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Electrophysiological correlates of decreasing and increasing emotional responses to unpleasant pictures

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Abstract

We examined event-related brain potential (ERP) modulations during the anticipation and processing of unpleasant pictures under instructions to cognitively decrease and increase negative emotion. Instructions to decrease and increase negative emotion modulated the ERP response to unpleasant pictures in the direction of emotional intensity beginning around 400 ms and lasting several seconds. Decrease, but not increase, instructions also elicited enhanced frontal negativity associated with orienting and preparation prior to unpleasant picture onset. Last, ERP modulation by unpleasant pictures began around 300 ms, just prior to regulation effects, suggesting that appraisal of emotion occurs before emotion regulation. Together, the current findings underscore the utility of ERPs in illuminating the time course of emotion modulation and regulation that may help to refine extant theoretical models.

Descriptors: Emotion regulation, Event-related potentials, Late positive potential, Unpleasant pictures

Although the term "emotion regulation" can have different meanings and refers to several modes of processing, researchers have focused particularly on better understanding a conscious, cognitive strategy for regulating emotions known as cognitive reappraisal (cf. Gross & Thompson, 2007; Ochsner & Gross, 2007). Cognitive reappraisal generally refers to a set of strategies individuals intentionally use to regulate their emotions—typically, to decrease or increase their intensity—by changing the way they think about the significance of an emotion-evoking event (e.g., "The snake is not harmful"; cf. Gross & Thompson, 2007). More specifically, according to Gross and colleagues (for reviews, see Gross & Thompson, 2007; Ochsner & Gross, 2005), reappraisal is a cognitive–linguistic change mechanism involving attention, memory, and imagery processes. Moreover, these change processes purportedly interact with and are applied to the automatically unfolding emotion-perception processes elicited by evocative stimuli.

In the broader context of emotion theory and research, Gross and colleagues (e.g., Gross & Thompson, 2007) have proposed a "modal model" that specifies processes involved in emotion generation and points at which emotion processing can be altered by emotion regulation strategies. They propose four basic stages of the emotion generation process at which emotion regulation strategies can have their effect: (1) confrontation with the emotion-eliciting event, (2) deployment of attention to the event, (3) engagement of appraisal processes by the event, and (4) engagement of response tendencies toward the event. Within this framework, emotion regulation strategies employed during Stages 1, 2, or 3—reappraisal being one of them—are considered to be "antecedent-focused" because they occur prior to the initiation of response tendencies such as physiological reactivity and emotional expression, whereas regulation strategies targeted at Stage 4 of emotion processing are dubbed "response-focused" because they occur at the response tendency/generation stage.

As an antecedent-focused strategy aimed at modulating the appraisal stage (Stage 3) of emotion processing, cognitive reappraisal has received growing attention, at least in part because of its association with physiological and psychological well-being (Gross & John, 2003). Current theorists propose that deficits in cognitive reappraisal characterize psychopathology, and therapeutic techniques are typically aimed at fostering more positive reappraisals of automatic negative thoughts and beliefs (e.g., cognitive restructuring; cf. Campbell-Sills & Barlow, 2007). Thus, a better understanding of cognitive reappraisal has implications for basic emotion theory as well as models and treatments of psychopathology. Given its links to psychopathology and psychotherapy, much of the research on reappraisal has focused on understanding its use in regulating responses to *negative* emotion elicited by unpleasant stimuli and therefore is also the focus of the current article.

Although reappraisal studies vary widely in terms of the measures employed, they share several common features: (1) They include visual stimuli as the evocative stimuli, (2) they compare passive viewing and reappraisal conditions that involve

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the viewing of stimuli without altering natural emotional responses and the viewing of stimuli while intentionally altering emotional responses, respectively, and (3) they include specific instructions for passively viewing and intentionally reappraising emotional responses. Reappraisal has been associated with changes in expressions of and self-reported negative emotion elicited by disgusting films (e.g., Gross, 1998), in memory recall of unpleasant pictures (e.g., Dillon, Ritchey, Johnson, & LaBar, 2007), in physiological measures of negative emotion elicited by unpleasant pictures (i.e., electromyogram and startle eyeblink; Jackson, Malmstadt, Larson, & Davidson, 2000), and in activity of emotion and cognitive centers of the brain elicited by unpleasant pictures (i.e., amygdala and prefrontal cortex, respectively; e.g., Ochsner et al., 2004). Thus, reappraisal seems to have a broad impact on behavioral, cognitive, physiological, and neural correlates of emotion stimulus processing.

Although the effects of reappraisal on a number of measures have been examined, little attention has been paid to investigating its impact on particular processing stages, which is at the heart of Gross and colleagues' modal/stage processing model of emotion and emotion regulation. According to the modal model, reappraisal should act on the appraisal stage of emotion processing. Gross and colleagues have addressed this seeming gap to a certain extent, however. First, in his seminal study referenced above, Gross (1998) examined differences between cognitive reappraisal and behavioral suppression—a strategy aimed at the regulation of Stage 4 processes involving response tendencies toward evocative stimuli—in decreasing behavioral and physiological responses to emotion-eliciting film clips. Here, Gross found that whereas reappraisal was associated with decreases in negative emotional experience, suppression was not, purportedly due to the fact that reappraisal altered the emotion processing stream at the appraisal stage, thus decreasing the emotional significance of the stimulus, whereas suppression acted only after the emotional significance of the stimulus was appraised as negative and response tendencies had been engaged. Second, a recent neuroimaging study by Gross's group (Goldin, McRae, Ramel, & Gross, 2008) showed that reappraisal was associated with early engagement of prefrontal cognitive control centers whereas suppression was associated with engagement of similar regions later in processing. Again, this group interpreted the findings as support for the modal/stage model of emotion regulation because reappraisal seemed to have an earlier effect on processing than suppression. These studies, however, were limited in their ability to make specific conclusions about the processing stages affected by reappraisal, primarily because they employed measures characterized by poor temporal resolution. Behavior ratings and hemodynamic activity reflect an amalgam of processes and therefore provide a less clear picture of what processing stages are affected by reappraisal. Event-related brain potentials (ERPs), on the other hand, are electrophysiological signals that allow for the examination of the sequence of constituent operations involved in processing and acting on incoming information on the order of milliseconds. Specifically, the ERP waveform represents multiple neural processes by discrete changes in voltage observed at the scalp—that is, components—that offers the opportunity to detect the effects of experimental manipulations on a number of different processing stages.

Recently, we have begun to use ERPs to study electrophysiological correlates of emotion regulation and its time course. We focused on the effects of reappraisal instructions on the amplitude of the late positive potential (LPP) of the visually evoked ERP, a centro-parietally maximal broad positive deflection that reaches its maximum amplitude between 300 and 800 ms after stimulus onset and can last for several seconds (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000). The LPP appeared to be an ideal first candidate for studying the effects of reappraisal on particular neural processes, as numerous studies have shown that the LPP is highly sensitive to the motivational relevance of visual stimuli such that its amplitude is commensurate with the arousal level of affective pictures, being largest for extremely arousing unpleasant (e.g., mutilations) and pleasant (e.g., erotic) pictures (Cuthbert et al., 2000; Schupp et al., 2000; Schupp, Junghofer, Weike, & Hamm, 2004). In our first study, we, indeed, showed that instructions to decrease emotional responding resulted in reductions of the LPP relative to a passive viewing condition (Moser, Hajcak, Bukay, & Simons, 2006). Specifically, we found that the effect of the decrease instructions began around 250 ms post-emotion stimulus and lasted for several hundred milliseconds, through the peak of the LPP. Curiously, we did not find an effect of increase instructions on the LPP in our initial study (Moser et al., 2006)—a point to which we will return later. Hajcak and Nieuwenhuis (2006) replicated and extended this finding, showing reduced electrophysiological activity beginning around 200 ms and lasting for over 1.5 s after stimulus onset under decrease instructions. At the time, such findings were interpreted in the context of theories proposing that electrophysiological activity in the time window of the LPP is linked to the arousal level of affective pictures (Cuthbert et al., 2000; Schupp et al., 2000, 2004), which was bolstered by findings from Hajcak and Nieuwenhuis indicating that the reduction in LPP magnitude during decrease instructions was positively correlated with reductions in self-reported emotional intensity.

What was not addressed in these studies was that the time course analyses might reveal important information about the processes affected by the reappraisal instructions and shed light on the modal model of emotion and emotion regulation proposed by Gross and colleagues. Beyond using the LPP as an index of emotional arousal, one can use the activity in the "neighborhood" of the LPP to investigate the unfolding of different processes across time, the purpose for which ERPs are principally useful (cf. Dien, Spencer, & Donchin, 2004). Dien et al., for instance, outlined a model suggesting the time course and ERP correlates of different information processing stages progressing from the simpler to the more complex: (1) stimulus registration indexed by exogenous activity elicited in the first 100 ms such as the P1 and N1, (2) stimulus selection indexed by endogenous activity elicited between 100 and 200 ms such as the N1, (3) stimulus identification indexed by endogenous activity elicited between 200 and 300 ms such as the N2, and (4) stimulus categorization indexed by endogenous activity elicited after 300 ms such as the P300. Olofsson, Nordin, Sequeira, and Polich (2008) later applied this model to emotional stimuli and suggested that the LPP indexes the degree to which attentional resources are engaged and the strength of the memory trace to be stored. Thus, one can use the ERP waveform more fully to characterize the processes affected by the reappraisal instructions. In this way, the reappraisal effects reported above beginning around 200 ms and continuing for upward of 2 s suggest that reappraisal alters the stimulus identification, categorization, attention allocation, and memory formation stages of processing motivationally relevant visual input. These results suggest more specific effects of reappraisal and help clarify the broad labels used in Gross and colleagues' model such as "attention" and "appraisal."

Although promising in further specifying the processing stages affected by reappraisal instructions, the designs employed by Moser et al. (2006) and Hajcak and Nieuwenhuis (2006) limit the conclusions that can be drawn from them. Specifically, Moser et al. utilized a block design such that the effects of the reappraisal instructions on emotion picture processing could have resulted from cumulative or mood effects. Hajcak and Nieuwenhuis also employed a version of a block design such that each picture was first passively viewed before either being passively viewed again or reappraised. Therefore, the current study employed a trial-by-trial manipulation of instructions to avoid potential confounds present in block designs. Additionally, the current study included both decrease and increase instructions to examine increase effects in a nonblocked design, as we failed to show significant effects of increase instructions in our previous study that employed a block design. Last, we included both unpleasant and neutral pictures under passive viewing instructions to investigate the similarities and differences between the time course of emotion modulation—that is, the difference between unpleasant and neutral—and emotion regulation—that is, the difference between passive viewing and reappraisal instructions. To a certain extent, this design allowed us to separate emotion modulation from emotion regulation (cf. Gross & Thompson, 2007).

Another issue mostly ignored to date in the designs of emotion regulation studies is the fact that instruction words indicating the subject's task are presented prior to the onset of the emotional picture and may be associated with their own physiological correlates. Any effects revealed during the processing of the instruction word would further modify Gross and colleagues' modal model to include preparatory processes engaged prior to the emotional content to be reappraised. To date, the only study that has evaluated this possibility was that conducted by Gross (1998). Gross (1998) found that reappraise instructions elicited increases in physiological activity such as skin conductance, suggesting the engagement of preparatory processes prior to the onset of the evocative stimulus. Unfortunately, these findings were never incorporated into Gross's modal model and have since not been evaluated in other studies. Thus, in the current study we began ERP recording at the onset of the instruction word and continued through the duration of emotional picture presentation for the purposes of more fully examining the temporal dynamics of emotion regulation in a cued paradigm. To this end, we measured fronto-centrally maximal slow cortical potentials (SCPs; for a review, see van Boxtel & Bocker, 2004). Specifically, we measured early and late time windows of the stimulus-preceding negativity (SPN). These SPCs are thought to reflect orienting, preparatory, and anticipatory processes, with the early time window reflecting orienting and processing of the cue and the later time window reflecting preparation for and anticipation of the impending imperative stimulus (cf. van Boxtel & Bocker, 2004). Such effects have been demonstrated with cognitive (Falkenstein, Hoorman, Hohnsbein, & Kleinsorge, 2003) and affective stimuli (Klorman & Ryan, 1980; Simons, Ohman, & Lang, 1979).

The current study therefore addressed the following questions:

1. What effect will decrease instructions have on ERPs elicited by unpleasant pictures? Based on previous ERP results (e.g., Moser et al., 2006), we hypothesized that decrease instructions would be associated with reduced ERP magnitudes that would begin as early as 200 ms after emotion stimulus onset.
2. What effect will increase instructions have on ERPs elicited by unpleasant pictures? Based on previous psychophysiological (Jackson et al., 2000) and neuroimaging studies (Ochsner et al., 2004) showing enhanced activity associated with increase instructions that did, in fact, use trial-by-trial manipulations of emotion regulation instructions, we expected that increase instructions would be associated with enhanced ERP magnitudes. We had no specific hypothesis, however, about the time course of this effect in our trial-by-trial design.
3. When will emotion modulation occur relative to emotion regulation effects? Based on Gross and colleagues' modal model, it was hypothesized that emotion regulation effects will occur at the same point as the emotion modulation effect, indicating that reappraisal instructions alter the emotion generation stream at the point at which emotion is differentiated from neutral—that is, the stimulus is "appraised" as emotionally significant.
4. What will happen in the ERP waveform during cue processing? Based on previous psychophysiological results showing enhanced activity during instruction processing (Gross, 1998), we expected that instructions to decrease would be associated with enhanced SPN magnitudes. If this effect represents general preparation, then enhanced SPN magnitudes should be associated with increase instructions as well.

Method

Participants

Sixteen undergraduates (10 female) in an introductory psychology class participated in the current study for course credit. To encourage participants to follow task instructions closely, participants were told that the top two regulators, 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 showed the largest emotion regulation effects on ERP measures were awarded the bonus.

Stimuli and Procedures

The stimulus set comprised 30 unpleasant, high arousing and 30 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 mutilation and threat (human and animal). The neutral picture set included images of household items and neutral faces. Unpleasant and neutral images differed significantly from each other on IAPS normative valence ($M = 2.48$ and 4.92, respectively) and arousal ($M = 6.57$ and 2.85, respectively) ratings.

After participants received a general description of the experiment, EEG/EOG sensor electrodes were attached. Participants

[1]The numbers of the IAPS pictures used were the following: neutral (2190, 2200, 2210, 2230, 2570, 2840, 5500, 7000, 7002, 7009, 7010, 7020, 7025, 7035, 7050, 7080, 7100, 7150, 7160, 7170, 7175, 7190, 7217, 7224, 7233, 7235, 7550, 7700, 7950, 9070) and unpleasant (1050, 1090, 1110, 1113, 1120, 1201, 1220, 1300, 1301, 1930, 3000, 3010, 3053, 3060, 3062, 3063, 3100, 3102, 3130, 3170, 6230, 6243, 6260, 6313, 6350, 6360, 6540, 6560, 6570, 6821).

were then seated approximately 0.5 m directly in front of a computer monitor and given detailed task instructions. Participants performed two blocks of the emotion regulation picture viewing task administered on a Celeron D class computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli.

On each trial, participants first saw a cue word indicating their task during the viewing of the upcoming picture. The cue word "LOOK," "DECREASE," or "INCREASE" was presented at the center of the screen in white font for 2 s, instructing participants to view and respond naturally to the upcoming photo, decrease their emotional responding to the photo, or increase their emotional responding to the photo, respectively. "LOOK" cues were paired with neutral (look–neutral trials) and unpleasant pictures (look–unpleasant trials), whereas "DECREASE" and "INCREASE" cues were paired exclusively with unpleasant pictures (decrease–unpleasant and increase–unpleasant trials, respectively) to avoid confusion about how to regulate responses to neutral pictures, which presumably elicit little or no emotion. Following the cue word, a blank screen was presented for 500 ms immediately followed by a white fixation cross presented for 500 ms at the center of the screen in order to focus participants' attention for the upcoming picture. IAPS pictures were then displayed for 4 s and occupied the entire screen of a 17-in. monitor. The period between the offset of the IAPS picture and the onset of the next cue word lasted 2.5 s, during which time participants were instructed to relax.

Two blocks of trials were presented, each consisting of 90 cue–picture trials: The decrease block included 30 look–neutral trials, 30 look–unpleasant trials, and 30 decrease–unpleasant trials; the increase block included the same look–neutral and look–unpleasant trials, as well as 30 increase–unpleasant trials. The order of trials was random within each block. We chose not to utilize a completely randomized design, as we wanted to avoid potential task switching effects (e.g., switching from decreasing to increasing on successive trials; cf. Monsell, 2003) that might obscure differences between regulation and passive viewing trials.

Prior to each of the experimental blocks, participants performed two practice blocks in order to familiarize themselves with the task and emotion regulation instructions (described in more detail below). During the first practice block, participants were given detailed instructions regarding the order and timing of the stimuli as well as the meaning of each cue to be presented. The participant then performed approximately five trials in which they were asked to verbally generate proper appraisals of the stimuli in accordance with the instructional cue. This practice block allowed the experimenter an opportunity to help shape the participant's appraisals and determine that the participant understood the task. During the second practice block, participants performed 10 trials of the task and were asked to continue generating appropriate appraisals in accordance with the instructional cue, but this time silently as they would be doing during the experimental blocks. Finally, participants were reminded of the task procedures and emotion regulation instructions and were given a last chance to ask any additional questions.

Following the last experimental block, physiological sensors were removed and participants filled out a questionnaire in which they were asked to report what strategies they used for the look-unpleasant, decrease-unpleasant, and increase–unpleasant trials. This served primarily as a manipulation check, but also provided information that could be used to more thoroughly characterize the strategies subjects reported using to regulate their emotions.

Emotion Regulation Instructions

Instructions for the current study were adapted from Ochsner et al. (2004), as they were found to be effective in modulating neural responses to unpleasant pictures. For look–neutral and look–unpleasant trials, participants were instructed to view the pictures and respond naturally. Participants were explicitly instructed not to alter their natural response. For the decrease– and increase–unpleasant trials, participants were given two strategies each that corresponded to Ochsner et al.'s (2004) self- and situation-focused strategies. For the decrease–unpleasant trials, participants were given the option to either view the picture from a detached, third-person perspective as someone with no personal attachment to the pictured events or as if it were fake/from a movie (self-focused) or imagine that the pictured scene improved (situation-focused). For the increase–unpleasant trials, participants were given the option to either view the picture from an attached or first-person perspective as someone personally invested or personally partaking in the pictured events (self-focused) or imagine that the pictured scene worsened (situation-focused). In both cases, participants were explicitly told not to generate unrelated thoughts or images to increase or decrease their responses.[2]

Psychophysiological Recording, Data Reduction, and Analysis

The electroencephalogram (EEG) was recorded using an ECI electrocap. Recordings were taken from four 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 electrooculogram (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 10 kΩ and the data from all channels were recorded by a Grass Model 7D polygraph

[2]Verbatim instructions for decrease–unpleasant trials were as follows: "When you see the word 'DECREASE', you should think about the following picture in such a way that you feel your negative emotions less strongly. For example, you could view the picture as a detached, third-person who is not present at the scene pictured. If you were viewing an image of a sick person you could view this person from a detached, clinical perspective like someone not personally connected in any way to the individual. You can think of the picture as being fake or from a movie. You could also imagine that the pictured event gets better. If you were viewing an image of a sick person you could imagine that the person is not experiencing any pain and will recover quickly. The only thing I ask that you do not do is to simply think about something unrelated to the scene. For example, do not simply 'think happy thoughts' in order to decrease your negative emotions. Just try to reappraise the context of the scene as I just described." Verbatim instructions for increase–unpleasant trials were as follows: "When you see the word 'INCREASE', you should think about the following picture in such a way that you feel your negative emotions more strongly. For example, if you were viewing an image of a sick person you could imagine that you or a loved one are this individual, or that you are observing that individual suffering in their hospital bed. You could also imagine that the pictured event gets worse. If you were viewing an image of a sick person you could imagine that the person is in great pain and is unlikely to ever recover. The only thing that I ask that you do not do is to simply think about something unrelated to the scene. For example, do not simply think of an unrelated negative situation in order to make your negative emotions more prominent. Just try to reappraise the context of the scene as I just described."

with Grass Model 7P1G preamplifiers (bandpass = 0.008–35 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 cue onset and continued for 7500 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). Based on these rejection criteria, the six trial types did not significantly differ with respect to the number of rejected trials (all *M*s between 1.69 and 2.81) $F(5,75) < 1$. Single-trial EEG data were lowpass filtered at 20 Hz with a 51-weight FIR digital filter as per Cook and Miller (1992).

ERPs were constructed by separately averaging look-neutral, look–unpleasant and decrease– or increase–unpleasant trials for each recording site. For each ERP, the average activity in the 100-ms window prior to cue onset served as the baseline. This baseline was chosen because it was the period of EEG recording that was identified as being closest to participants' true baseline—they were instructed to relax during this time (cf. Luck, 2005)—as well as to examine changes in brain activity occurring in anticipation of the emotional picture as a function of regulation instruction.

First, to examine the time course of emotion regulation effects on electrophysiological activity associated with emotion picture processing, we measured the LPP at Pz as the average activity across multiple time windows following visual inspection of the grand averaged ERP waveforms. Then, to examine emotion regulation instruction effects on electrophysiological activity associated with anticipation of and preparation for the upcoming emotional picture, we measured the early and late SPN at recording site Fz as the average activity in successive time windows following visual inspection of the grand averaged ERP. The SPN and LPP components were measured at Fz and Pz, respectively, to reduce the potential confounding overlap effects of the other (cf. Luck, 2005).

ERPs were statistically evaluated using SPSS (Version 15.0) General Linear Model software with Greenhouse–Geisser correction applied to *p* values associated with multiple *df* repeated measures comparisons where appropriate. Specifically, we employed a 2 (Order: decrease first vs. increase first) × 2 (Regulation Block: decrease vs. increase) × 3 (Trial Type: look unpleasant vs. look neutral vs. regulate unpleasant) repeated measures analysis of variance (rANOVA) for all ERP measures described below. There were no significant effects involving the order of the two blocks, and this factor is therefore not mentioned further.

Results

Stimulus-locked grand averaged ERPs at Fz, FCz, Cz, and Pz for the three trial types—regulate–unpleasant, look-unpleasant, and look-neutral—in the two regulation blocks are presented in Figures 1 and 2. Table 1 contains the mean amplitudes for the LPP time windows at Pz and early and late SPN at Fz in the decrease and increase blocks, analyses of which are presented below.

Emotion Regulation Effects on Emotion Picture Processing: LPP Time Windows

We first examined the maximal LPP time window (400–700 ms) to show replication of our previously demonstrated decrease effect and to investigate whether the current design allowed for the increase effect to emerge. Analysis of the maximal LPP time window revealed significant Regulation Block, $F(1,14) = 16.06$, $p = .001$, and Trial Type effects, $F(2,28) = 28.72$, $p < .001$, that were qualified by a significant Regulation Block × Trial Type interaction, $F(2,28) = 5.74$, $p = .014$. Follow-up analyses in the decrease block showed a significant Trial Type effect, $F(2,28) = 20.22$, $p < .001$. Replicating our previous finding, positivity was smaller on decrease–unpleasant than look–unpleasant trials ($p = .023$), and positivity was smaller still on look–neutral trials ($p < .006$; see Table 1 and Figure 1). In the increase block, the Trial Type effect was also significant, $F(2,28) = 19.33$, $p < .001$. The LPP in the 400–700-ms time window tended to be larger on increase–unpleasant trials than on look–unpleasant trials ($p = .053$), and positivity was significantly larger on both of these types of trials compared to look–neutral trials ($ps < .001$).

We then examined the LPP in the subsequent 700–1000-ms time window where it seemed to decline in strength. This analysis revealed significant Regulation Block, $F(1,14) = 11.24$, $p = .005$, and Trial Type effects, $F(2,28) = 18.84$, $p < .001$, that were qualified by a significant Regulation Block × Trial Type interaction, $F(2,28) = 3.89$, $p = .04$. Follow-up analyses showed a significant Trial Type effect, $F(2,28) = 10.36$, $p = .001$, in the decrease block for this time window. LPPs on look–unpleasant and decrease–unpleasant trials remained larger than on look–neutral trials in this time window ($ps < .001$ and .026, respectively; see Table 1 and Figure 1), but the difference in positivity between decrease–unpleasant compared to look–unpleasant trials was no longer significant ($p = .132$). In the increase block, on the other hand, positivity was greater on increase–unpleasant compared with look–unpleasant trials ($p = .047$), both of which showed greater positivity than look–neutral trials in this time window ($ps = .003$ and $< .001$, respectively), Trial Type, $F(2,28) = 15.75$, $p < .001$. See Table 1 and Figure 2.

Analysis of the sustained LPP from 1 to 3.5 s after picture onset revealed significant Regulation Block, $F(1,14) = 12.42$, $p = .003$, and Trial Type effects, $F(2,28) = 5.76$, $p = .013$, that were qualified by a significant Regulation Block × Trial Type interaction, $F(2,28) = 5.57$, $p = .014$. Follow-up analyses in the decrease block showed greater positivity on look–unpleasant than on decrease–unpleasant trials and look–neutral trials ($ps = .028$ and .013, respectively), which did not differ from one another ($p = .584$), Trial Type $F(2,28) = 4.17$, $p = .03$. See Table 1 and Figure 1. In the increase block, positivity was significantly larger on increase–unpleasant than on look–unpleasant and look–neutral trials ($ps = .026$ and .003, respectively), which did not differ from each other ($p = .118$), Trial Type $F(2,28) = 7.29$, $p = .005$. See Table 1 and Figure 2.

Overall, analyses conducted on the maximal and sustained LPP time windows confirmed our hypotheses that the magnitude of the LPP would follow the direction of emotion regulation to unpleasant pictures—relative to a passive viewing condition—such that it would be smaller during instructions to decrease emotional responding and larger during instructions to increase emotional responding. The nuances of the temporal dynamics of these effects will be considered more thoroughly in the discussion section.

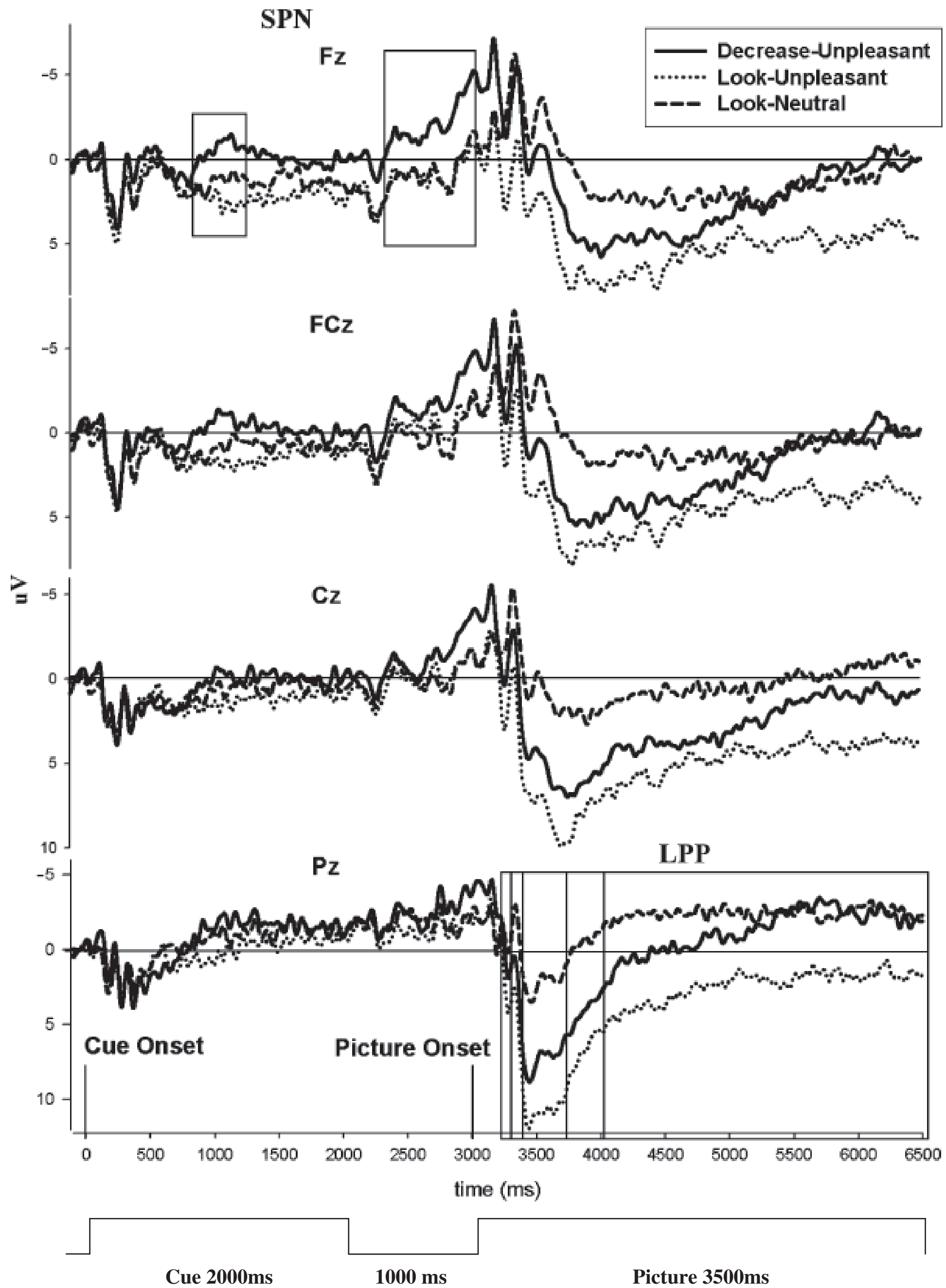

Figure 1. Stimulus-locked ERPs at Fz, FCz, Cz, and Pz for the decrease block. The x-axis runs from the beginning of the baseline (–100 ms precue onset) to the end of the LPP period, 3.5 s after picture onset. Boxed regions and labels indicate during which time windows and at what site the SPN and LPP components were measured.

As in our previous studies, inspection of the grand averaged waveform seemed to suggest that the LPP modulation by emotion regulation instructions began prior to the point where it reached its maximum amplitude. We therefore examined the LPP in two successive time windows prior to its peak: 200–300 ms and 300–400 ms after picture onset. Analysis of the 200–300 ms LPP time window revealed only a significant Regulation Block effect, $F(1,14) = 7.07$, $p = .019$; all other ps $> .11$), reflecting more positivity overall in the increase block compared to the decrease block. The same analysis conducted on the 300–400-ms LPP time window again yielded a significant Regulation Block effect, $F(1,14) = 8.03$, $p = .013$, suggesting continued enhanced positivity overall in the increase block. This analysis also showed a significant overall Trial Type effect, $F(2,28) = 13.67$, $p < .001$. Look–unpleasant and regulate–unpleasant trials (increase– and decrease–unpleasant trials combined) elicited larger positivity than look–neutral trials ($p < .001$ and $p = .002$, respectively), and did not differ from each other ($p = .975$). The Regulation Block × Trial Type interaction, however, only approached significance, $F(2,28) = 2.88$, $p = .089$.

Analysis of these earlier LPP time windows, therefore, failed to show significant emotion regulation effects, although the magnitudes were in the expected directions. Instead, these analyses revealed the typical emotion modulation effect—that is,

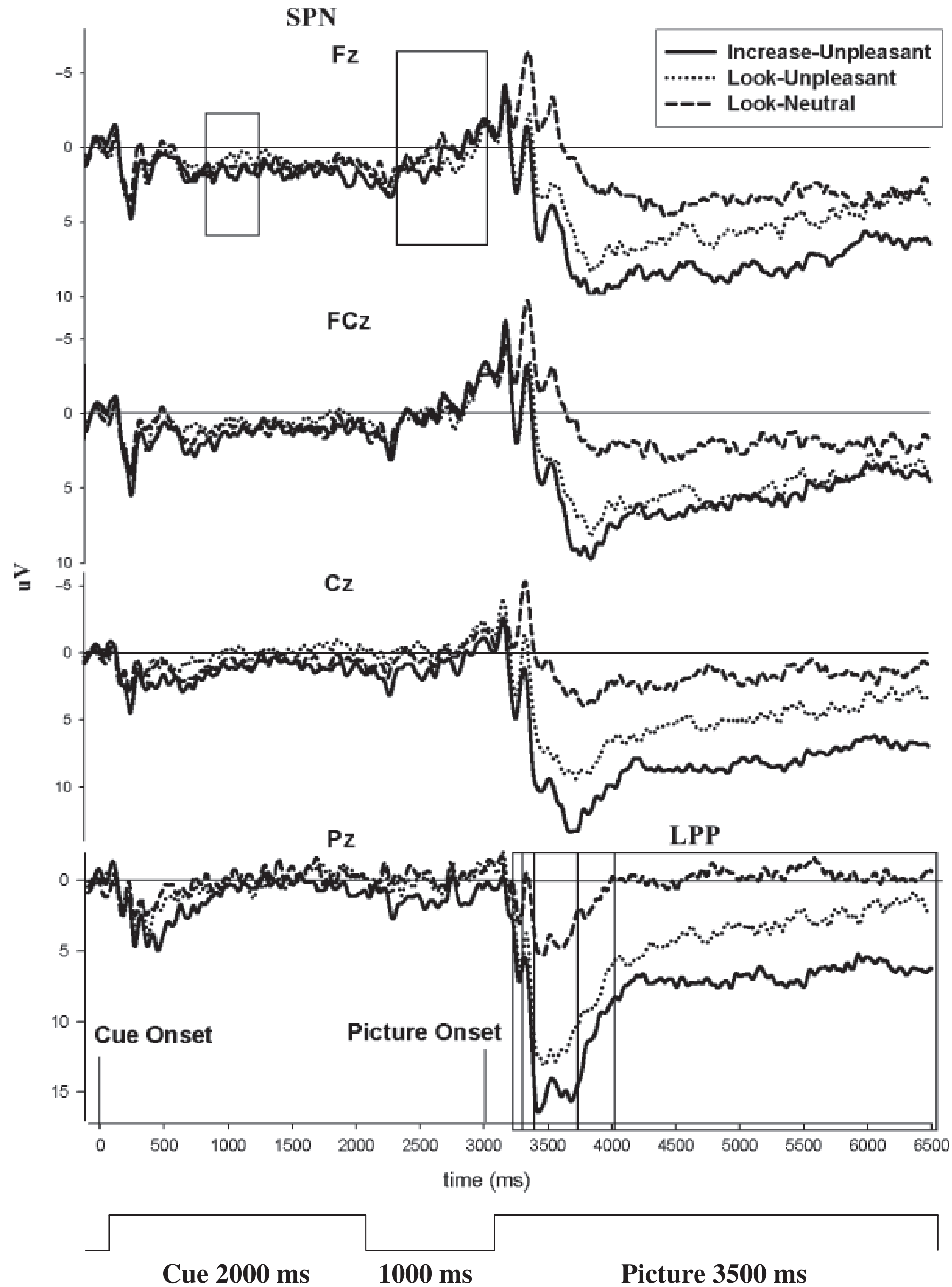

Figure 2. Stimulus-locked ERPs at Fz, FCz, Cz, and Pz for the increase block. The x-axis runs from the beginning of the baseline (–100 ms precue onset) to the end of the LPP period, 3.5 s after picture onset. Boxed regions and labels indicate during which time windows and at what site the SPN and LPP components were measured, respectively.

larger LPPs to unpleasant compared to neutral pictures—that seemed to emerge around 300 ms after picture onset.

Emotion Regulation Effects on Anticipatory/Preparatory Processing: Early and Late SPN

Consistent with previous ERP studies of anticipatory and preparatory processing (cf. van Boxtel & Bocker, 2004), Figures 1 and 2 show the early and late peaks of the SPN as frontocentral negative deflections, with the early peak occurring after the onset of the cue and the late peak reaching its magnitude just prior to emotional picture onset. To capture the early and late SPN, we measured the average activity in the 800–1200-ms postinstruction word onset time window and the average activity in a 700-ms time window immediately preceding emotional picture onset, respectively. Analysis of the early SPN revealed a significant Regulation Block × Trial Type interaction effect, $F(2,28) = 3.97$, $p = .032$; all other $ps > .16$. Follow-up analyses in the decrease block showed a significant effect of Trial Type, $F(2,28) = 5.00$, $p = .024$, such that decrease–unpleasant trials were associated with a larger early SPN than look–unpleasant trials ($p = .004$; see Figure 1 and Table 1). Follow-up analyses in the increase block failed to yield a significant effect of Trial Type, $F(2,28) < 1$. Direct comparison of the decrease and increase early SPN effects—that is, decrease – look versus increase – look—revealed that,

Table 1. *Mean (Standard Deviation) LPP and SPN Magnitudes (in Microvolts) for the Decrease and Increase Blocks*

	Decrease block			Increase block		
Measure	Look-unpleasant	Decrease-unpleasant	Look-neutral	Look-unpleasant	Increase-unpleasant	Look-neutral
LPP (400–700 ms)	10.88 (4.61)	7.41 (5.67)	2.35 (5.64)	12.22 (6.34)	15.16 (7.53)	4.49 (5.89)
LPP (700–1000 ms)	7.20 (3.53)	4.41 (6.44)	– 0.24 (4.64)	8.56 (5.56)	11.32 (6.33)	1.62 (4.93)
LPP (1–3.5 s)	2.43 (4.02)	– 1.26 (7.55)	– 2.42 (5.81)	3.22 (6.19)	6.75 (6.48)	– 0.33 (4.51)
LPP (200–300 ms)	1.65 (5.86)	– 0.23 (6.65)	– 0.70 (7.06)	3.62 (6.63)	4.91 (7.37)	1.50 (5.29)
LPP (300–400 ms)	4.92 (5.79)	2.57 (5.94)	– 1.08 (6.32)	6.47 (6.62)	8.72 (7.66)	1.11 (5.80)
Early SPN	2.33 (2.22)	– 0.40 (3.12)	1.40 (2.57)	0.94 (2.95)	1.59 (3.33)	1.43 (2.98)
Late SPN	1.49 (3.67)	– 1.21 (4.64)	1.48 (3.93)	1.40 (4.37)	1.31 (4.69)	0.58 (3.69)

indeed, the decrease effect ($M = -2.73$; $SD = 3.46$) was significantly larger than the increase effect ($M = 0.66$; $SD = 2.55$), $t(15) = 2.89$, $p = .011$.

Analysis of the late SPN revealed a marginal, yet nonsignificant, Regulation Block × Trial Type interaction, $F(2,28) = 2.43$, $p = .11$; all other $ps > .22$. In light of the early SPN findings we tested the Trial Type effect separately in each regulation block. Results of these analyses in the decrease block again showed a significant effect of Trial Type, $F(2,28) = 3.67$, $p = .046$, such that decrease–unpleasant trials continued to be associated with larger negativity than look–unpleasant trials ($p = .028$; see Table 1 and Figure 1). Analyses in the increase block again failed to yield a significant effect of Trial Type, $F(2,28) < 1$. Comparison of the decrease and increase late SPN effects showed numerically, but not statistically, larger late SPNs for the decrease effect ($M = -2.69$; $SD = 4.98$) than for the increase effect ($M = -0.09$; $SD = 5.23$), $t(15) = 1.49$, $p = .16$.

Emotion Regulation Strategies

Two trained undergraduates independently coded subjects' responses to the posttask emotion regulation strategies questionnaire on a 4-point scale: 1 = *Person did not try to change emotional experience* (corresponding to our LOOK instructions), 2 = *Person tried to change emotional experience by changing the personal relevance of the scene* (corresponding to our self-focused instructions for decrease and increase trials), 3 = *Person tried to change emotional experience by reinterpreting the emotions, actions and outcome of the scene* (corresponding to our situation-focused instructions for decrease and increase trials), and 4 = *Person tried to change emotional experience by doing both 2 and 3* (corresponding to a combination of our self- and situation-focused instructions for decrease and increase trials). Raters were also instructed to indicate whether they felt a response did not fall into one of these four categories. None of the responses were judged to be uncodable, indicating that the four categories were sufficient in capturing participants' responses. A kappa of .86 was achieved between the two raters, indicating excellent agreement.

All of the subjects in the current study reported using the self-focused techniques to decrease (e.g., "I looked at the picture as if I was detached from the situation") and increase (e.g., "I tried to view them as happening to someone I know") negative emotions and a minority (5/16) also reported employing situation-focused techniques along with the self-focused techniques (e.g., for decrease, "I tried to detach myself from the situation as much as possible. I imagined the scene was from a movie, or that the person was in no pain, or that the person got away from the bad situation"; e.g., for increase, "I'd think that it was going to get worse or imagine it happening to someone I knew"). None of the subjects reported only using the situation-focused techniques. For illustrative purposes, an example of a response coded as falling in the look category by both raters is: "I looked at the picture and let my emotions run naturally."

Discussion

The current study built on previous findings and theory of emotion regulation by using ERPs elicited prior to and during unpleasant picture processing under different regulation instructions to examine the time course of emotion generation and regulation. We now return to our initial questions and hypotheses that motivated the current study.

What Effect Will Decrease Instructions Have on ERPs Elicited by Unpleasant Pictures?

Consistent with our previous work (Moser et al., 2006) and that of Hajcak and Nieuwenhuis (2006), ERPs elicited by unpleasant pictures were reduced under decrease instructions. This effect began around 400 ms and lasted up to 3.5 s after picture onset. Going beyond previous results, the current findings demonstrate that decrease instructions impact the magnitude of the LPP for several seconds, as the two previous studies had shorter picture presentations (i.e., no longer than 2 s). Interestingly, the current regulation effect for decrease instructions began about 200 ms later than that of the previous two studies—the decrease effect began around 400 ms in the present study and around 200 ms in the previous two studies. This difference in time course might reflect inherent differences between blocked and trial-by-trial manipulation designs. Compared to the current study, for example, participants in the Hajcak and Nieuwenhuis (2006) study had ample time to initially appraise the significance of the picture during the first viewing as well as significantly more time to begin reappraising during the long instruction period, thus possibly moving the impact of the decrease instructions earlier in the processing stream.

As suggested by our results and Figure 1, decrease–unpleasant trials were associated with equally small LPPs as look–neutral trials during the late time window (1–3.5 s), whereas look–unpleasant trial LPPs remained enhanced compared to look–neutral trial LPPs during this later window. This differential effect was not present prior to 1 s; even when decrease–unpleasant trials elicited smaller LPPs than look–unpleasant trials in earlier time windows they were still associated with larger LPPs than look–neutral trials. These findings suggest that decrease instructions affect early and late time windows of the LPP differently and perhaps that the process of reappraisal unfolds over time as reflected in associated changes in neural activity. Early on reappraisal seems to reduce the significance of unpleasant stimuli relative to passive viewing instructions; however, these reappraised unpleasant stimuli are still tagged as more significant than passively viewed neutral pictures. Later, reappraisal appears to reduce the significance of unpleasant stimuli to the point that they no longer differentiate themselves from passively viewing neutral pictures, at least as indexed by the LPP.

In the context of Dien et al.'s (2004) and Olofsson et al.'s (2008) models of information processing stages, the current ERP results suggest that decreasing emotional responses to unpleasant pictures by cognitive reappraisal diminishes later attentional allocation to and early memory formation of motivationally relevant visual input. Decreasing emotional responses by cognitive reappraisal did not seem to affect earlier processes such as stimulus identification and categorization, indexed by activity in the 200–400-ms time window, although future studies are needed to elucidate the differences in onset of emotion regulation effects in different experimental paradigms as described above. The effect of decrease instructions on memory are mixed, however, as one behavioral study (Dillon et al., 2007) found somewhat enhanced recall of unpleasant pictures previously viewed under decrease instructions whereas another (Richards & Gross, 2000) failed to show consistent memory effects for reappraisal. Differences in reappraisal instructions, however, may play a role in these mixed findings. For example, Dillon et al. emphasized mental imagery during all emotion regulation and therefore this may have resulted in the formation of stronger memories.

Insofar as the LPP indexes the emotional arousal of unpleasant stimuli (e.g., Cuthbert et al., 2000), the current findings fit with previous results demonstrating decreases in emotional intensity ratings (e.g., Gross, 1998) and amygdala activity (for a review, see Ochsner & Gross, 2005) during decrease instructions. More direct evidence for this link comes from Hajcak and Nieuwenhuis (2006), who showed a positive correlation between reductions in the LPP and reductions in self-reported emotional intensity during decrease instructions. An interesting alternative that may integrate the arousal and memory interpretations of the LPP modulations during decrease instructions is that its magnitude reflects the activity of what Ochsner and Gross (2007) refer to as the perceptual appraisal system, including the parietal, occipital, and temporal cortices, which do, in fact, contribute to the generation of the LPP (Sabatinelli, Lang, Keil, & Bradley, 2007). They propose that alternative stimulus representations are generated in the perceptual appraisal system during emotion regulation to support changes in emotional experience. Given the rapid LPP reductions observed here and previously, it is possible that they reflect the replacement of the initial arousing/aversive percept with an alternative, less arousing/aversive stimulus representation that results in decreased emotional intensity during unpleasant picture viewing. Taken together, the current findings suggest the need for future studies combining ERPs with measures of memory and emotional experience.

What Effect Will Increase Instructions Have on ERPs Elicited by Unpleasant Pictures?

The current design also revealed increases in the LPP as a result of instructions to increase negative emotions. As with the decrease instructions, this effect began around 400 ms and lasted up to 3.5 s after picture onset. Thus, the current study revealed a similar time course for the effects of increase and decrease instructions on emotion picture processing; however, different from the decrease effects, LPPs during increase were always larger than those during look–neutral trials. It appears as though trial-by-trial manipulations of instructions as well as longer picture presentation are important factors in revealing an increase effect, as our original study involved a block design and fairly brief picture presentations (1 s). Consistent with this notion, previous studies utilizing long picture presentations and trial-by-trial manipulations of instructions also found enhancement of psychophysiological measures during increase instructions (Jackson et al., 2000; Ochsner et al., 2004).

As with the effects of the decrease instructions, the current effects for the increase instructions on the LPP can be interpreted as reflecting attentional, memory, and arousal processes (cf. Olofsson et al., 2008). In terms of the attentional allocation and memory hypothesis of the LPP, the current data fit nicely with the enhanced recall memory effect reported by Dillon et al. (2007) for increase instructions. The current data also fit with the arousal hypothesis of the LPP insofar as the enhanced LPP reported here for increase instructions would relate to increased emotional arousal during increase instructions. The view that the LPP indexes activity of perceptual appraisal areas, as per Ochsner and Gross (2007), is also relevant. In this case, the enhanced LPP may reflect the generation of more arousing/aversive stimulus representations that results in increased emotional intensity during unpleasant picture viewing.

When Will Emotion Modulation Occur Relative to Emotion Regulation Effects?

Based on Gross and colleagues' modal model of emotion generation and regulation (cf. Gross & Thompson, 2007), it was hypothesized that emotion regulation effects would occur at the same point as the emotion modulation effect, indicating that reappraisal instructions altered the emotion generation stream at the point at which the appraisal of unpleasant versus neutral was made. This hypothesis was not supported. Rather, our results suggest that appraisal of unpleasant versus neutral pictures was made prior to the emergence of regulation effects. More specifically, unpleasant pictures in all three conditions—look, decrease, and increase—were differentiated from neutral pictures approximately 300 ms after picture onset. The timing of this emotion modulation effect is very typical (for a review, see Olofsson et al., 2008). Yet, regulation effects were not present during this time window. As shown by Figures 1 and 2, the regulation effects emerged approximately 100 ms later, during the peak amplitude of the LPP. Thus, the current data suggest that appraisal of the emotional significance of visual input is conducted first, followed by the modulation of such input by reappraisal instructions.

Although these results need not be inconsistent with Gross and colleagues' model, they suggest that refinement of the conceptualization is warranted. "Attention" and "appraisal" are broad and vague terms utilized by Gross and colleagues that deserve further explication, and the current results can help begin to specify the meaning of such constructs within emotion regulation research. For instance, in the context of Olofsson et al.'s (2008) review of information processing stages involved in emotion picture processing, the current data suggest that the "appraisal" of unpleasant versus neutral stimuli occurs around 300 ms after picture onset when sufficient attentional resources have been allocated to encode the motivational significance of the stimuli and update working memory. Following this appraisal, reappraisal starts to exert its effect during points in processing when memory representations are being fortified and stored. Therefore, reappraisal does not seem to be a filter through which visual input must sift, but rather it is a sculpting mechanism that reworks the already appraised information.

What Will Happen in the ERP Waveform during Cue Processing?
Based on previous psychophysiological results showing enhanced activity elicited during instruction processing in an emotion regulation study (Gross, 1998), we expected that regulation instruction words would likewise elicit enhanced electrophysiological activity, as indexed by the early and late SPN. The current study revealed enhanced early and late SPN magnitudes to decrease instruction words only. Based on previous research, these results suggest that decrease instruction words were associated with enhanced orienting and preparation to and anticipation of the upcoming unpleasant picture (cf. van Boxtel & Bocker, 2004), whereas increase instruction words were not. Direct comparison of the decrease and increase SPN effects generally supported this distinction, most strongly during the early SPN time window. It appears, then, that processes associated with decreasing emotional responses to unpleasant pictures engage prior to the onset of the emotional content, whereas such processes are absent under instructions to increase emotional responses.

It is possible that the current findings reflect the fact that decreasing one's emotions might begin prior to the presentation of emotional content, as subjects place themselves in a neutral, distant mode immediately after seeing the decrease instruction word. On the other hand, increasing one's emotions might require having the unpleasant content on the screen before one can personalize the material and imagine himself/herself or a loved one in the scene. Another possibility is that decreasing emotions is habitually performed by humans and such ''practice'' or ''knowledge'' effects facilitate engagement of regulatory processes even prior to the presentation of emotional content (cf. Gross, 2007). Nevertheless, effects of decrease and increase instructions on emotion picture processing had a similar time course, suggesting that any preparation advantage on decrease trials did not speed up the impact of reappraisal.

A Note on Emotion Regulation Strategies Purportedly Used by Subjects
Analysis of the emotion regulation strategies questionnaire suggests that participants understood the reappraisal instructions, and, at least, consistently reported using the specific strategies we asked them to use. Our raters agreed that all subjects only reported using strategies they were instructed to use and reached excellent agreement on which one of the strategies each subject used on the different types of trials. Furthermore, the results of the raters suggest that participants were quite uniform in the strategies they chose for the different types of trials. Specifically, all subjects reported using the self-focused strategy provided to them to decrease and increase their emotions, and only a minority reported using both self- and situation-focused strategies. These data therefore suggest that there was very little individual variation in strategies employed to regulate emotions and lends additional support to our claim that our ERP effects reflect true attempts at using cognitive reappraisal.

Concluding Remarks
Decreasing and increasing emotional responses by cognitive reappraisal modulates the electrophysiological response to unpleasant pictures in accord with the direction of instructed emotional engagement beginning around 400 ms and lasting for several seconds. Current conceptualizations of the LPP suggest that attentional, memory, and arousal processes are the primary targets of reappraisal. These reappraisal effects emerged after unpleasant pictures were differentiated from neutral ones suggesting that emotion modulation precedes emotion regulation. Finally, decreasing one's emotions was associated with enhanced preparatory activity during the instruction period whereas increasing one's emotions was not. Overall, these results point to the potential of using ERPs to refine extant models of emotion regulation by more fully characterizing the temporal dynamics of emotion regulation processes.

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