

**INTENTIONAL REGULATION OF NEGATIVE EMOTIONS IS REFLECTED
IN EVENT-RELATED BRAIN POTENTIALS**

by

Jason Scot Moser

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirement for the degree of Masters of Arts in Psychology

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This manuscript is dedicated to:

My family, for letting me explore myself at my own pace.

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ABSTRACT

Functional neuroimaging studies have demonstrated significant modulation of the amygdala and anterior cingulate cortex (ACC) during emotion regulation. The late-positive potential (LPP) and P2-N2 complex of the stimulus evoked brain potential (ERP) appear to reflect similar processes as the amygdala and ACC, respectively. In the present study, we measured the LPP and P2-N2 to examine the effects of intentional emotion regulation on early neural correlates of emotional and cognitive processing. Seventeen participants performed a blocked emotion regulation task: in the first block all participants passively viewed unpleasant and neutral pictures; in the second and third blocks participants were instructed to either suppress or enhance their emotional response to unpleasant pictures. Results revealed significantly decreased LPP magnitudes during suppression and enhanced P2-N2 magnitudes during both suppression and enhancement of negative emotions. These data suggest that ERPs can be used to identify early neural responses underlying intentional emotion regulation.

Chapter 1

INTRODUCTION

The ability to successfully regulate responses to emotion eliciting stimuli is essential to implementing adaptive behaviors (cf. Gross, 1999). Being able to cope in the face of daily stressors and hold back laughter in a crowded business meeting are examples of our basic human capacity to alter our internal emotional responses. Although researchers have debated the precise meaning of “emotion regulation”, Ochsner and Gross (2005) provide a rather succinct definition that seems to capture the essence of the construct: “Emotion regulation involves the initiation of new, or the alteration of ongoing, emotional responses through the action of regulatory processes” (pp. 242-243). In general, these regulatory processes constitute some form of cognitive control such as positive reinterpretation and objectification to suppress negative emotions and personalization to enhance negative emotions.

Much of the research on emotion regulation has focused on better understanding the physiological and neural processes underlying the regulation of negative emotions or responses to unpleasant stimuli, as difficulties in regulating negative emotions is central to a number of psychological disorders (cf., Kring & Werner, 2004). More specifically, many psychological disorders are characterized by dysfunctional suppression or

inhibition of negative emotions and thus most studies of emotion regulation examine the physiological and neural underpinnings of voluntary suppression of negative emotions. There are only a few studies that have examined physiological (e.g., Jackson, Malmstadt, Larson, & Davidson, 2000) and neural (Ochsner et al., 2004) correlates of voluntary enhancement of negative emotions, however.

Research on the physiological underpinnings of voluntary suppression of negative emotions has revealed the modulation of a number of physiological responses. For example, Gross and Levenson (1993, 1997) reported decreases in heart rate and somatic activity when participants were instructed to suppress their emotional responses to unpleasant stimuli. They also reported increases in skin conductance response (SCL) during suppression. Jackson et al. (2000) reported decreases in startle eyeblink magnitude and corrugator electromyogram (EMG) activity during suppression of responses to unpleasant stimuli. Interestingly, Jackson et al. also found the reverse pattern of results (i.e., increases in startle and EMG) when participants were instructed to enhance their responses to unpleasant stimuli. Taken together, it appears as though the SCL response might reflect arousal-related “effortful” processing, and startle and EMG activity might reflect valence related processing during regulation.

More recently, a number of researchers have begun to examine the neural correlates of voluntary suppression of negative emotions using functional magnetic resonance imaging (fMRI). Many of these studies have highlighted the involvement of the anterior cingulate cortex (ACC) and amygdala (for a review see Ochsner & Gross, 2005). In particular, studies indicate that suppression of negative emotions is associated

with increased activity of the ACC and decreased activity of the amygdala (e.g., Phan et al., 2004). The ACC is thought to subserve cognitive control processes such as action monitoring (Yeung, Botvinick, & Cohen, 2004) and behavioral inhibition (Braver, Barch, Gray, Molfese, & Snyder, 2001) and thus its engagement seems to reflect participants' use of control processes to successfully suppress or inhibit emotional responding. The amygdala, on the other hand, has long been recognized as a central structure in the processing of emotional and motivationally relevant stimuli (c.f., LeDoux, 1996). Therefore, the decreased amygdala response reported in emotion regulation studies seems to indicate blunted emotional processing during suppression.

Interestingly, one study (Ochsner et al., 2004) also found that both ACC and amygdala activity was increased during voluntary enhancement of negative emotion. These data suggest that the ACC indexes general recruitment of control processes during any sort of emotion regulation, while amygdala activity varies as a function of the degree of emotional engagement involved in the regulation task at hand.

The fMRI data reviewed above seem to suggest that both cortical and subcortical structures underlie the conscious regulation of emotional responses to unpleasant events. Moreover, along with the somatic and autonomic data, the fMRI data suggest that there are at least two processes involved in emotion regulation – effortful control and affect modulation – that might be subserved by the ACC and amygdala, respectively. The methods employed in fMRI studies thus far make it difficult to understand the earlier temporal dynamics of emotion regulation, however. Event-related brain potentials (ERPs), on the other hand, are characterized by better temporal resolution and provide the

unique opportunity to examine the neural responses underlying emotion regulation that are engaged milliseconds after the presentation of unpleasant stimuli. Two ERPs, in particular, seem appropriate for measuring the early neural responses underlying emotion regulation: the late positive potential (LPP), a measure that reflects facilitated perceptual processing of emotional stimuli (Schupp et al., 2000), and the P2-N2 complex, a measure that reflects cognitive control-related ACC activity (Yeung et al., 2004).

The LPP is a centro-parietally maximal broad positive deflection in the ongoing ERP that reaches its maximum amplitude between 300 and 800 ms after stimulus onset and can last for several hundred milliseconds (Cuthbert, Schupp, Bradley, Birbaumer, & Land, 2000; Schupp et al., 2000). Numerous studies have now shown that the LPP is enhanced for motivationally relevant events such as highly arousing pleasant (e.g., erotica) and unpleasant (e.g., mutilations) stimuli (Cuthbert et al., 2000; Schupp et al., 2000; Schupp et al., 2004; Schupp, Junghofer, Weike, & Hamm, 2004). Given that late positive potentials in cognitive tasks are generally thought to reflect attentional engagement and additional perceptual processing of task-relevant stimuli (Donchin & Coles, 1988; Ritter & Ruchkin, 1992), the LPP is thought to index increased attention to and facilitated perceptual processing of motivationally relevant stimuli (Schupp et al., 2000; Schupp, Junghofer, Weike, & Hamm, 2003).

Like the LPP, the amygdala and visual cortex show enhanced activity for arousing stimuli (e.g., Bradley et al., 2003; Lang et al., 1998; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005; Schupp et al., 2000). Based on data such as these as well as findings from animal models (e.g., Amaral, Price, Pitkanen, Carmichael, 1992), Lang et al. (1998) and

Bradley et al. (2003) hypothesized that increased activity in visual cortex may result from reentrant processes from the amygdala. Additional support for this idea comes from the Sabatinelli et al. study that also found that increased activation of the amygdala was highly related to increased activation in the visual cortex during affective picture viewing. It is possible, then, that the enhanced LPP to arousing stimuli might likewise reflect facilitated perceptual processing of motivationally significant stimuli resulting from increased activation of subcortical structures such as the amygdala.

The stimulus-locked P2-N2 complex is a fronto-centrally maximal positive-to-negative complex that is largest between 150 and 300 ms following stimulus onset in a number of different cognitive and emotional paradigms such as the flankers tasks (Kopp, Rist, & Mattler, 1996), the traditional oddball task (Kenemans, Verbaten, Melis, & Slangen, 1992) and emotional oddball task (Carretie, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004). The P2-N2 seems to be generated by the ACC (Carretie et al., 2004; Liotti, Woldorff, Perez, & Mayberg, 2000), a structure involved in emotional and attentional processing (Bush, Luu, & Posner, 2000). The P2-N2 is therefore believed to reflect attention- and cognitive control-related ACC activity, as it is consistently larger for emotional stimuli (e.g., Carretie et al., 2004) and cognitively demanding stimuli such as incongruent flankers (cf. Yeung et al., 2004).

In the current study, we utilized the LPP as a measure of perceptual/attentional processing of arousing unpleasant stimuli and the P2-N2 as a measure of attention/cognitive control-related ACC activity to investigate the early neural responses underlying emotion regulation in a paradigm adapted from Jackson et al. (2000). To this

end, unpleasant stimuli were presented during three different emotion regulation blocks: a passive viewing block, a suppress block, and an enhance block. Based on our conceptualization above, we hypothesized that, like the amygdala, the magnitude of the LPP would vary as a function of the degree to which participants were emotionally engaged in the stimuli. That is, the amplitude of the LPP would be decreased during suppression of negative emotions and increased during enhancement of negative emotions relative to a passive viewing condition. We further hypothesized that the P2-N2, like ACC activity, would be enhanced during conditions involving both suppression and enhancement of negative emotions.

Chapter 2

METHOD

Participants

Nineteen undergraduate students (16 female) in an upper level psychology class participated in the current study for extra credit. Participants were told that the top two enhancers and suppressers, as measured by brain activity, would be awarded \$20 in bonus money. At the completion of the study, individual ERP averages were calculated for each participant and the two students who evidenced the largest emotion regulation effects on ERP measures were awarded \$20. Data from 2 female participants were excluded due to data acquisition malfunction.

Stimuli and Procedures

The stimulus set comprised 60 unpleasant, high arousing and 20 neutral, low arousing color images taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999)¹. The unpleasant picture set included images of mutilations and threats (human and animal). The neutral picture set included images of household items and neutral faces. Unpleasant and neutral images differed significantly

from each other in IAPS normative valence ratings ($M = 2.03$ and 5.14 , respectively) and arousal ratings ($M = 6.24$ and 2.96 , respectively).

After participants received a general description of the experiment, EEG/EOG sensor electrodes were attached, participants were seated approximately 0.5 m directly in front of the computer monitor, and then given detailed task instructions. Participants performed a blocked picture viewing task administered on a Pentium I class computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli. During the task, pictures from the IAPS were displayed for 1000 ms and occupied the entire screen of a 17" monitor. The order of pictures was perceptually random within each block.

In the first block of the task, participants viewed 20 unpleasant and 20 neutral IAPS pictures and were instructed to simply view the pictures as they were presented and pay close attention to each one (hereafter referred to as the *view* condition). This condition was designed to serve as a baseline for comparison to the effects of the instructions given in the last two blocks. A fixation mark (+) was presented for 2000 ms at the beginning of each trial to orient participants to the center of the screen. IAPS pictures appeared 500 ms after the offset of the fixation cross. The interval between the offset of the IAPS picture and the following fixation cross was 1000 ms.

The second and third blocks of the task consisted of 20 unpleasant IAPS images each. In one block, participants received instructions to suppress their emotional response to the pictures and in the other block participants received instructions to enhance their emotional response to the pictures (hereafter referred to as the *suppress* and

enhance conditions, respectively). The order of these two emotion regulation blocks was counterbalanced across subjects. The word “SUPPRESS” or “ENHANCE” was presented for 2000ms at the beginning of each trial to remind subjects what to do. IAPS pictures appeared 500ms after the offset of the instruction word. The interval between the offset of the IAPS picture and the following instruction word was 1000ms. Following the third and final block, physiological sensors were removed and participants were asked to fill out a questionnaire indicating what strategies they used to prepare to regulate their emotions after seeing the instruction word as well as what strategies they used during picture viewing in each of the two emotion regulation blocks.

Emotion Regulation Instructions

Instructions for the emotion regulation conditions were adapted from Jackson et al. (2000) since they were found to be effective in modulating physiological responses to unpleasant pictures. Thus, participants were not restricted in using any particular emotion regulation strategy during the second and third blocks. For the *suppress* condition, participants were given the following verbatim instructions:

During this block, you will see only negative pictures and be instructed to suppress the emotion you are currently feeling in response to the picture. Before each picture, the word **SUPPRESS** will be presented on the screen to remind you what to do. By suppress we mean that we would like you to decrease the intensity of the emotion you feel in response to the picture. Try and feel the emotion less strongly. For example, think of how a doctor enters an emergency room. The doctor knows that he/she will be entering a negative environment and prepares him/herself to deal with that by decreasing the negative emotions he/she might feel when he/she enters the room. So, when you see the word **SUPPRESS**, prepare yourself to decrease the intensity of whatever negative emotion you might feel in response to the picture. Prepare yourself to feel the negative emotion less strongly. Suppression of an emotion is not equivalent to replacing that emotion with a different one. Do not generate thoughts and images that are completely unrelated to the presented stimulus in order to produce a different emotion to compete with or replace your initial emotional response to the picture. For example, if you are asked to suppress the fear you feel in response to a picture of a poisonous snake, do not think of something unrelated that generates a

positive emotion ~e.g., the end of finals week and beginning of winter holiday! However, feel free to focus on a positive aspect of the picture or on a possible positive outcome of the situation in the picture. For example, you can imagine that the poisonous snake is about to be killed, which may help you to decrease the fear you may feel in response to the picture.

For the *enhance* condition, participants were given the following verbatim instructions:

During this block, you will see only negative pictures and be instructed to enhance the emotion you are currently feeling in response to the picture. Before each picture, the word **ENHANCE** will be presented on the screen to remind you what to do. By enhance we mean we would like you to increase the intensity of the emotion you feel in response to the picture. Try and feel the emotion more strongly. For example, think of how someone who likes scary movies enters a movie theatre to see a scary movie. This person knows that he/she will see something scary and wants to feel as scared as he/she possibly can to get the most out of the movie. So, when you see the word **ENHANCE**, prepare yourself to increase the intensity of whatever negative emotion you feel in response to the picture. Prepare yourself to feel the negative emotion more strongly.

Following these instructions, participants were given the chance to ask questions and provided with additional examples until the experimenter felt the participant completely understood the emotion regulation instructions. As an additional manipulation check, the experimenter reviewed participants' responses on the emotion regulation strategies questionnaire to determine whether or not participants understood the instructions and reported using strategies typical of what research has shown.

Psychophysiological Recording, Data Reduction and Analysis

The electroencephalogram (EEG) was recorded using an ECI electrocap. Recordings were taken from 4 locations along the midline: Frontal (Fz), Frontocentral (FCz), Central (Cz), and Parietal (Pz). In addition, Med-Associates tin electrodes were placed on the left and right mastoids (M1 and M2, respectively). During the recording, all activity was referenced to Cz. The electro-oculogram (EOG) generated from blinks and vertical eye-movements was also recorded using Med-Associates miniature electrodes placed approximately 1 cm above and below the subject's right eye. The right earlobe

served as a ground site. All EEG/EOG electrode impedances were below 10K Ω and the data from all channels were recorded by a Grass Model 78D polygraph with Grass Model 7P511J preamplifiers (bandpass = 0.1-100 Hz).

All bioelectric signals were digitized on a laboratory microcomputer using VPM software (Cook, 1999). The EEG was sampled at 200 Hz. Data collection began 500 ms prior to picture onset and continued for 1500 ms. Off-line, the EEG for each trial was corrected for vertical EOG artifacts using the method developed by Gratton, Coles and Donchin (1983; Miller, Gratton & Yee, 1988) and then re-referenced to the average activity of the mastoid electrodes. Trials were rejected and not counted in subsequent analysis if there was excessive physiological artifact (i.e., 25 ms of invariant analog data on any channel or A/D values on any channel that equaled that converters minimum or maximum values). Single trial EEG data were lowpass filtered at 20 Hz with a 51-weight FIR digital filter as per Cook and Miller (1992).

Event-related brain potentials (ERPs) were constructed by separately averaging unpleasant and neutral picture trials in the *view* condition; separate averages were also created for unpleasant picture trials in the *suppress* and *enhance* conditions. ERP averages from the *view* condition were constructed to serve two purposes: 1) to confirm the well-established arousal effect on the magnitude of the LPP, such that unpleasant IAPS images elicit larger LPPs than neutral IAPS images, and 2) to provide a baseline condition for unpleasant pictures that could be compared to the emotion regulation conditions. For each ERP average, the average activity in the 0-200 window prior to picture onset served as the baseline. ERP components were quantified at the sites of their

respective maxima determined by ANOVA with orthogonal polynomial contrasts conducted on the four midline electrode sites. The LPP was then defined as the average activity in the 350-600 ms window following stimulus onset. The P2-N2 was measured peak-to-peak as the difference between the maximum value between 200 ms and 300 ms following stimulus onset and the most positive point between this maximum and 150ms following stimulus onset (for similar methods see Kenemans et al., 1992).

ERP measures were statistically evaluated using SPSS (Version 12.0) General Linear Model software with orthogonal polynomial contrasts conducted on the electrode site factor and Greenhouse-Geisser correction applied to p values associated with multiple df repeated measures comparisons. After conducting the omnibus analysis of variance (ANOVA), the Newman-Keuls procedure (cf. Sheskin, 1997) was used to test for significant post-hoc comparisons at $\alpha = .05$.

Chapter 3

RESULTS

Late Positive Potential – View Condition

Consistent with the literature and as illustrated in the top panel of Figure 1, the trend analysis on Electrode Site revealed a significant linear trend across the four sites ($F_{\text{lin}}(1,16) = 22.10, p < .001$). This analysis also revealed a near significant quadratic trend ($F_{\text{quad}}(1,16) = 4.46, p < .051$) and a significant cubic trend ($F_{\text{cub}}(1,16) = 7.21, p < .05$). The linear trend accounted for almost all of the variance (96%), suggesting that the LPP grew consistently larger from anterior to posterior recording sites. The subsequent analysis of the Pz data, where the LPP was maximal, confirmed the impression gleaned from the bottom panel of Figure 1 that unpleasant images elicited larger LPPs than neutral images ($t(16) = 5.74, p < .001$).

Late Positive Potential – Emotion Regulation Effects

The top panel of Figure 2 presents the averaged LPP amplitudes at Fz, FCz, Cz, and Pz for the *view*, *enhance*, and *suppress* conditions. The ANOVA with orthogonal trends revealed significant linear ($F_{\text{lin}}(1,16) = 25.53, p < .001$), quadratic ($F_{\text{quad}}(1,16) = 6.64, p < .05$), and cubic ($F_{\text{cub}}(1,16) = 6.27, p < .05$) trends across the four recording sites

indicating a nearly identical scalp distribution to that found in the *view* condition. The linear trend accounted for most of the variance (95%) reflecting, again, a parietal distribution of the LPP. A one-way ANOVA conducted on Emotion Regulation Condition (View, Enhance, Suppress) at the Pz site revealed that the LPP varied significantly as a function of condition ($F(2,32) = 5.86, p < .01$). At the .05 level, the Newman-Keuls test confirmed that the LPP was significantly smaller in the *suppress* condition than in the *view* and *enhance* conditions, and that the LPPs in the *enhance* and *view* conditions did not differ from one another (see Figure 2, bottom panel). Table 1 contains the mean LPPs associated with unpleasant pictures during the view, suppress, and enhance conditions.

P2-N2 – Emotion Regulation Effects

The top panel of Figure 3 presents the averaged P2-N2 amplitudes at Fz, FCz, Cz, and Pz for the *view*, *enhance*, and *suppress* conditions. The ANOVA with orthogonal trends revealed significant linear ($F_{lin}(1,16) = 8.85, p < .01$), quadratic ($F_{quad}(1,16) = 21.16, p < .001$), and cubic ($F_{cub}(1,16) = 8.60, p < .01$) trends across the four recording sites. Consistent with previous research, the linear trend accounted for 52 % of the variance, indicating that the P2-N2 grew larger moving from posterior to anterior recording sites. The quadratic trend accounted for an additional 46% of the variance, reflecting the fronto-*central* distribution of the P2-N2 component. Because the magnitude of the P2-N2 was largest at the FCz recording site (See Figure 3, top panel), we chose to analyze the P2-N2 at FCz to test the effects of emotion regulation. The one-

way ANOVA conducted on Emotion Regulation Condition (View, Enhance, Suppress) revealed that the P2-N2 also varied significantly as a function of condition ($F(2,32)=5.37, p<.011$). In this case, Newman-Keuls post-hoc comparisons indicated that the P2-N2 was larger in the both the *suppress* and *enhance* conditions than it was in the *view* condition; however, the magnitude of the P2-N2 did not differ between the *suppress* and *enhance* conditions (See Figure 3, bottom panel). Table 1 contains the mean P2-N2s associated with unpleasant pictures during the view, suppress, and enhance conditions.

Emotion Regulation Strategies Questionnaire

Participants reported using a few different strategies to regulate their responses to the unpleasant pictures in each of the emotion regulation conditions. All participants reported using at least one emotion regulation strategy that had been reported in previous research (e.g., Jackson et al., 2000; Ochsner, Bunge, Gross, Gabrieli, 2002). Some participants reported using more than one emotion regulation strategy, thus participants are likely to be included in more than one of the following percentages. In the suppress condition, eleven (65%) participants reported objectifying the pictures or viewing the pictures as an impartial third party. For instance, participants reported thinking of the pictures as fake or as if they were from a movie. Seven (41%) participants reported using breathing regulation such as taking deep breaths or slowing down their breathing. Four (24%) participants reported they told themselves to expect something gruesome. Last, three (18%) participants reported thinking of the picture in a positive light or thinking of possible positive outcomes of the picture. During the enhance condition, 11 (65%)

participants reported using behavioral regulation strategies such as speeding up their breathing or tensing up their body and face. Eight participants (47%) reported personalizing the image, such that they would imagine themselves or a loved one experiencing the horrible incident depicted in the pictures. Last, four (24%) participants reported exaggerating the possible negative outcomes related to the pictures (e.g., imagining that everyone in the car accident died although the picture did not depict mutilated bodies).

Table 1. Mean (Standard Deviation) LPP Magnitude at Pz and P2-N2 Magnitude at FCz (in microvolts) for Unpleasant Pictures in the View, Suppress, and Enhance Conditions.

| | View Condition | Suppress Condition | Enhance Condition |
|-------|-------------------|-----------------------|----------------------|
| LPP | 9.67 (6.40) | 5.17 (5.65) | 9.01 (6.63) |
| P2-N2 | 15.72 (9.42) | 19.32 (11.84) | 20.36 (9.34) |

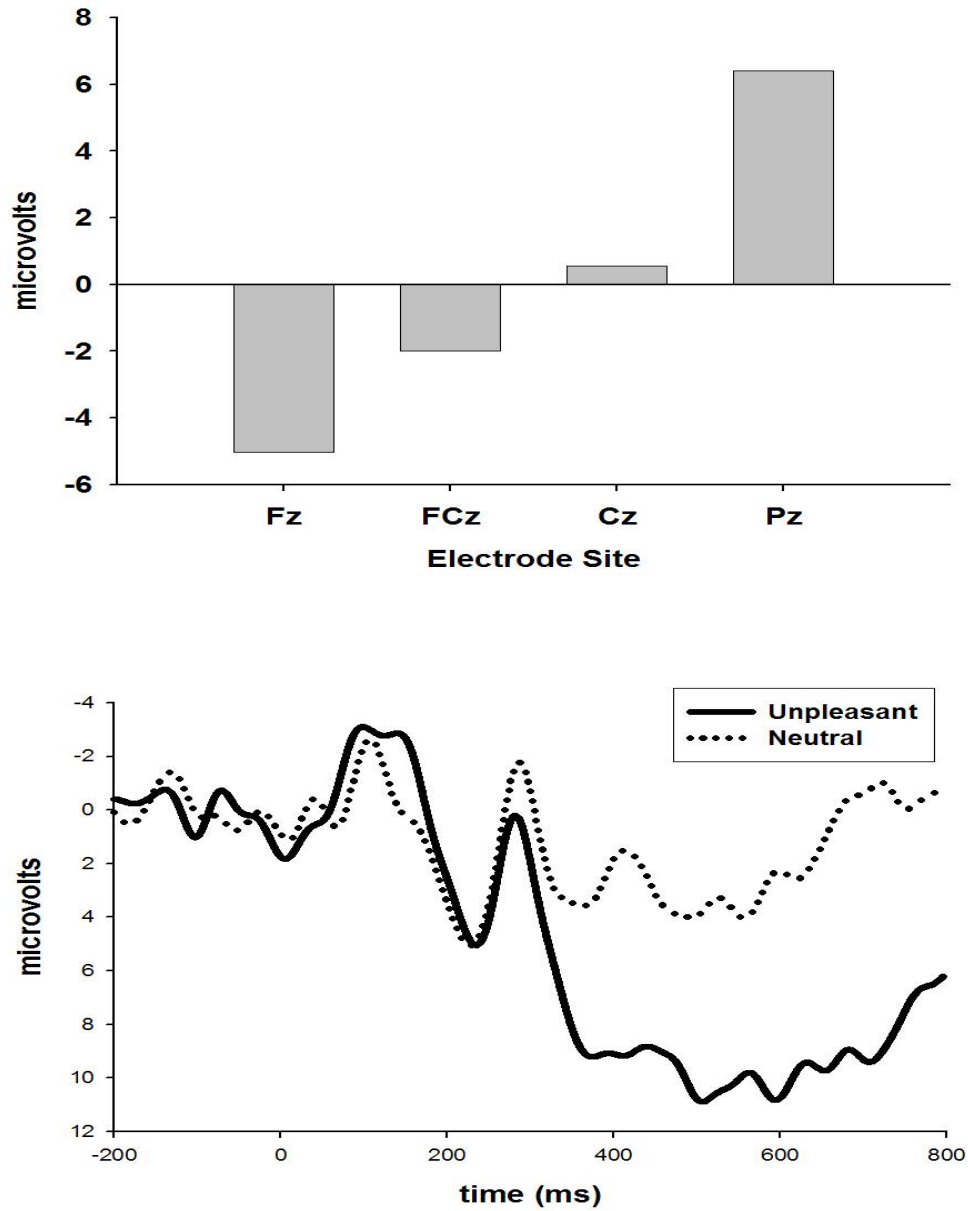


Figure 1. Overall magnitude of the LPP at Fz, FCz, Cz, and Pz during the view condition (top), and stimulus-locked ERPs at Pz where the LPP was maximal (bottom).

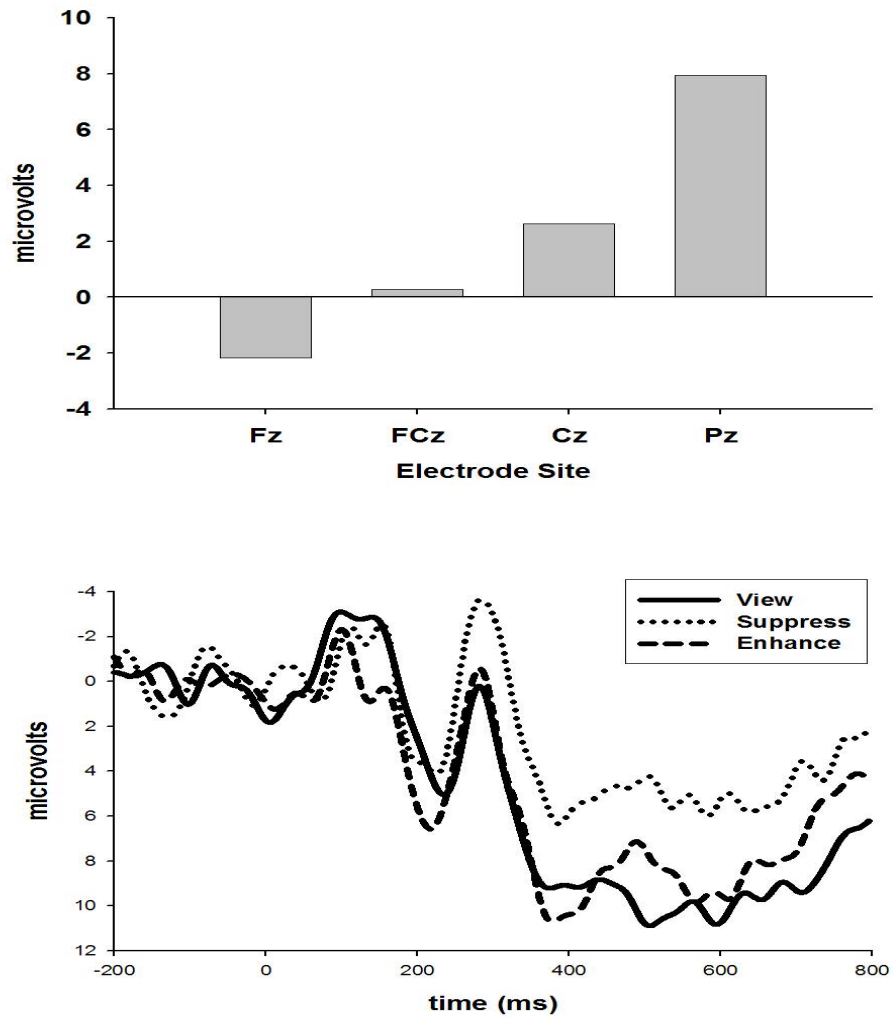


Figure 2. Overall magnitude of the LPP at Fz, FCz, Cz, and Pz during the view, suppress, and enhance conditions (top), and stimulus-locked ERPs at Pz where the LPP was maximal (bottom).

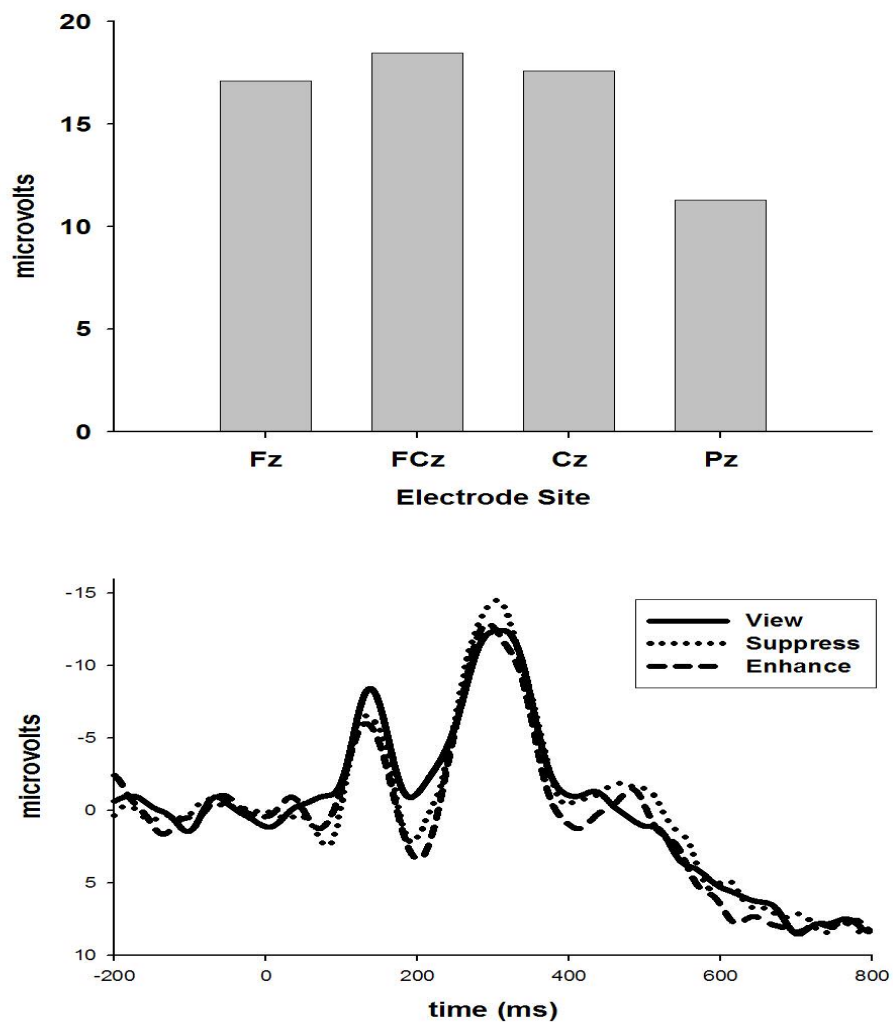


Figure 3. Overall magnitude of the P2-N2 at Fz, FCz, Cz, and Pz during the view, suppress, and enhance conditions (top), and stimulus-locked ERPs at FCz where the P2-N2 was maximal (bottom).

Chapter 4

DISCUSSION

In this study, we utilized ERP measures of attentional/perceptual processing and cognitive control to examine the early neural correlates of emotion regulation. During the view condition of the current study, participants passively viewed highly arousing unpleasant and neutral IAPS images for the purposes of confirming the well established arousal modulation of the LPP and creating a baseline measure to compare to the emotion regulation conditions. Confirming our hypothesis and consistent with previous reports, LPPs in the view condition were larger for highly arousing unpleasant stimuli than for neutral stimuli (Cuthbert et al., 2000; Schupp et al., 2000).

More important to the primary aims of the current study, results revealed significant modulation of the LPP as a result of the emotion regulation instructions. Specifically, the LPP was reduced during voluntary suppression of responses to highly arousing unpleasant stimuli. This reduction was evident relative to the LPP magnitudes found in both the passive viewing and enhance conditions. Thus, this suppression effect on the LPP appears to be robust under these experimental conditions. The LPP was not larger during the enhance condition than it was during the passive view condition, however.

The current finding that the LPP was significantly reduced during conscious suppression of responses to unpleasant stimuli is consistent with our conceptualization that LPP modulation would parallel that previously reported for the amygdala (cf., Ochsner & Gross, 2005). Thus, these results suggest that voluntary suppression of negative emotions is associated with blunted perceptual processing of motivationally significant stimuli. Not only are these data consistent with the notion that the LPP might reflect processes related to amygdala activity (cf., Bradley et al., 2003), but they also suggest that the brain's dynamic response to emotion eliciting stimuli can be changed early in time (i.e., on the order of milliseconds after picture presentation). Although future studies will have to determine the exact nature of the relationship between the LPP and amygdala activity – as we are not suggesting here that they reflect identical processes – the present data suggest that the LPP appears to be a useful tool in determining the early neural correlates of emotion regulation.

Unlike the results concerning suppression's effect on the LPP, we did not find support for our hypothesis that the LPP, like amygdala activity, would be increased during enhancement of negative emotions (Ochsner et al., 2004). Although the LPP associated with enhancement of negative emotions was larger than the LPP elicited during suppression, it was not larger than the LPP during passive viewing. One possibility is that this finding simply reflects a 'ceiling effect' on the LPP, such that enhanced processing of already very arousing stimuli is difficult to achieve. Ochsner and colleagues allude to another potential explanation for this failure to find an enhancement effect, suggesting that *earlier* amygdala-related activity might not be sensitive to such

emotion regulation processes (p. 495). Therefore, the unchanged LPP during enhancement might indicate that it is difficult to increase the level of emotional processing *early on* after emotion elicitation.

Taken together, the LPP results of the current study and the amygdala results of the Ochsner et al. (2004) study suggest interesting temporal and spatial brain dynamics underlying emotion regulation. In terms of suppression of negative emotions, decreased LPPs were reported in the current study and decreased activity in bilateral amygdala was reported in the Ochsner et al. study. The decreased activity in bilateral amygdala reported in the Ochsner et al. study was strongest during early time points after regulation instructions. Thus, together with the LPP results of the current study, the Ochsner et al. amygdala results suggest that suppression affects early encoding of valence and arousal information associated with motivationally relevant pictorial stimuli. On the other hand, in terms of enhancement of negative emotions, we found no increase in LPP magnitude and Ochsner et al. found only increases in left amygdala activity. The increases in left amygdala activity in the Ochsner et al. study appeared largest during later processing stages. Therefore, enhancement of negative emotions might have a more specific affect on brain activity during later stages of processing related to the use of verbal regulation strategies to alter responding to emotional stimuli (cf. Schneider et al., 1997). Undoubtedly, future research that combines ERPs and fMRI will be needed to better understand the temporal and spatial brain dynamics of emotional processing and regulation.

Consistent with our hypotheses, we also found that enhanced P2-N2 amplitudes were associated with *both* regulation conditions and that the amplitude of the P2-N2 did not differ between these two conditions. Insofar as the P2-N2 reflects attention – and cognitive control-related ACC activity (Kenemans et al., 1992; Liotti et al., 2000; Yeung et al., 2004), these data are highly consistent with previous studies reporting increased ACC activity during suppression (cf. Ochsner & Gross, 2005) and enhancement of negative emotions (Ochsner et al., 2004). The fact that the magnitude of the P2-N2 was similar for both emotion regulation conditions is consistent with the Ochsner et al. study suggesting similar recruitment of attentional control processes during suppression and enhancement of negative emotions. Thus, these data provide additional support for the notion that the P2-N2 may reflect control related ACC activity and suggest a rapid engagement of the ACC during emotion regulation – as quickly as 200 milliseconds following stimulus onset. Again, combining ERPs with fMRI will prove most fruitful in identifying the temporal dynamics of frontal brain engagement during emotion regulation.

The results of the self-reported emotion regulation strategies in the current study are consistent with those described in previous research (e.g., Jackson et al., 2000). Although we did not require participants to utilize a specific regulation strategy such as ‘reappraisal’ (cf., Gross 1998), it is clear from the results that they were able to follow the instructions provided, and did in fact report using reappraisal strategies such as objectification and reinterpretation to suppress negative emotions and personalization to enhance negative emotions. Furthermore, given that our ERP results mirror many of the

findings of fMRI studies examining the specific effects of ‘reappraisal’, it is our belief that our more general regulation instructions resulted in similar neural changes as those reported for ‘reappraisal’. In part, these results might also be due to the fact that when participants are instructed to regulate emotions, they tend to use ‘reappraisal’ without specific instructions to do so, like the participants in the current study. Future studies could further investigate this issue by examining the specific effects of different types of emotion regulation instructions such as ‘reappraisal’.

In sum, the present study indicates that ERP correlates of attentional/perceptual processing and cognitive control reflect very early neural processes involved in the regulation of negative emotions. Specifically, we found that the LPP was decreased during conscious suppression of negative emotions and the P2-N2 was increased for both suppression and enhancement of negative emotions. Thus, multiple neural correlates of emotion regulation are apparent within 700 milliseconds after presentation of motivationally relevant stimuli. Functionally, these ERP data bear striking resemblance to findings from fMRI studies indicating decreased amygdala activity during suppression of negative emotions and increased ACC activity during both suppression and enhancement of negative emotions (cf., Ochsner & Gross, 2005). Therefore, we conclude that the LPP and P2-N2 can be used as early markers of amygdala induced facilitated processing of emotional stimuli and ACC related control processes, respectively, during emotion regulation.

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¹ The numbers of the IAPS pictures used were the following: neutral (2480, 2880, 5390, 5500, 5531, 5740, 5800, 5900, 7000, 7002, 7009, 7010, 7025, 7035, 7140, 7175, 7190, 7224, 7560, 7950) and unpleasant (2205, 2800, 2900, 3000, 3010, 3030, 3051, 3053, 3060, 3061, 3062, 3064, 3071, 3080, 3100, 3102, 3110, 3130, 3140, 3150, 3170, 3180, 3230, 3261, 3350, 3400, 3500, 3530, 6212, 6230, 6243, 6260, 6350, 6360, 6370, 6510, 6540, 6560, 6570, 6821, 9006, 9040 9050, 9140, 9220, 9405, 9410, 9420, 9421, 9500, 9560, 9570, 9800, 9910, 9911).