ratings task. Then, on a laptop, they were shown a self-paced presentation of 30 images from the experiment. The participants then rated each image based on valence and arousal using the SAM.

ERP Data Reduction

First, the data were amplified 20,000 times using an ANT amplifier. Afterward, the ERP data were filtered using a bandpass filter between 0.1 to 30 hertz in order to exclude extremely high or extremely low frequencies. Data outside of this range are usually a result of environmental noise; therefore it is not pertinent to the neural data. Independent component analysis (ICA) was applied after filtering to identify and remove eye-blink artifact from the data. Furthermore, data that exceeded ± 150 μV (e.g., due to muscle movement) were excluded from analysis. Participants who contributed fewer than 12 trials per condition were excluded from analysis.

ERP Data Analysis

Examination of the data was guided by findings in similar investigations (Hajcak & Dennis, 2009). The ERP data were constructed by averaging the voltage across participants for each picture valence (positive, negative, and neutral) independently. Based on previous research (Hajcak & Dennis, 2009; Dennis & Hajcak, 2009), three time windows of interest were identified (early: 500-1000 ms; middle: 1000-1500 ms; and late: 1500-2000 ms; see Figure 6 for depiction) and the researchers observed the data at each electrode to determine clusters of interest. Using these previous studies as a guide, data were visually inspected for the presence of the late positive potential (LPP). The LPP was observed in the posterior electrodes examined in Hajcak and Dennis (2009), as well as in frontal electrodes examined in Dennis and Hajcak (2009), which have not been previously compared in the developmental literature. The electrodes of interest are as follows (see Figure 4 for head plot): posterior (left hemisphere: O1, P3, P7; right hemisphere: O2, P4, P8) and frontal (left hemisphere: Fp1, F3, F7; right hemisphere: Fp2, F4, F8). Mean amplitude was used to measure the size of the LPP during the early, middle, and late time windows. The mean amplitude measures the size of the voltage, however, the mean amplitude is computed by calculating the average difference between the baseline and the size of the voltage across a time window. This measure is expected to show the size of neural activity to each type of stimulus (positive, negative, and neutral).

Results

Two repeated measures analysis of variances (ANOVAs) were conducted. The first analysis was a replication of the analytical approach of Hajcak and Dennis (2009), therefore a 3 (emotion: negative, positive, neutral) x 2 (hemisphere: right, left) x 3 (channel pair: O1/O2, P3/P4, P7/P8; see Figure 4 for electrode clusters) repeated measures ANOVA was conducted on mean amplitude during 3 time windows (early, middle, and late). The second analysis added to the Hajcak and Dennis (2009) findings by including frontal electrodes in order to test for the emotion effect across the scalp (e.g., Dennis & Hajcak, 2009). For this analysis a 3 (emotion: negative, positive, neutral) x 2 (hemisphere: right, left) x 2 (topography: front, posterior) x 3 (channel group: O1/O2/Fp1/Fp2, P3/P4/F3/F4, P7/P8/F7/F8; see Figure 4 for electrode clusters) was conducted. Only main effects of, and interactions with, emotion are presented, as main effects and interactions of the other variables are not the focus of this investigation because only effects with emotion are the interest of this paper. In all cases of violations of sphercity, we used a Greenhouse-Geisser correction. Significance values between .05 and .10 were viewed as trends toward significance and significance levels above .10 were not assessed.

Hajcak and Dennis (2009) Replication

Early time window (500-1000 ms). The interaction between emotion and channel pair was significant for mean amplitude ($F(4, 68) = 2.64$, $p < .05$, $\eta^2 = .13$). A one-way ANOVA was conducted to assess this interaction at each channel pair. The mean amplitude analysis indicated an interaction between emotion and the P7/P8 channel pair that approached significance ($F(2, 34) = 2.54$, $p = .92$, $\eta^2 = .13$). The interaction suggested the beginning of an effect of emotion at the lateral posterior electrode pair, P7/P8, which implies the emergence of the LPP. This effect of emotion was affected by the negative condition ($M = 12.78$, $SD = 11.91$) more than the positive condition ($M = 9.98$, $SD = 10.43$) as demonstrated by the Bonferroni corrected post-hoc analysis at this channel pair ($p = .10$). No other interactions with, or main effects of, emotion were found for the mean amplitude measure (see Figure 7 for means of mean amplitude for emotion at each channel pair).

Middle time window (1000-1500 ms). A main effect of emotion was detected in the middle time window for mean amplitude ($F(1.46, 27.73) = 4.03$, $p < .05$, $\eta^2 = .19$). In addition, there was a significant interaction between emotion and channel pair for mean amplitude ($F(4, 68) = 4.37$, $p < .01$, $\eta^2 = .21$). Further analysis of this interaction indicated main effects of emotion at the O1/O2 pair ($F(1.46, 24.73) = 4.73$, $p < .05$, $\eta^2 = .22$). Bonferroni corrected post-hoc analysis indicated that for the O1/O2 channel pair interaction, there was a trend toward significance for the negative ($M = 18.34$, $SD = 11.76$) versus the neutral ($M = 11.21$, $SD = 8.15$) condition ($p = .08$), which suggests that the negative condition was affecting the emotion response at this channel pair.

Analysis of the interaction between emotion and the P7/P8 pair ($F(2, 34) = 4.46$, $p < .05$, $\eta^2 = .21$) demonstrated a significant main effect of emotion. Bonferroni post-hoc analysis at the

P7/P8 channel pair for the mean amplitude measure detected a trend toward significance for the negative (*M* = 12.25, *SD* = 9.47) versus neutral (*M* = 7.17, *SD* = 5.19) condition ($p = .09$) and responses were larger for the negative (*M* = 12.25, *SD* = 9.47) versus positive (*M* = 8.83, *SD* = 8.40) condition ($p = .08$). This interaction suggests a valence effect, meaning that there was differential processing of emotional stimuli compared to neutral stimuli, as well as differential processing within the emotion conditions at the P7/P8 channel pair.

Lastly, the analysis of the interaction between emotion and the P3/P4 channel pair revealed a trend toward significance ($F(1.39, 23.70) = 3.07$, $p = .08$, $\eta^2 = .15$). There were no other main effects, or interactions, observed for the mean amplitude measure (see Figure 8 for means of mean amplitude for emotion at each channel pair).

Late time window (1500-2000 ms). There was an approach toward significance for the main effect of emotion for mean amplitude ($F(2, 34) = 2.85$, $p = .07$, $\eta^2 = .14$). A significant interaction between emotion and channel pair was detected for mean amplitude as well ($F(2.66, 45.22) = 3.07$, $p < .05$, $\eta^2 = .15$). Lastly, there was a significant interaction between emotion, hemisphere, and channel pair ($F(4, 68) = 3.05$, $p < .05$, $\eta^2 = .16$). For mean amplitude, a two-way ANOVA was conducted between emotion and channel in each hemisphere.

In the left hemisphere, there was a main effect of emotion ($F(2, 34) = 3.23$, $p = .05$, $\eta^2 = .16$). There was a significant interaction detected between emotion and channel in the left hemisphere as well ($F(4, 68) = 2.63$, $p < .05$, $\eta^2 = .13$). A one-way ANOVA was used to test the interaction between emotion and channel in the left hemisphere. For the O1 site, the test revealed a significant effect of emotion ($F(2, 34) = 3.53$, $p < .05$, $\eta^2 = .17$), however, Bonferroni post-hoc analysis at this channel did not detect any significant differences between the conditions. This suggests that there was not a specific emotion condition that affected the observed findings. For the P3 site, there was a significant effect of emotion ($F(2, 34) = 3.38$, $p < .05$, $\eta^2 = .17$), yet Bonferroni corrected post-hoc analysis did not reveal any differences between the conditions, which implied that there was not a particular emotion influencing the effect of emotion. No other main effects or interactions were detected in the left hemisphere.

In the right hemisphere, there was a significant interaction observed between emotion and channel ($F(2.77, 47.09) = 3.41$, $p < .05$, $\eta^2 = .17$). A one-way ANOVA determined there was a trend toward significance of emotion at the P4 site ($F(2, 34) = 2.99$, $p = .06$, $\eta^2 = .15$). No other main effects or interactions were observed in the right hemisphere (see Figure 9 for means of mean amplitude for emotion at each channel in its respective hemisphere).

Summary. There was a main effect of emotion during the middle and late time windows and a main effect of emotion at channel pairs throughout the early, middle, and late time windows (see Figure 10 for a depiction of the ERP data at each posterior electrode across each time window). In the early time window, the P7/P8 channel pair showed a trend toward significance for the main effect of emotion and this response was being affected by the negative condition. During the middle window, the effect of emotion was significant at the O1/O2 channel pair and this effect was primarily a result of the negative condition (negative v. neutral). Similarly, the effect of emotion was significant at the P7/P8 channel pair, and this was affected by the negative condition, however, there was a valence effect (differential processing within the emotion conditions) observed as well. Additionally, the effect of emotion approached significance for the P3/P4 channel pair, but there was no distinction between emotion conditions at this channel pair. During the late time window, a significant interaction between emotion, hemisphere, and channel appeared, as well as a trend toward significance for emotion, and a significant interaction between emotion and channel pair. There was left hemisphere dominance for emotion processing observed during this time window. In the left hemisphere, there was a main effect of emotion and a significant interaction between emotion and channel (emotion was significant at the O1 and P3 sites), however, there was not a particular emotion condition affecting this result. In the right hemisphere, there was a significant interaction between emotion and channel, and the P4 site revealed a trend toward significance for the effect of emotion but this response was not a result of a specific condition.

Analysis Including Topography

The analysis including topography was incorporated in the present investigation in order to extend the previous literature's findings (Dennis & Hajcak, 2009) of the emotion effect in the frontal electrodes as well. Additionally, some of the adult literature has identified the LPP in the frontal electrodes (Schupp et al., 2000), therefore we wanted to assess whether this effect would be detected in children as well.

Early time window (500-1000 ms). There was a trend toward significance for the interaction between emotion and topography for mean amplitude ($F(2, 34) = 2.84$, $p = .07$, $\eta^2 = .14$). A trend toward significance was observed for the interaction between emotion, topography, and channel group for mean amplitude ($F(2.83, 48.13) = 2.39$, $p = .08$, $\eta^2 = .12$) as well. Additionally, there was a trend toward significance for the interaction between emotion, hemisphere, topography, and channel group (mean amplitude: $F(2.63, 44.66) = 2.53$, $p = .08$, $\eta^2 = .13$). A significant interaction was detected for emotion, hemisphere, and topography for mean amplitude ($F(2, 34) = 3.27$, $p = .05$, $\eta^2 = .16$). Lastly, the interaction between emotion, hemisphere, and channel group was significant as well (mean amplitude: $F(4, 68) = 2.46$, $p = .05$, $\eta^2 = .13$). Two-way ANOVAs for the significant interaction between emotion, hemisphere, and topography, as well as the interaction between emotion, hemisphere, and channel group, did not reveal any significant main effects, or trends towards significance for any of the variables. No other main effects, or interactions, were observed during the early time window.

Middle time window (1000-1500 ms). A main effect of emotion was observed in the middle time window for mean amplitude (F(2, 34) = 4.07, p < .05, η^2= .19; see Figure 11 for main effect of emotion during each time window). A significant interaction between emotion and topography was detected for mean amplitude (F(2, 34) = 5.84, p < .01, η^2= .26) as well. A one-way ANOVA was conducted for the emotion and topography interaction in both the front and back of the scalp.

At the frontal sites, there was a significant effect of emotion for mean amplitude (F(2, 34) = 4.57, p < .05, η^2= .21). Bonferroni corrected post-hoc analysis detected larger responses to the positive (M = -.15, SD = 7.65) versus the neutral (M = -7.54, SD = 9.13) condition (p < .05), which suggests that the positive condition was influencing the effect of emotion, as no significant interaction was detected for the negative condition between the positive or the neutral conditions.

At the posterior sites, emotion had a significant effect for mean amplitude (F(1.46, 24.73) = 4.03, p < .05, η^2= .19). Bonferroni corrected post-hoc analysis did not detect any significant differences between the emotion conditions, which suggests that there was not a particular condition affecting the observed response. No further interactions of emotion were detected during the middle time window (see Figure 12 for means of mean amplitude for emotion at the frontal and posterior clusters).

Late time window (1500-2000 ms). There was significant main effect for emotion during the late window (mean amplitude: F(2, 34) = 4.47, p < .05, η^2= .21; see Figure 11 for main effect of emotion during each time window). Bonferroni corrected post-hoc analysis comparisons showed a significant difference between the neutral (mean amplitude: $M = .12$, $SD = 7.69$) versus the positive (mean amplitude: $M = 6.58$, $SD = 9.06$) condition ($p < .05$), which suggests that the positive condition was influencing the main effect of emotion, as no significant interaction was detected for the negative condition between the positive or the neutral conditions. There was a trend toward significance observed for the interaction between emotion and topography (mean amplitude: $F(2, 34) = 2.90$, $p = .07$, $\eta^2 = .15$) as well. There were no other interactions, or main effects, observed during this time window (see Figure 13 for means of mean amplitude for emotion at the frontal and posterior clusters).

Summary. The findings from analysis including topography builds upon the Hajcak and Dennis (2009) replication by demonstrating that the emotion effect is observed in the frontal and the posterior channel groups during the early, middle, and late time windows (see Figure 14 for a depiction of the ERP data at each frontal electrode across each time window). Within the early time window, there were significant interactions between emotion, hemisphere, and topography as well as emotion, hemisphere, and channel group. However, there were no significant interactions detected between the emotion conditions, which suggests that there was not a particular emotion condition affecting the results. Additionally, there was a trend toward significance, during the early time window, for emotion and topography; emotion, topography, and channel group; and emotion, hemisphere, topography, and channel group. These trends toward significance imply that there is the beginning of an emotion effect evidenced in the early time window. During the middle time window, there was a significant main effect of emotion and a significant interaction between emotion and topography. Further analysis demonstrated an emotion effect at both the frontal and posterior sites, and analysis at the frontal sites detected larger responses to the positive stimuli over the neutral stimuli, which might suggest a positive effect (e.g., positive stimuli elicit larger responses than both the neutral and negative stimuli). Finally, the late window showed a main effect of emotion and a trend toward significance for the interaction between emotion and topography. Post-hoc analysis demonstrated larger responses to the positive stimuli versus the neutral stimuli, and there were no significant interactions detected for the negative condition during the late time window. This suggests that the positive condition influenced the effect of emotion more than the negative or neutral conditions. With all of this information taken into account, the results indicate that there is an emotion effect observed across the time windows, this response is sustained throughout the late window, and is apparent across the scalp; however, the response is likely affected by the positive condition in the frontal electrodes.

Discussion

In this study, we examined how school-age children process emotions at the neural level when viewing various images differing on valence and arousal. The late positive potential was identified in school-age children and generally we observed larger responses for the emotional stimuli compared to the neural stimuli. This further demonstrates that emotional stimuli are attended to more than non-emotional stimuli, as observed in adults as well (Hajcak, MacNamara, & Olvet, 2010). Findings from the electrophysiological data are generally consistent with previous reports of the late positive potential in children at posterior sites (Hajcak & Dennis, 2009), found evidence of the LPP in the frontal sites (Dennis & Hajcak, 2009), and further demonstrated that children during the school years mirror the emotional processing observed in adults.

There was a main effect of emotion across the time windows, as well as interactions with particular sites and channel pairs, and this effect first appears at the posterior sites (500 msec) then over the frontal sites (1000 msec), similar to findings in Dennis and Hajcak (2009). The results support patterns observed in Hajcak and Dennis (2009) and add to the small body of literature, which demonstrates that children reflect the adult emotion processing, albeit at a slower rate, thereby supporting our expectations. Most importantly, the results contribute to the emotion processing literature by demonstrating that the negative condition is primarily affecting emotion in the posterior electrodes, whereas the positive condition is primarily affecting emotion in the frontal electrodes. Furthermore, at the lateral posterior electrode pair P7/P8, there is differential emotion processing between the positive and negative conditions, which suggest the presence of the LPP, as well as a valence effect.

The pertinent results regarding differential processing within the emotion conditions has not been observed in the literature on children, and has very rarely been documented in the adult literature either (see Bradley, Hamby, Löw, & Lang, 2007 for differential processing of aversive compared to pleasant stimuli; see Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000 for results that did not detect differential emotion processing). Brain imaging paradigms have demonstrated that there is a sufficient amount of evidence indicating that the LPP is generated by visual processing that is regulated by the amygdala (e.g., Gerdes et al., 2010), which may explain why the negative images affect emotion in the posterior electrode clusters. Furthermore, studies have demonstrated that the amygdala detects novelty (Yamasaki, LaBar, & McCarthy, 2002), and since negative scenes are not seen as frequently on a daily basis as positive scenes, there could be a novelty associated with the negative scenes to which the amygdala is responding. But, the positive condition influencing the effect of emotion in the frontal electrodes is more difficult to assess. However, there is evidence that positive images are correlated with activation in the nucleus accumbens and dorsolateral prefrontal cortex (Gerdes et al., 2010); and since these structures are implicated in the reward pathway, the positive condition influencing emotion in the frontal electrodes might be a result of cognitive assessment of the images, which may elicit a cortical reward. Although these imaging studies have analyzed the adult population, cortical and subcortical connections may be developed by school-age years, which could give an additional context to what we observed in the electrophysiological data.

In addition to the differential influence of emotion conditions at the front and back of the scalp, there seems to be a larger effect of emotion over the left hemisphere, during the late time window, as opposed to the right, which is in contrast to previous adults studies (Junghöfer, Bradley, Elbert & Lang, 2001) and children studies (Dennis & Hajcak, 2009). This difference in neural processing, which favors the left hemisphere in this study, may be a result of the age group assessed or a difference in stimuli (e.g., only neutral and negative stimuli were utilized in Dennis & Hajcak, 2009). That is, at a younger age, as the brain is still maturing and both cortical and subcortical structures are developing their connections to one another (Toga, Thompson, & Sowell, 2006), possibly there is a preference of the left hemisphere to process emotional content. The slower emotion processing rate and emergence of the main effect of emotion in the middle window may also be a result of brain development not having yet reached the adult level during this age range.

The behavioral results of the self-assessment manikin (SAM; Bradley & Lang, 1994) further indicate that children view the images similarly to adults in regards to valence; however, the children's arousal ratings of negative images are not as large as has been demonstrated in the adult arousal ratings. It is important to ensure that the children assess the images in a similar pattern as adults in order to show how the LPP identified in children can be evaluated in a similar manner. By identifying the LPP across the scalp in school-age children, researchers can determine how the way in which children process emotions influences their behaviors (e.g., avoidance of negative stimuli). As demonstrated in infancy literature, there are differential looking times to emotional stimuli (Montague & Walker-Andrews, 2001), which could be the emergence of what we observed in children in the present research. Furthermore, the way children process emotions has implications for cognitive behaviors as well (Strayer, 1993).

These findings are part of a larger study where we are analyzing whether the LPP in school-age children observed during encoding will assist memory recognition after a delay. The LPP has many applications, however, one of particular interest is how humans encode emotions may assist our memory systems. Adult literature has indicated that emotional stimuli are remembered better than neutral stimuli (Palomba, Angrilli, & Mini, 1997), so with the information from this study, we can compare the children's emotional encoding to which items were remembered or forgotten.

Further, future research using this paradigm can evaluate younger children to see if they can parse out when this LPP emotional pattern begins to emerge and how that is associated with changes in behavior throughout development. By comparing the neural responses to emotional stimuli across age groups, there can be a clearer developmental picture. Furthermore, there can be an evaluation of gender differences in neural processing in children to see whether girls and boys process emotion differently, and if so, how that difference can contribute to differing rates of pathologies (e.g., depression).

As this paradigm has been validated by previous studies, there can be a confident interpretation of the findings. This research has important implications for how children respond to emotional stimuli, why they might respond in a particular way, how emotional encoding might assist in other cortical processes (e.g., memory), and demonstrating the emergence of adult-like processes that are advantageous to our species exist in children as well. The late positive potential exists in children and this finding has opened the doors to why, how, and when the patterned encoding of emotional stimuli emerges.

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Appendix

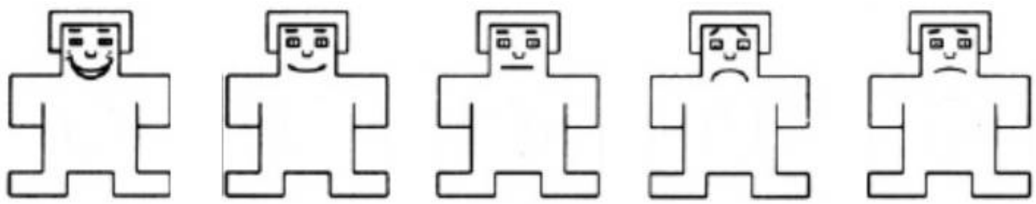


Figure 1. SAM Valence Ratings. This figure illustrates the valence scale that the participants used to rate whether the image they were viewing was positive, neutral, or negative.

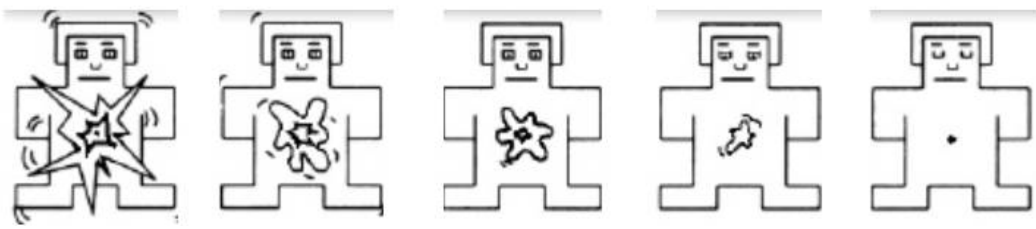


Figure 2. SAM Arousal Ratings. This figure illustrates the arousal scale that the participants used to rate how the image made them feel.

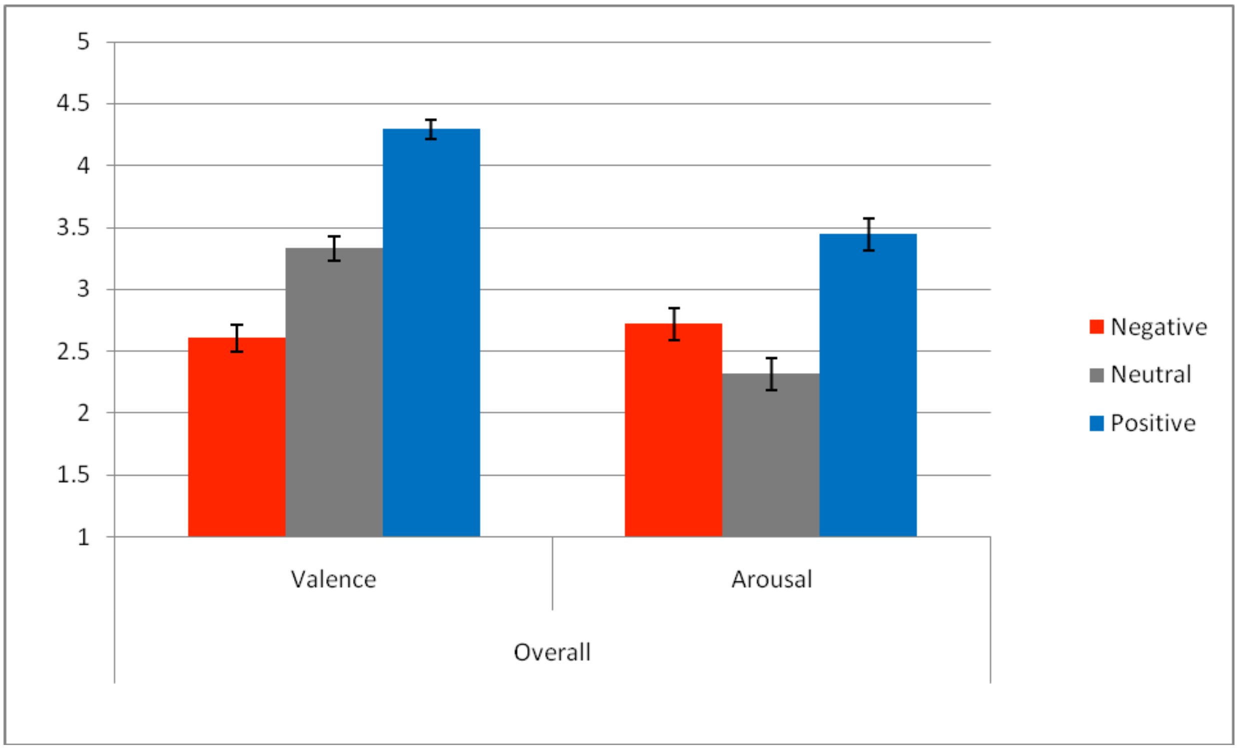


Figure 3. Average SAM Valence and Arousal Ratings. This figure demonstrates how the participants rated both the valence and arousal of the images.

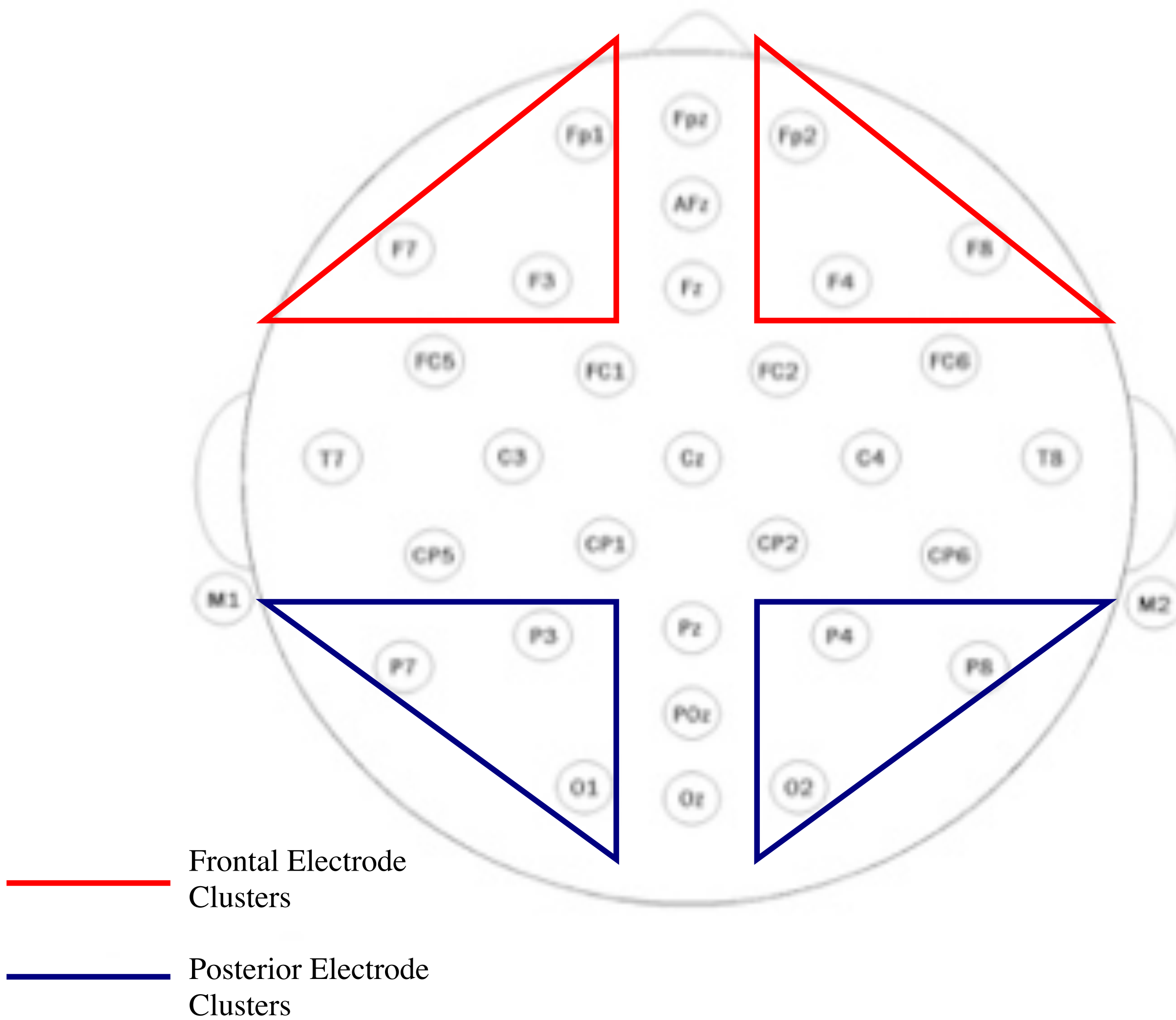


Figure 4. Head plot of electrode locations. This figure demonstrates the frontal and posterior electrode clusters that were subsequently analyzed.

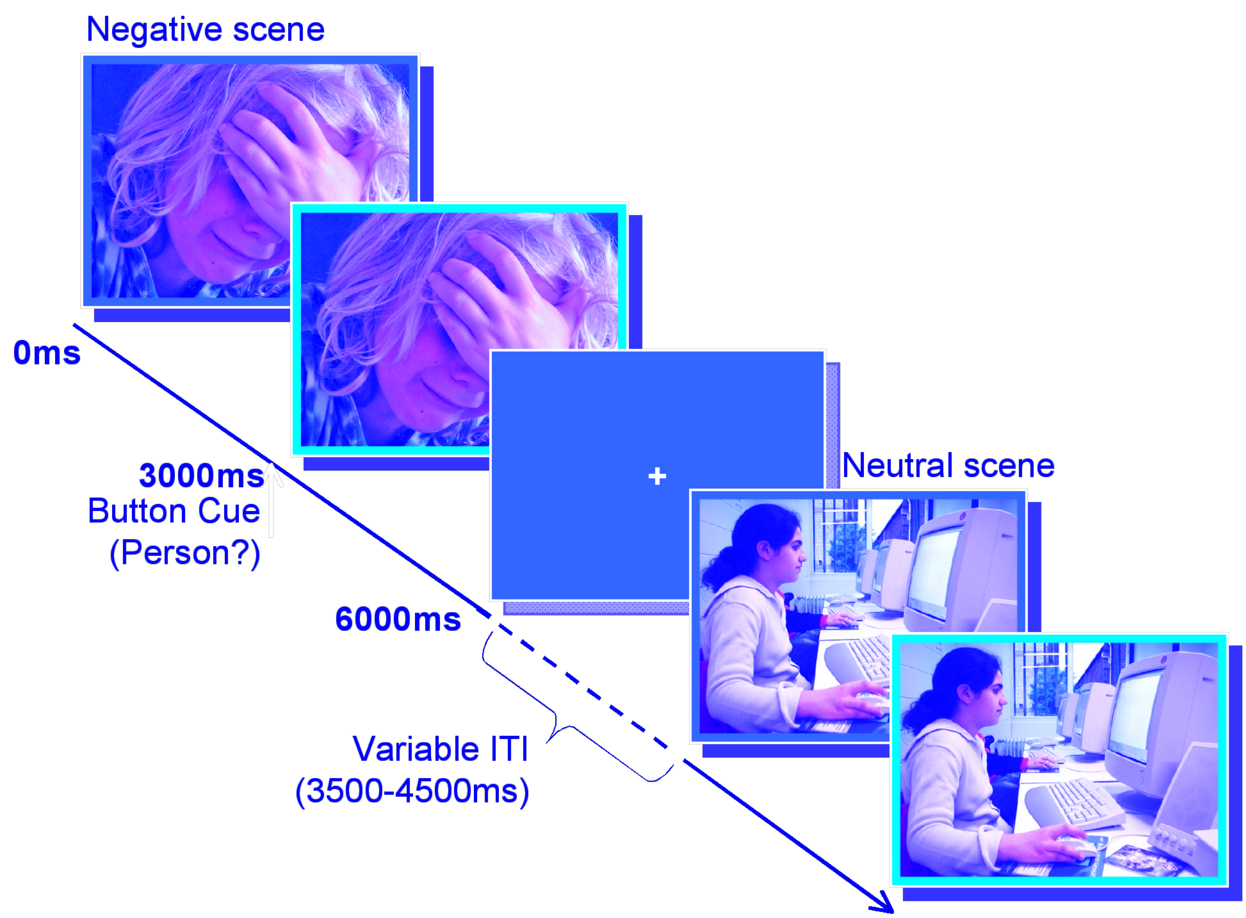


Figure 5. Encoding session image presentation. This image illustrates an example of the image presentation each participant viewed during the encoding session.

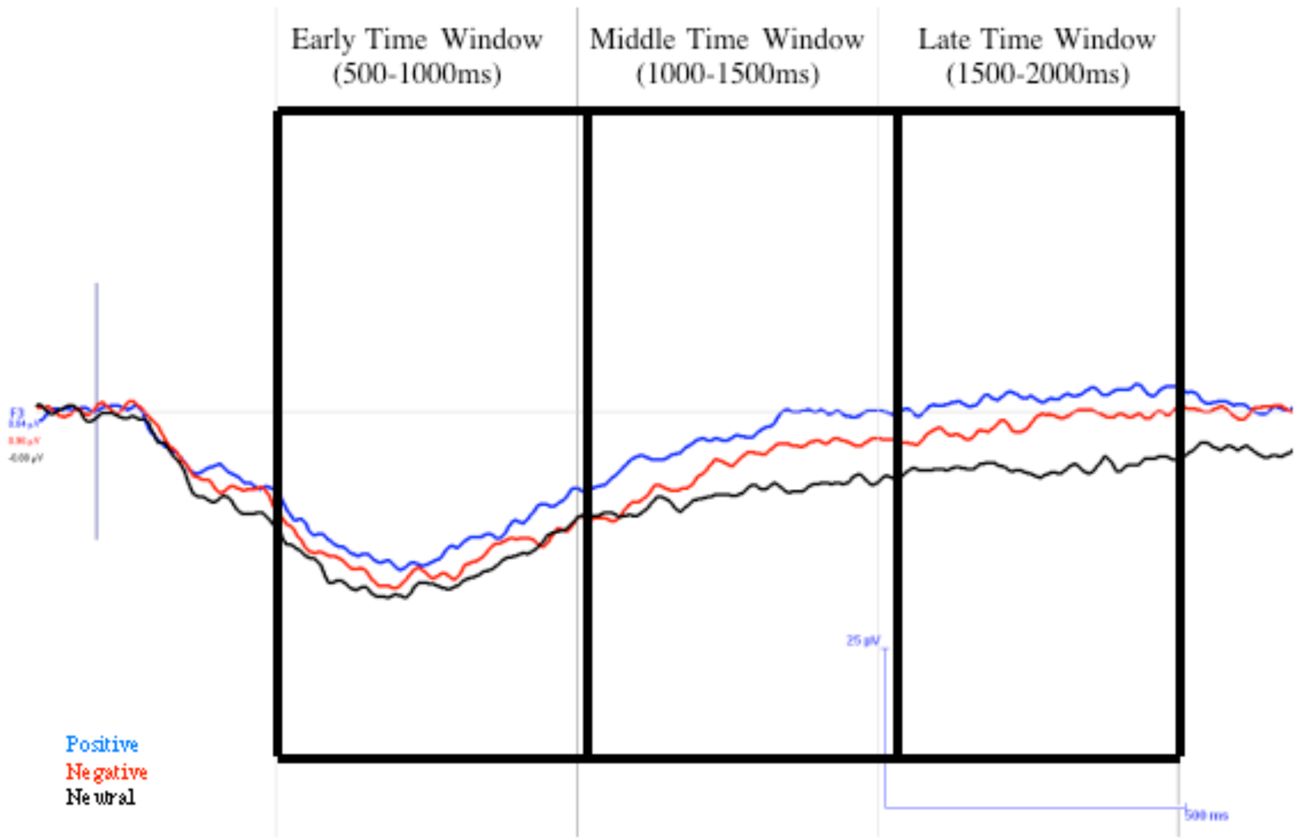


Figure 6. Time Windows. This figure demonstrates where each time window separates the ERP data at each electrode.

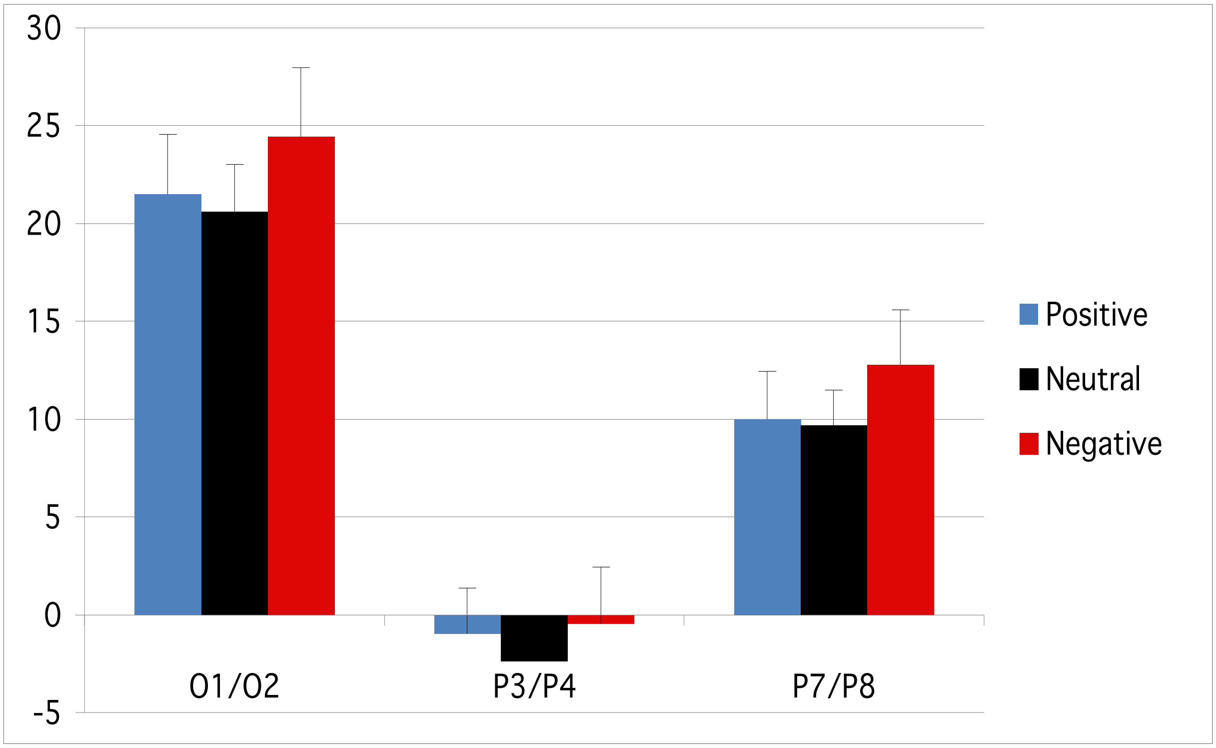


Figure 7. Early Time Window for Hajcak and Dennis (2009) Replication. This figure displays the means for each emotion condition at the posterior channel pairs during the early time window.

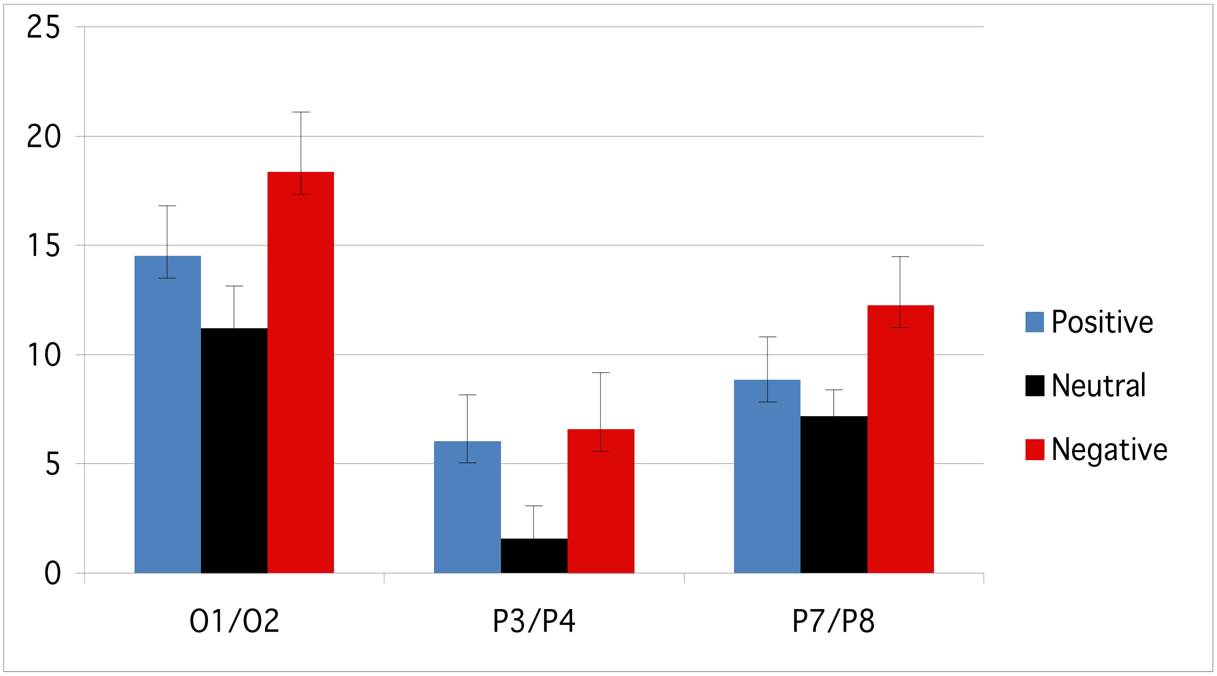


Figure 8. Middle Time Window for Hajcak and Dennis (2009) Replication. This figure displays the means for each emotion condition at the posterior channel pairs during the middle time window.

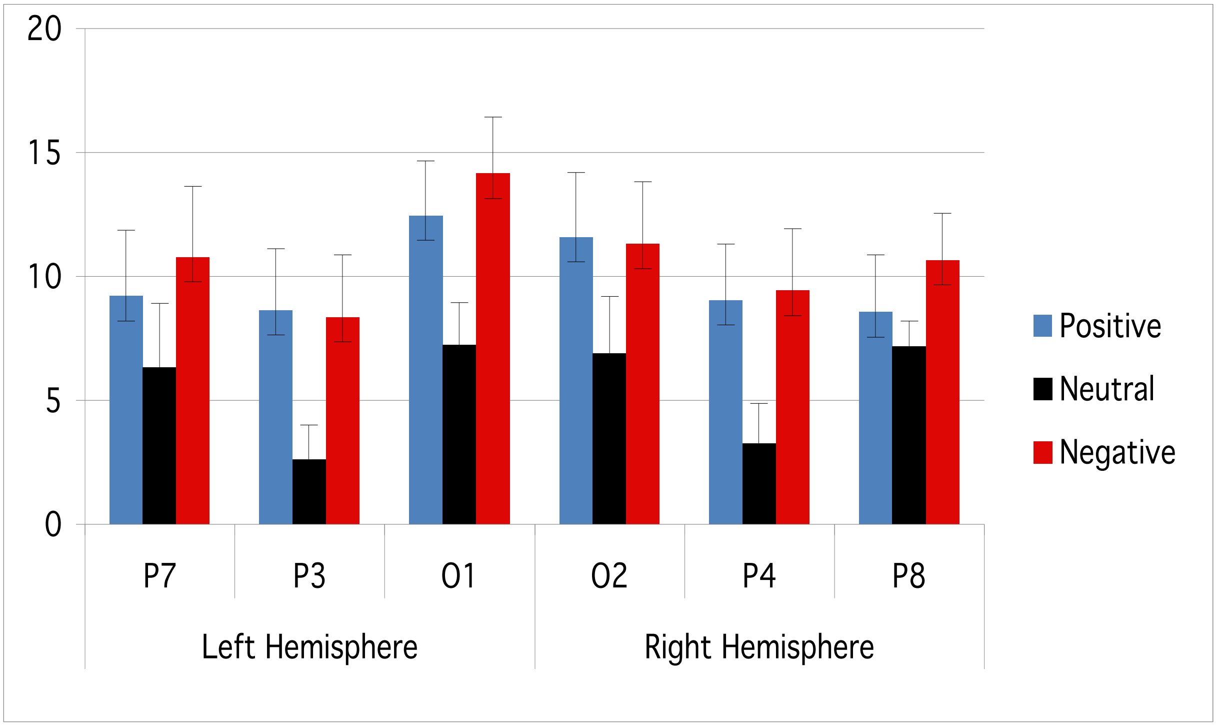
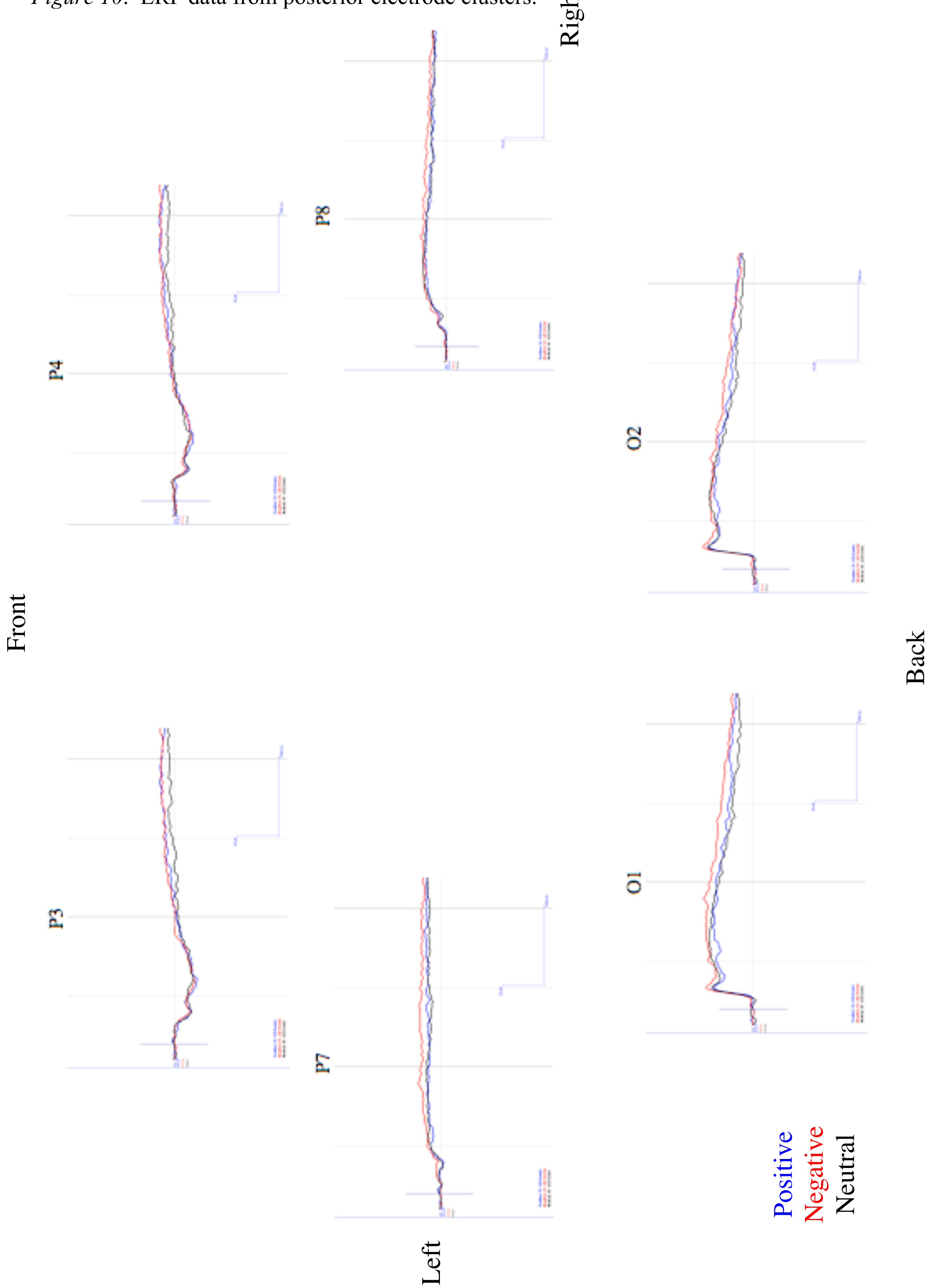


Figure 9. Late Time Window for Hajcak and Dennis (2009) Replication. This figure displays the means for each emotion condition at each posterior eletrode, in its respective hemisphere, during the late time window.

Figure 10. ERP data from posterior electrode clusters.



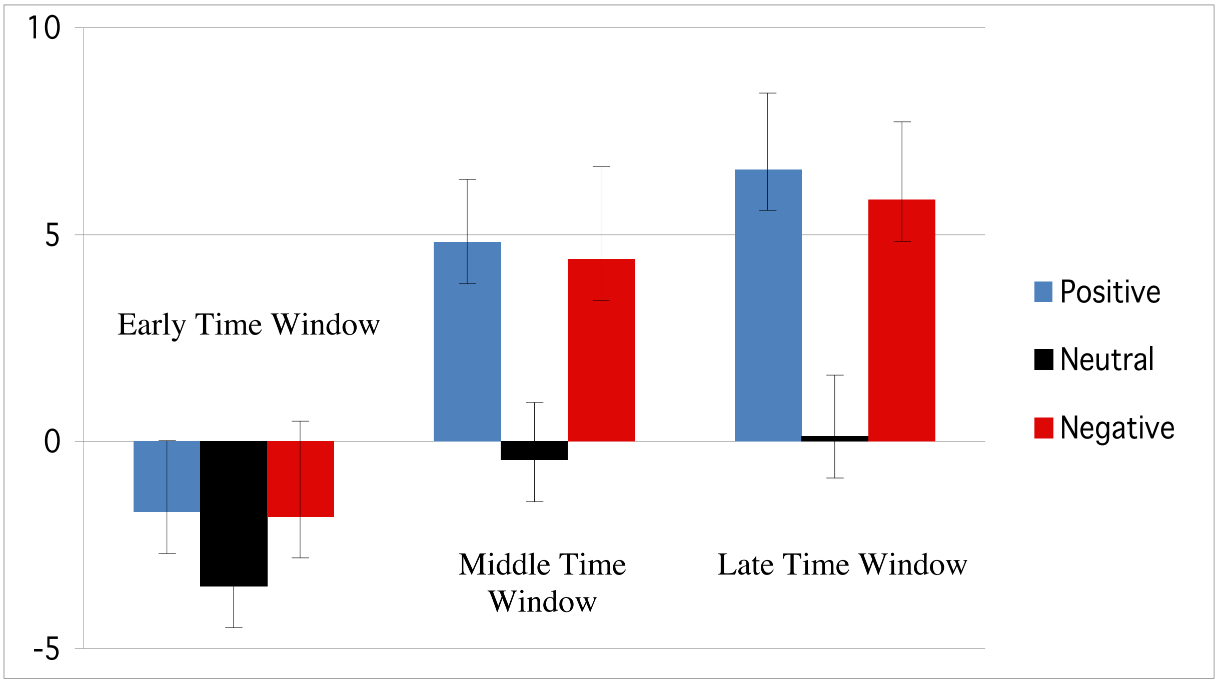


Figure 11. Main Effect of Emotion for Analysis Including Topography. This figure displays the means for each emotion condition during each time window (early, middle, and late).

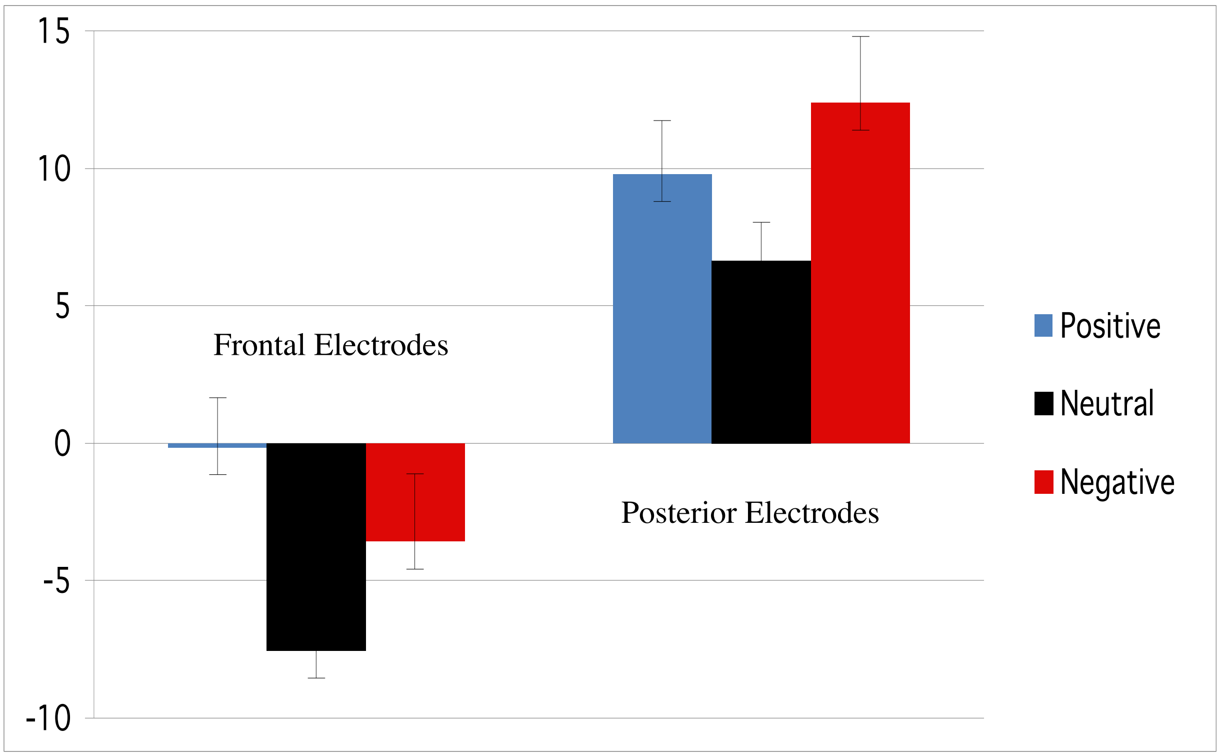


Figure 12. Middle Time Window for Analysis Including Topography. This figure displays the means for each emotion condition in the frontal electrodes cluster and the posterior electrodes cluster during the middle time window.

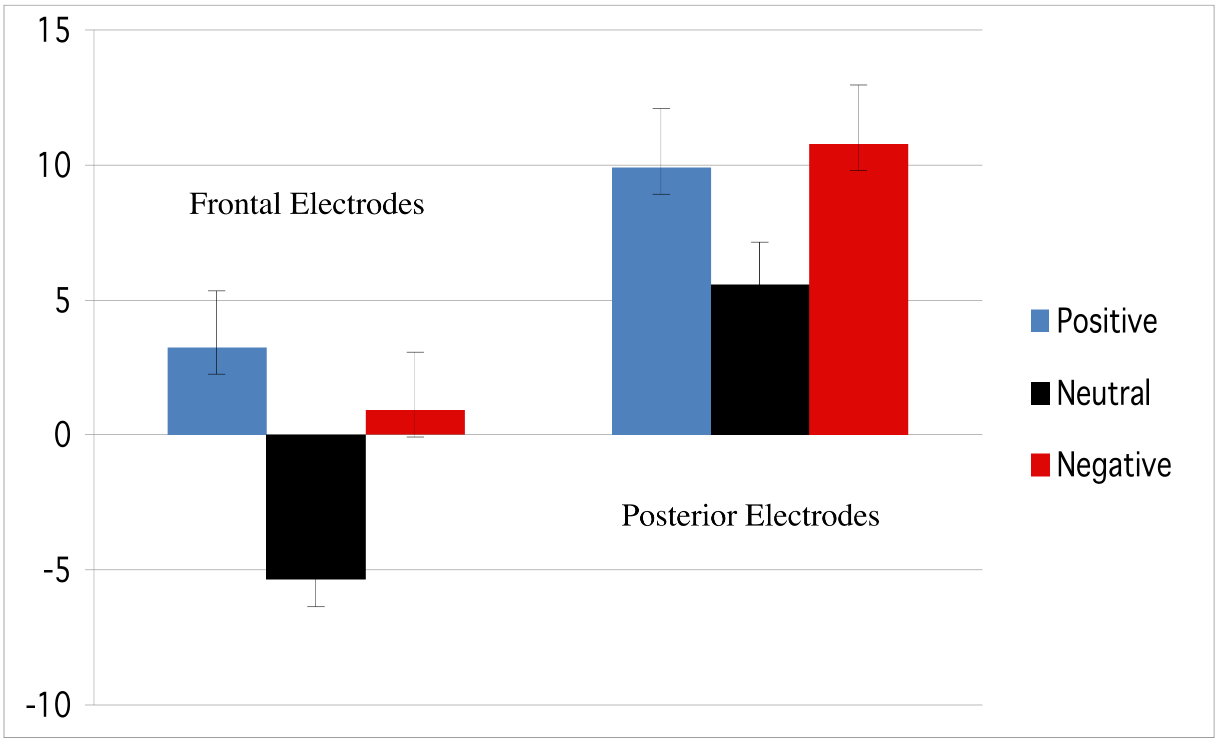


Figure 13. Late Time Window for Analysis Including Topography. This figure displays the means for each emotion condition in the frontal electrodes cluster and the posterior electrodes cluster during the late time window.

Figure 14. ERP data from frontal electrode clusters.