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Effects of Instructed Emotion Regulation on Valence, Arousal, and Attentional Measures of Affective Processing

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Cognitive control of emotion has been investigated using tasks prompting participants to increase or decrease emotional responding to affective pictures. This study provides a more comprehensive evaluation of responding in this task by including: pleasant and unpleasant pictures, increase and decrease instructions, additional physiological measures, and a fully randomized design. Findings suggest that control efforts did modulate higher-level affective responses indexed by self-reported valence and expressive facial muscles, but not lower-level affective responses indexed by startle blink and heart rate. Similarly, electrocortical measures evidenced expectable affective responses and control-related activity, but no modulation of affective patterns due to the control efforts.

In recent years, work investigating the cognitive control of emotion has focused on experimental tasks that cue participants to use cognitive reappraisals (Gross, 1998b) to increase or decrease emotional responding to affective stimuli. The first implementation (Jackson et al., 2000) presented the emotional stimulus (picture) first and then presented a cue asking participants to modulate their emotional response. Later implementations (like the current one) often present the cue first, then the stimulus to be regulated. The cue generally involves three classes of instruction, asking the participant to modulate their emotional reaction accordingly: increase/enhance, decrease/suppress, and view/look (i.e., do not modulate). In general the decrease/suppress condition has emphasized cognitive reappraisal as the strategy for modulation (Gross, 1998b). Investigators then assess the effects of instructions on various cognitive- and emotion-sensitive measures, including electroencephalogram (EEG), functional magnetic

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resonance imaging (fMRI), startle, facial muscles, skin conductance, and others. Several consistent patterns of response have been observed using variants of this task, and work in this area continues to provide new information about processes involved in voluntary emotion regulation.

For a number of reasons, implementations of this task have tended to focus on unpleasant affective stimuli, to be inconsistent in the number and types of regulation instructions, and to measure different physiological outcomes. As will be reviewed below, due to this selective use of measures and task manipulations (likely due to the difficulties involved in coordinating a full range of manipulations and measures), there are several important inferences that have not been tested as rigorously as possible. Findings suggesting that cognitive control efforts directly modulate emotion as indexed by the startle blink reflex, which were recently questioned by Dillon and Labar (2005), stand out in this regard. Similarly, there have been efforts to better control instruction implementation by blocking instead of randomizing trials (e.g., Kropfing, Moser, & Simons, 2008; Moser, Kropfing, Dietz, & Simons, 2009). While findings from these experiments have offered positive findings, suggesting emotional responding can be modulated by control efforts, important questions remain about the nature of these effects and the experimental conditions under which they occur. The goal of the current study is to provide a more comprehensive evaluation of responding during instructed emotion regulation tasks by implementing a full complement of the primary manipulations, including a full range of affective stimuli (pleasant, unpleasant, and neutral) and all three instructional cues (enhance, view, suppress), a fully-randomized trial structure, and a broader array of simultaneously administered physiological measures than in prior studies.

To appropriately set the stage for the larger number of conditions and measures in the current study, this introduction first reviews known patterns of affective responding for the measures included in this study, then details what is known about the modulation of these responses in emotion regulation tasks. Also, to simplify the presentation of the analyses, measures and hypotheses are organized in terms of sensitivity to either valence or arousal affective dimensions or attention allocation.

Emotional Processing and Physiological Response

Emotion plays a crucial role in human survival and adaptive behaviors (Ekman & Davidson, 1994). Emotions trigger motivations that promote survival and guide human behavior by exerting a “bottom-up” influence on cortical functioning that serves to modulate various cognitive processes, including working memory (Gray, 1999, 2001) and decision making (Bechara, Damasio, & Damasio, 1991; Damasio, 1996). There is agreement that affective responding at the highest level can be organized into a bipolar valence dimension (i.e., pleasant–unpleasant; Russell & Carroll, 1999a, 1999b; Tellegen & Watson, 1999a, 1999b). There is debate about whether more multidimensional models of affect should further characterize valence relative to a single orthogonal arousal dimension (see, e.g., Russell and Carroll, 1999a, 1999b) or separable (but non-orthogonal) positive and negative activation dimensions (PA/NA; cf. Tellegen and Watson, 1999a, 1999b). For the purposes of the current study this lower-order distinction is not critical, because the valence dimension is primary in both models and debate regarding functional distinctions between arousal and PA/NA centers on whether increased arousal drives increases

in positive and negative valence together (orthogonal arousal) or more independently (PA/NA). Because the bipolar-valence/orthogonal-arousal model has been more extensively studied with the physiological measures reported in the present study, this framing is more useful for current purposes.

Affective experiences manifest within multiple response domains, including experiential, behavioral, and physiological systems (Lang, Rice, & Sternbach, 1972; Gross & Levenson, 1993; Gross, 1998a, 1999). Affective variance from many of these domains can be characterized using valence and arousal dimensions, such that some measures discriminate the valence of the emotion and others better discriminate how arousing the emotion is (Greenwald, Cook, & Lang, 1989; Lang, Greenwald, Bradley, & Hamm, 1993). Affective responses organized around the valence dimension include subjective hedonic experience, most often measured via self-report ratings of internal reactions to affective stimuli (e.g. Self-Assessment Manikin, Lang, 1980), particularly pictures as used in the current study. Previous studies of facial behavior using electromyography (EMG) suggest they are sensitive to the valence dimension, with increases observed in corrugator activity during the processing of unpleasant stimuli and in zygomatic activity during the processing of pleasant stimuli (Lang et al., 1993; Schwartz, Brown & Ahern, 1980; Tassinary, Cacioppo, & Geen, 1989). It is worth noting that these studies have suggested that whereas corrugator responding is also reduced during the processing of pleasant stimuli, relative to neutral (compatible with a bipolar valence indicator), zygomatic activity does not consistently decrease during the processing of unpleasant stimuli. Other physiological indicators of emotional valence include changes in heart rate (HR), such that greater HR acceleration is seen to pleasant pictures and greater deceleration to unpleasant pictures (Greenwald et al., 1989), and modulation of the defensive startle reflex, with unpleasant pictures eliciting stronger responses than pleasant pictures (e.g., Vrana, Spence, & Lang, 1988). Indicators of the arousal dimension of affect include self-reported ratings of subjective arousal experience and electrodermal responses. For reviews of the literature regarding self-report, facial EMG, and peripheral physiology associated with emotional reactions during picture-viewing paradigms, see Bradley, Codispoti, Cuthbert, and Lang (2001) and Bernat, Patrick, Benning, and Tellegen (2006).

Two event-related potential (ERP) electroencephalographic (EEG) measures have also been developed recently as indices of affective responding. The first is the late positive potential (LPP), a late slow-wave ERP component which is positively related to the rated arousal of picture stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp, Cuthbert, Bradley, Cacioppo, Ito, & Lang, 2000; Schupp, Cuthbert, Bradley, Hillman, Hamm, & Lang, 2004). Increases in LPP amplitude have been interpreted to indicate an increase in “motivated attention” and recent empirical investigations of the effects of directed attention on the LPP have supported this view (Dunning and Hajcak, 2009; Hajcak, Dunning, and Foti, 2009). The second ERP measure of interest—a P300 response to startle probes that are often administered during picture viewing to record reflex responses—provides a more direct index of attentional processing during picture viewing. Attending to these probes can be understood as a secondary task, producing decreases in P300 when individuals are more engaged in the primary task (picture viewing). Indeed, the observed pattern of modulation is associated with arousal, such that there is a decrease in the probe P300 amplitude while viewing affective stimuli relative to neutral (Cuthbert, Schupp, Bradley, McManis & Lang, 1998; Schupp et al., 2004), suggesting that more attention is allocated toward the picture when it is more emotionally arousing.

COGNITIVE CONTROL AND EMOTION

Valence measures including the startle blink reflex and the corrugator EMG have been previously assessed in emotion regulation tasks. For unpleasant stimuli, the startle blink reflex has shown consistent increases when enhancing relative to suppressing, with passive viewing eliciting an intermediate response (Dillon & Labar, 2005; Jackson, Malmstadt, Larson, & Davidson, 2000; Piper & Curtin, 2006). This pattern has also been replicated during a threat of electric shock (Lissek et al., 2007); further, Dillon and Labar (2005) found that the same pattern (enhance > view > suppress) held for startle responses during pleasant stimuli. They suggested that startle reflex modulations may reflect changes in emotional arousal, rather than valence, in response to regulation efforts. If so, this suggests that emotion-regulation control efforts may not have manipulated the primary fear/defense processes understood to underlie the valence-based emotion-modulated startle blink response (cf. Lang, 1995).

The corrugator EMG has evidenced this same pattern (enhance > view > suppress) for unpleasant stimuli (Jackson et al., 2000), but investigations of control efforts during pleasant stimuli have not yet been reported for this measure. There have been at least two other studies that have focused on pleasant film clips, but have utilized measures of fMRI (Beauregard, Lévesque, & Bourgouin, 2001) or autonomic physiology (including HR, respiration, and sympathetic nervous system activation; Giuliani, McRae, & Gross, 2008). Thus, while demonstrating that control efforts do modulate physiological responding to pleasant stimuli, and providing interesting information in their own right, they do not help understand modulation of the previously reported valence-sensitive startle and corrugator measures. The paucity of studies evaluating control efforts during pleasant stimuli is striking; the current study employs both pleasant and unpleasant stimuli in an effort to extend this literature. In terms of arousal-based indices of emotion regulation, Gross (1998a) found skin conductance increases during both reappraisal and physical suppression of responses to unpleasant film clips; a similar, although not significant, pattern emerged during pleasant clips (Gross & Levenson, 1997). The authors interpreted these findings as reflecting increased effort for suppressing both positive and negative emotions.

A large and growing body of work in this area has assessed central nervous system measures (including fMRI and EEG LPP measures) during emotion-regulation tasks. EEG and fMRI both index local field potential activity (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001), and thus yield related results. These studies have typically used blocked designs rather than the fully random trial structure more common in work with peripheral physiological measures (cf. Jackson et al., 2000), and again have also focused mostly on unpleasant stimuli. In terms of the fMRI studies, increases in lateral prefrontal cortex (LPFC) have been observed during control efforts (Beauregard et al., 2001; Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003; Lévesque et al., 2003; Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner et al., 2004). Some of these studies have suggested that LPFC increases may be lateralized to the right, and that effects are also associated with increases in anterior cingulate cortex activity (ACC; Beauregard et al., 2001; Hariri et al., 2003). Increases in LPFC and ACC activity during control efforts are consistent with current models of neural recruitment during cognitive control (Miller & Cohen, 2001). Interestingly, some of these studies also found amygdala activity to be modulated in tandem with the regulation instruction (Hariri et al., 2003; Ochsner et al., 2002), with activation in this region inversely correlated with LPFC activity. Modulation of the ERP LPP component

has also been investigated recently (Kropfingger et al., 2008; Moser, Hajcak, Bukay, & Simons, 2006; Moser et al., 2009; Hajcak & Nieuwenhuis, 2006). In contrast to the fMRI studies, these studies provide evidence that LPP amplitude increases and decreases in tandem with regulation instructions. Thus, while fMRI has been sensitive to general control-related efforts, the LPP work has been more sensitive to the outcome of such efforts—a resulting increased or decreased response.

PRESENT STUDY

To address some of the limitations of previous work, the current study more comprehensively investigates relationships between cognitive control mechanisms and emotion by using an affective regulation task that requires enhancing, maintaining, and suppressing responses to both pleasant and unpleasant pictures. The design utilizes a fully random presentation order to replicate the format of earlier studies investigating peripheral physiological responses during emotion regulation tasks (cf. Jackson et al., 2000). Measures are organized along valence, arousal, and attention dimensions. Valence-based measures include: self-reported valence (SAM), corrugator (“frown”) EMG, zygomatic (“smile”) EMG, startle blink magnitude, and HR. Arousal-based measures include: self-reported arousal (SAM), skin conductance response (SCR), and the LPP ERP component. Attention allocation is measured via the P300 in response to the startle probe.

Here we briefly detail expected directions of responses on these measures, and how they will be interpreted. First, we predict Valence \times Instruction interactions across measures, such that responses on valence-based measures will increase following “enhance” instructions and will decrease (i.e., be closer to neutral) following “suppress” instructions for both pleasant and unpleasant stimuli. For responses on arousal-based measures, we will evaluate whether enhance and suppress instructions both produce increased responses (cf. effort or “cost” of emotion-regulation, Gross & Levenson, 1997) or whether instruction modulates responses (i.e., amplitude decreases following decrease instructions and increases following increase instructions—like the LPP effects that Moser et al. 2009 found). Attention-based probe P300 measures will index attention allocation across the time-course of the regulation efforts, with decreases in P300 anticipated when increased engagement with the foreground stimulus occurs.

METHOD

Participants

The current study recruited 68 participants from undergraduate psychology classes at the University of Minnesota and from an advertisement in the student newspaper. Eight participants were excluded from data analysis due to corrupted data, resulting in 60 participants for analysis (mean age = 21.66, $SD = 5.08$; 24 male). Participants were assessed via a screening questionnaire to be free of visual and hearing impairments. Prior to commencing the study, ethical approval was obtained and all participants provided informed, written consent. Participants were compensated with course credit or money.

Experimental Stimuli

Participants observed 140 pictures (60 pleasant, 60 unpleasant, 20 neutral) selected from the International Affective Picture System (IAPS; Center for the Study of Emotion and Attention, 1999).¹ Twenty pleasant and 20 unpleasant pictures were presented in each condition (enhance, view, and suppress) and the 20 neutral images were presented in the view neutral condition. Pictures were presented for 6 sec each in a counterbalanced and randomized manner as described below. Based on normative affective ratings, separate pictures sets were chosen for males and females to maximize the arousal and valence levels for each gender. Pleasant contents [valence: $M = 7.3$, $SD = .54$ (males); $M = 7.34$, $SD = .70$ (females); arousal: $M = 5.79$, $SD = 1.15$ (males); $M = 5.52$, $SD = .56$ (females)] included erotic themes ($N = 30$; e.g., nude individuals, intimate couples), food themes ($N = 15$; e.g., French fries, desserts) and nurturance themes ($N = 15$; e.g., human and animal infants). Unpleasant contents [valence: $M = 3.13$, $SD = .96$ (males); $M = 2.41$, $SD = .80$ (females); arousal: $M = 5.93$, $SD = .69$ (males); $M = 6.35$, $SD = .75$ (females)] included scenes of threat ($N = 30$; e.g., pointed guns, snakes), mutilation ($N = 15$, e.g., burn victims, severed hand) and contamination ($N = 15$; e.g., pollution, dead carcass). Neutral scenes [valence: $M = 4.95$, $SD = .23$ (males); $M = 4.96$, $SD = .24$ (females); arousal: $M = 2.51$, $SD = .46$ (males); $M = 2.57$, $SD = .42$ (females)] included household objects (e.g., hair dryer), buildings, or expressionless human faces. Regulation instructions consisted of the words “Enhance,” “Suppress,” or “View” presented on an otherwise black screen.

There is evidence that startle reflex modulation changes as a function of time. Specifically, Bradley, Cuthbert, and Lang (1993) demonstrated different startle modulation patterns for probes presented at 300 and 800 msec than probes presented at 1,300 and 3,800 msec. Accordingly, startle probes (50 msec, 105 dB, $<10 \mu\text{s}$ rise time) were presented in the current study at both early (300 and 800 msec) and late (3,000, 4,000, and 5,000 msec) time points after picture onset. Three probed trials were presented during a practice session prior to the experiment in order to familiarize participants with the stimuli and to habituate large initial startle responses (cf. Graham, 1979). Probes were also presented at varying times during the inter-trial interval (ITI) on a total of seven trials to decrease predictability.

Participants used the Self-Assessment Manikin (SAM; Lang, 1980) to report their affective responses to pictures. This measure included two nine-point indices on which participants rated

¹The 140 pictures, listed by their IAPS identification numbers, were as follows: erotic: 4599, 4608, 4650, 4659, 4660, 4670, 4677, 2352/4002, 2550/4003, 4470/4005, 4503/4142, 4510/4180, 4531/4210, 4532/4232, 4538/4250, 4550/4290, 4572/4300, 4603/4302, 4609/4310, 4610/4607, 4623/4631, 4640/4651, 4641/4652, 4656/4666, 4676/4669, 4680/4672, 4681/4683, 4687/4750, 4689/4770, 4810/4800; food: 7200, 7230, 7260, 7270, 7330, 7350, 7400, 7430, 7460, 7470, 7220/7250, 7282/7289, 7390/7291, 7410/7320, 7450/7480; nurturance: 1710, 2040, 2050, 2058, 2070, 2071, 2080, 2150, 2160, 1463/1440, 1722/1460, 2165/1750, 2260/1920, 2655/2311, 5831/2340; neutral: 2190, 2890, 5740, 7004, 7010, 7020, 7491, 2393/2200, 2440/2214, 2480/2870, 2575/5120, 5130/5390, 7000/5731, 7031/7080, 7036/7090, 7100/7110, 7140/7180, 7175/7233, 7500/7490, 7950/9700; threat: 1040, 1050, 1052, 1070, 1090, 1114, 1120, 1201, 1300, 1301, 1525, 5971, 5972, 6210, 6213, 6230, 6242, 6243, 6250, 6260, 6830, 1019/1110, 1051/1220, 1101/1302, 1113/1930, 1205/1931, 1932/6244, 6190/6840, 6410/9630; mutilation: 3053, 3063, 3064, 3069, 3080, 3120, 3130, 9410, 3051/3030, 3061/3060, 3062/3071, 3261/3100, 3266/3102, 9253/3110, 9420/3400; disgust - 2730, 2981, 9140, 9180, 9182, 9300, 9341, 9500, 9570, 1280/1274, 9008/9280, 9181/9290, 9301/9340, 9330/9520, 9571/9560. Pairs with slashes between them represent parallel items seen by females/males; items without slashes were seen by both genders.

how pleasant/unpleasant and arousing/calming they found each picture. Lower scores on the valence scale indicate that images were rated as more pleasant; lower scores on the arousal scale indicate that images were more calming. In the interest of brevity, affective ratings were only obtained for 30% of the images (42 pictures) for each person.

Stimulus Delivery and Physiological Response Measurement

Twenty-four stimulus orders (12 for each gender) were used to balance the presented stimuli. Within each stimulus order, regulation instruction type, startle probe onset, and normative affective ratings were distributed equally across valence category and proportionately across content category. As an exception, neutral pictures were only presented within the view condition, so as not to confuse participants by asking them to regulate responses to a non-affective picture. In addition, affective ratings were also distributed equally across instruction type. Stimuli were rotated across orders so that each individual picture was represented in every instruction category (except for neutral), probed at every onset time, and rated for affective response at least once. No more than two trials containing the same valence category, regulation instruction, startle probe onset or affective rating were presented consecutively.

All images were presented on a 21" computer monitor placed 100 cm away from the participants' eyes. Two IBM-compatible computers were used during data collection. One utilized E-prime software (Psychology Software Tools) to deliver stimuli and collect affective rating data. The other used Neuroscan Acquire software to acquire physiological data with a 64-channel Neuroscan SynAmps amplifier. A Neuroscan Quick-cap was used to measure EEG/ERP responses from AF3, FP1, FP2, AF4, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC3, FC1, FCZ, FC2, FC4, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, TP7, CP3, CP1, CP2, CP4, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO5, PO3, POZ, PO4, PO6, O1, OZ, and O2, following the 10–20 system. The midline electrode AFZ was used as a ground. CPZ was used as an online reference during the recording. During post-processing, the data were re-referenced to an average mastoid reference offline and CPZ was recovered. Impedances were kept below 10 KOhms. Signals were recorded at a sampling rate of 500 Hz with an on-line analog bandpass filter of .05–100 Hz. Facial EMG activity and eyeblink startle were measured with Med Associates .25 cm Ag-AgCl electrodes on the orbicularis oculi (left eye), zygomaticus major (left cheek), corrugator (left eye). Both electrocardiogram (left and right forearms) and skin conductance (palmar surface of the non-dominant hand) were measured with pairs of 1 cm Med Associates Ag-AgCl electrodes. All sensors were filled with electrolyte paste, except for the sensors placed on the palm to record skin conductance. These were filled with 0.05-m NaCl unibase paste.

Procedure

To closely replicate Jackson et al. (2000), we obtained and used their regulation instructions. The aim was to encourage participants to use cognitive reappraisal strategies as articulated by Gross (1998b). In short, participants were told that before a picture was presented, they would be instructed to enhance, suppress, or view the emotion they felt toward the picture. To enhance the emotion, they were asked to increase the intensity of emotion they felt. To suppress the emotion, they were instructed to decrease the intensity of emotion they felt. Suppress, as operationalized

here (and in Jackson et al., 2000), corresponds to a reappraisal strategy (cf. Gross, 1998b). In addition, it was explained that participants would sometimes be asked simply to view pictures, in which case they were not to attempt to manipulate their emotions. In all cases they were advised to stay focused on the picture and the induced emotion. Incorrect methods of regulation were described as generating unrelated emotions, thinking of things unrelated to the picture, looking away from the picture, or only focusing on parts of the picture. A demonstration of the SAM ratings system also preceded the task. A practice session including three example pictures allowed participants to rehearse the instructional conditions and the rating system. Regulation strategies were discussed to ensure that strategies used were consistent with cognitive reappraisal.

For all 140 trials, a fixation point appeared randomly for 2 or 3 sec before a screen containing the regulation instruction appeared for 6 sec. Immediately after the instruction screen, the picture stimulus was presented for 6 sec. On 42 of these trials, a ratings display appeared after picture offset. For all trials, the beginning of the baseline period for the next picture lasted 3,500 msec.

Data Reduction

Corrugator and zygomatic EMG data were first high-pass filtered at 10 Hz with a 3rd order Butterworth filter, rectified, and then passed through a single-pole recursive IIR filter (cf. “leaky-capacitor” filter), with a 120 msec time constant. EMG responses were then measured as the difference in mean activity during the 6 sec picture presentation compared with that during a 1 sec pre-stimulus baseline. Like EMG, raw startle blink EMG data were first high-pass filtered at 10 Hz with a 3rd order Butterworth filter, rectified, and then passed through a single-pole recursive IIR filter, but with a shorter 30 msec time constant (due to the rapid rise of startle; cf. Bernat et al., 2006). The resulting startle blink activity was measured as the difference between peak orbicularis activity 15–120 msec post-probe onset and the median of a 50 msec pre-stimulus baseline; negative values were scored as zero. Startle blink values were then converted to *t* scores separately for each participant [$t\text{-score} = 50 + (z\text{-score} * 10)$; $z\text{-score} = \text{raw blink} - \text{mean}(\text{raw blinks}) / SD(\text{raw blinks})$] to create standardized scores with a mean of 50 and a standard deviation of 10 (cf. Bradley, Codispoti, Cuthbert et al., 2001; Levenston, Patrick, Bradley, & Lang, 2000). SCR was measured from the onset to peak of the response within a .9–4 sec window following picture onset. SCR values were log transformed ($\log(\text{SCR} + 1)$) to normalize the data, and then scored by visual inspection as just described. Cardiac R-spikes were detected and converted to beats per minute (bpm) estimates for successive 500-msec intervals prior to and during each picture presentation. HR reactions to pictures were measured as the peak acceleration (positive peak within a 3–6 sec window relative to peak deceleration within a 0–3 sec window).

EEG activity to the onset of the picture presentation was reduced to an epoch from 500 msec pre-onset to 1,500 msec post-onset and adjusted off-line for vertical and horizontal ocular artifacts (Semlitsch, Anderer, Schuster, & Presslich, 1986). Trials with startle probes presented within the epoch (i.e., 300 and 800 msec post-probe onset) were not included. Within this activity, an LPP component was defined for statistical analysis as the average activity between 470 and 1,000 msec post-picture onset at electrode site Pz. EEG activity to the onset of the startle probe was reduced to an epoch from 150 msec pre-probe onset to 600 msec post-onset. A P300 component was then defined within this activity as the average amplitude between 250 to 375 msec post-probe onset at electrode site Pz. This component was defined separately for startle probes presented at 300, 800, 3,000, 4,000, and 5,000 msec post-picture onset (5 trials

for each cue/valence condition). For statistical analysis, activity from startle probes presented at 3,000, 4,000, and 5,000 msec post-picture onset were averaged together. Each dependent measure was averaged within each valence category (pleasant, neutral, unpleasant) and each regulation instruction (enhance, view, suppress).

For the 140 stimuli, averaging was conducted within each 20-stimulus valence/instruction set. Within-set averages were defined for each content type. Pleasant consisted of 5 food, 5 nurture, and 10 erotic items split into even groups of 5. Unpleasant had 5 mutilation, 5 contamination, and 10 threat items split into even groups of 5. Neutral stimuli were split randomly into 5-item sets. For peripheral physiological recordings (startle blink, SCR, EMG, and HR), measures were taken from trial level data, and then averaged. For EEG recordings, data were averaged first, and then measurements taken. It is worth noting that for EEG/ERP work, and to a lesser degree, for peripheral physiological measures, a maximum of 5 trials per average can be considered a small number. It is thus possible that our power to detect significant effects would have been greater if we had included more trials in the task. However, it is critical to be clear that the number of trials per average was equal across conditions and stimulus categories.

Statistical Analysis

A series of analyses of variance (ANOVA) were conducted separately for each dependent measure, including valence and arousal ratings; repeated measures ANOVAs were conducted for measures that yielded data at multiple time points. For each analysis, omnibus main effects are reported using Wilks' multivariate statistic (Λ).

The first set of one-way ANOVAs included a 3-level Valence factor (pleasant, neutral, unpleasant) for trials from the view condition only. Omnibus analyses were followed by planned orthogonal linear (pleasant vs. unpleasant) and quadratic (pleasant/unpleasant vs. neutral) contrasts and simple effects analyses.

A second set of two-way ANOVAs included a 2-level Valence factor (pleasant, unpleasant) and a 3-level Instruction factor (enhance, view, suppress). These analyses excluded neutral pictures, which were only presented during the view instruction, and thus could not be evaluated for effects of Instruction. Omnibus instruction effects were decomposed using orthogonal planned linear (enhance vs. suppress) and quadratic (enhance/suppress vs. view) contrasts.

Results are reported first for valence-based dependent measures (i.e., valence ratings, corrugator and zygomatic EMG, startle blink, and HR), followed by arousal-based dependent measures (i.e., arousal ratings, skin conductance, and the LPP). Finally, modulations in attentional processing are reported (i.e., startle probe P300).

Gender was also assessed as a covariate in these analyses, with largely non-significant results, none of which affect the primary inferences.² In addition, a preliminary 3-level Instruction \times 3-level Time (300 msec, 800 msec, 3–5 sec) analysis was performed for the startle reflex and

²For corrugator, a significant main effect for Gender, $F(1,58) = 9.38, p < .003$, revealed greater overall activity for females than for males. A significant Valence \times Gender interaction, $F(2,57) = 4.11, p < .022$, revealed that females displayed greater activity during the unpleasant pictures than males and males showed greater attenuation of activity during the pleasant pictures than females. For SCR, a significant main effect for Gender, $F(1,58) = 8.40, p < .005$, revealed that males showed greater overall SCRs than females. For startle-probe P300, there was a significant Instruction \times Gender interaction $F(2,57) = 5.25, p < .008$, in which females showed greater overall P300 amplitudes than males while suppressing, while males and females showed similar P300 amplitudes while enhancing.

startle probe P300 to ascertain whether cognitive control results varied according to the time course of the startle probe. Where omnibus findings were significant, separate analyses were conducted for each time point. To characterize the topographical distribution of the Valence and Instruction effects, topographical maps were constructed for LPP and startle probe P300 results. These represent the statistical significance of paired *t*-test comparisons at each electrode.

RESULTS

Statistical comparisons are presented for valence measures in Table 1, for arousal measures in Table 2, and for attention allocation measures in Table 3. Means and simple effects analyses for the various measures are presented in figures as follows: corrugators and zygomatic facial muscle measures in Figure 1, startle-blink and HR in Figure 2, SCR in Figure 3, LPP in Figure 4, and the probe-P300 in Figure 5.

Valence Measures

Valence ratings. For the one-way ANOVA conducted within the view condition, a significant omnibus main effect for the 3-level Valence term was best described by a linear pattern; ratings for pleasant pictures ($M = 2.95$, $SD = .88$) were significantly lower than those for neutral pictures ($M = 4.80$, $SD = .56$), $F(1,59) = 236.21$, $p < .001$, which were lower, in turn, than those for unpleasant pictures ($M = 7.21$, $SD = .89$), $F(1,59) = 393.59$, $p < .001$. Unpleasant-neutral differences were significantly larger than pleasant-neutral differences when directly compared ($F(1,59) = 11.70$, $p < .001$), although this difference was small relative to the highly significant unpleasant-neutral ($F(159) = 393.59$, $p < .001$) and pleasant-neutral ($F(1,59) = 236.21$, $p < .001$) differences separately.

The 2-way (Valence \times Instruction) ANOVA yielded main effects for both valence and instruction that were qualified by a significant interaction. Decomposition of this interaction with linear contrasts indicated that pleasant pictures were rated as more pleasant during the enhance ($M = 2.58$, $SD = .81$) than the suppress ($M = 3.54$, $SD = .90$) condition, and unpleasant pictures were rated as more unpleasant during the enhance ($M = 7.43$, $SD = .85$) than the suppress ($M = 7.27$, $SD = .93$) condition.

Corrugator EMG. One-way ANOVA results indicated a significant omnibus main effect for overall corrugator EMG response; planned contrasts yielded evidence of a linear effect, with stronger responses to unpleasant than pleasant pictures.

For the 2-way ANOVA, there was a significant omnibus main effect for valence, qualified by a significant Valence \times Instruction interaction. A linear contrast decomposing this interaction showed that unpleasant pictures evoked significantly greater corrugator EMG responses during the enhance condition than the suppress condition; pleasant pictures elicited smaller EMG responses during the enhance condition than the suppress condition.

Zygomatic EMG. Although there was no significant omnibus main effect for Valence in the view condition alone, pleasant pictures evoked nominally greater activity than unpleasant pictures.

TABLE 1
F Values and Significance Levels From Repeated Measures ANOVAs (Omnibus Effects and Univariate Linear and Quadratic Contrasts)

<i>Model</i>	<i>Effect/Contrast</i>	<i>df</i>	<i>Valence Ratings</i>	<i>Corrugator</i>	<i>Zygomatic</i>	<i>Startle Blink (3–5 sec)</i>	<i>df(Heart Rate)</i>	<i>Heart Rate</i>
<i>Valence (view)</i>	Valence (PI ¹ /Neu ² /Unpl ³)	2,58	288.70***	4.41*	1.81	31.74***	2,56	3.48*
	PI vs. Unpl	1,59	577.26***	7.84**	1.25	55.30***	1,57	6.57*
	PI/Unpl vs. Neu	1,59	11.70***	4.06*	2.28	14.47***	1,57	<1
<i>Valence × Instruction (neutral excluded)</i>	Valence (PI/Unpl)	1,59	661.62***	13.30***	11.44***	114.50***	1,57	17.99*
	Instruction (Enh ⁴ /View/Sup ⁵)	2,58	22.36***	<1	7.85**	18.15***	2,56	17.21***
	Enh vs. Sup	1,59	39.40***	1.69	13.91***	36.82***	1,57	35.03***
	Enh/Sup vs. View	1,59	4.44*	<1	<1	1.70	1,57	2.21
	Instruction × Valence	2,58	27.16***	5.35**	8.09***	<1	2,56	<1
	Valence × Enh-Sup	1,59	52.38***	9.62**	14.95***	<1	1,57	<1
	Valence × Enh/Sup ⁻ View	1,59	<1.0	<1	7.85**	1.40	1,57	<1
				<i>SCR</i>	<i>LPP</i>	<i>Probe P300 (800 msec)</i>	<i>Probe P300 (3–5 sec)</i>	
<i>Valence (view)</i>	Valence (PI/Neu/Unpl)	2,58	61.99***	3.04+	16.21***	2.40+	9.57***	
	PI vs. Unpl	1,59	13.37***	1.30	<1	<1	2.68	
	PI/Unpl vs. Neu	1,59	123.09***	5.50*	32.37**	3.63+	16.29***	
<i>Valence × Instruction (neutral excluded)</i>	Valence (PI/Unpl)	1,59	20.79***	2.77	<1	<1	7.76**	
	Instruction (Enh/View/Sup)	2,58	18.73***	6.52**	2.73+	4.32*	11.45***	
	Enh vs. Sup	1,59	34.24***	1.94	1.83	<1	23.12***	
	Enh/Sup vs. View	1,59	7.32**	9.03**	5.41*	7.78**	<1	
	Instruction × Valence	2,58	<1	<1	<1	<1	<1	
	Valence × Enh-Sup	1,59	<1	<1	<1	<1	2.02	
	Valence × Enh/Sup ⁻ View	1,59	<1	<1	<1	<1	<1	

¹Pleasant; ²Neutral; ³Unpleasant; ⁴Enhance; ⁵Suppress.
 +*p* < .10; **p* < .05; ***p* < .01; ****p* < .001.

TABLE 2
F Values and Significance Levels From Omnibus Main Effects and Univariate Linear and Quadratic Contrasts From Repeated Measures ANOVAs for Self-reported Arousal, Skin Conductance and LPP

ANOVA	Effect	Contrast	df	Arousal Ratings	SCR	LPP
<i>Valence (view)</i>	Valence (Ple. ¹ /Neu. ² /Unp. ³)	Ple. vs. Unp.	2, 58	61.99***	3.04+	16.21***
			1, 59	13.37***	1.30	<1
		Ple./Unp. vs. Neu.	1, 59	123.09***	5.50*	32.37**
<i>Valence × Instruction (neutral/view condition excluded)</i>	Valence (Ple./Unp.)		1, 59	20.79***	2.77	<1
	Instruction (Enh. ⁴ /View/Sup. ⁵)	Enh. vs. Sup.	2, 58	18.73***	6.52**	2.73+
			1, 59	34.24***	1.94	1.83
		Enh./Sup. vs. View	1, 59	7.32**	9.03**	5.41*
	Instruction × Valence		2, 58	<1	<1	<1
		Val × Enh.-Sup.	1, 59	<1	<1	<1
Val × Enh./Sup.-View		1, 59	<1	<1	<1	

¹Pleasant; ²Neutral; ³Unpleasant; ⁴Enhance; ⁵Suppress.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

TABLE 3
F Values and Significance Levels From Omnibus Main Effects and Univariate Linear and Quadratic Contrasts From Repeated Measures ANOVAs for Probe P300

ANOVA	Effect	Contrast	df	Probe P300 (800 msec)	Probe P300 (3–5 sec)
<i>Valence (view)</i>	Valence (Ple. ¹ /Neu. ² /Unp. ³)	Ple. vs. Unp.	2, 58	2.40+	9.57***
			1, 59	<1	2.68
		Ple./Unp. vs. Neu.	1, 59	3.63+	16.29***
<i>Valence × Instruction (neutral/view condition excluded)</i>	Valence (Ple./Unp.)		1, 59	<1	7.76**
	Instruction (Enh. ⁴ /View/Sup. ⁵)	Enh. vs. Sup.	2, 58	4.32*	11.45***
			1, 59	<1	23.12***
		Enh./Sup. vs. View	1, 59	7.78**	<1
	Instruction × Valence		2, 58	<1	<1
		Val × Enh.-Sup.	1, 59	<1	2.02
Val × Enh./Sup.-View		1, 59	<1	<1	

¹Pleasant; ²Neutral; ³Unpleasant; ⁴Enhance; ⁵Suppress.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

In the 2-way (Instruction × Valence) ANOVA for zygomatic EMG, significant main effects for both instruction and valence were qualified by a significant interaction. Increased activity was evident during the enhance condition relative to the suppress condition for pleasant pictures. Unpleasant pictures showed the same pattern in the significant linear contrast for instruction and simple effects analyses, but effects were weaker.

Startle blink. The initial repeated measures ANOVA revealed a significant main effect of Time, $F(2,57) = 41.82$, $p < .001$, qualified by Time × Valence, $F(2,57) = 3.54$, $p < .04$, and

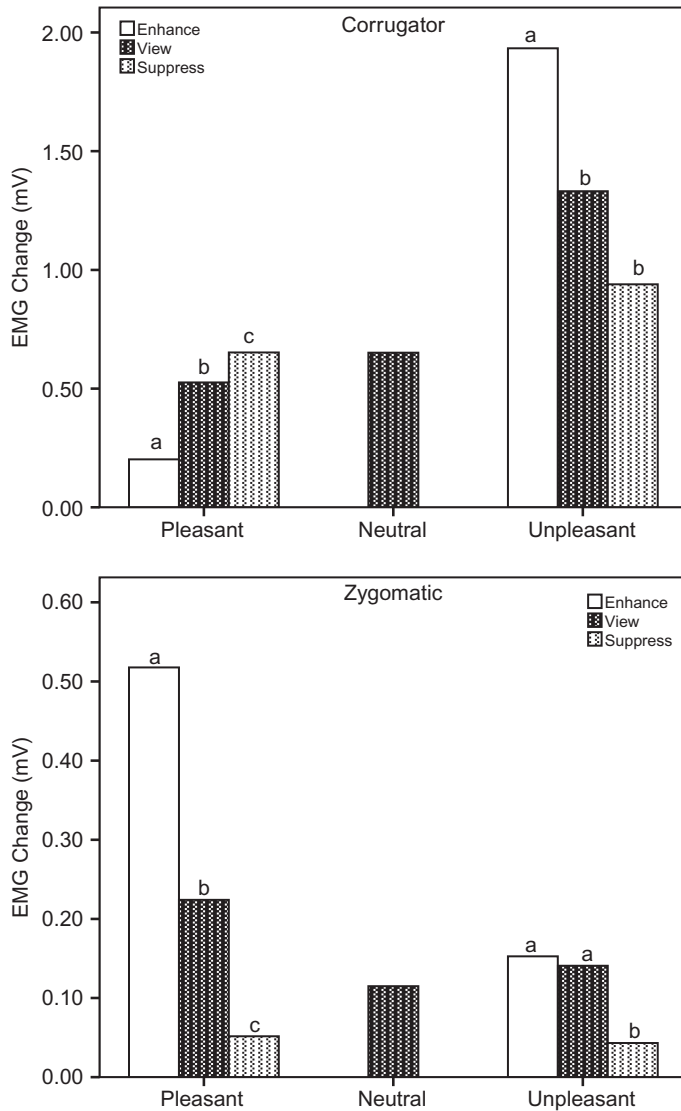


FIGURE 1 Bar charts depicting mean corrugator (upper panel) and zygomatic (lower panel) electromyography (EMG) responses under enhance, view, and suppress instructional cues, in reaction to pleasant, neutral, and unpleasant stimuli. Within pleasant and unpleasant clusters separately, bars that share no letters are significantly different. For valence comparisons, corrugator responses were larger to unpleasant than pleasant stimuli and zygomatic responses were larger to pleasant stimuli. Discrepant effects of instructional cue for responses to pleasant and unpleasant stimuli are apparent for corrugator. Zygomatic responses are in the same direction for pleasant and unpleasant stimuli, but are larger for the pleasant.

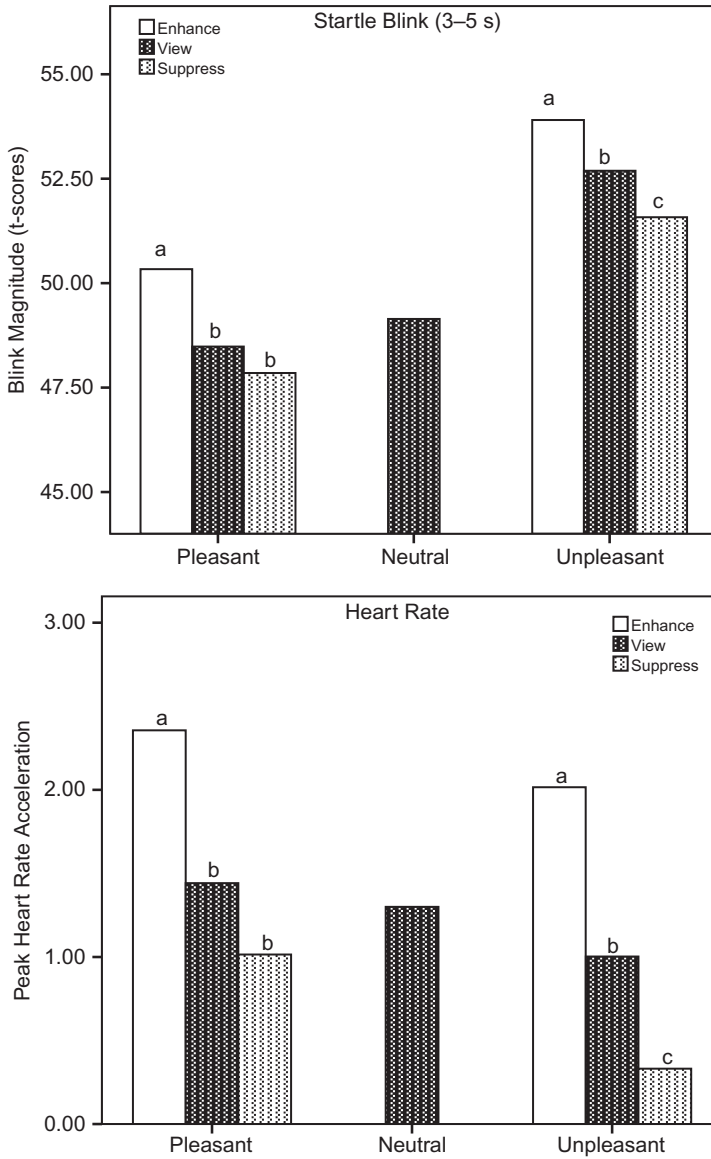


FIGURE 2 Bar charts depicting mean startle blink magnitude (upper panel) and peak heart rate (HR) acceleration (lower panel) for the same conditions and stimulus categories as Figure 1. Within pleasant and unpleasant clusters separately, bars that share no letters are significantly different. For valence comparisons, mean responses to unpleasant stimuli were larger than pleasant for the startle, and pleasant greater than unpleasant for zygomatic. The effect of instructional cue was the same for pleasant and unpleasant and for both startle and HR—enhance was associated with increases and suppress with decreases.

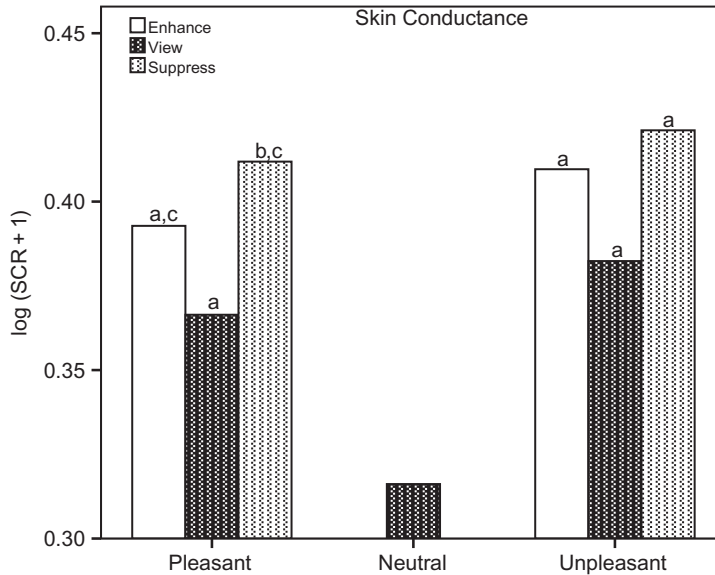


FIGURE 3 Bar chart depicting mean skin conductance response for the same conditions and stimulus categories as Figure 1. Within pleasant and unpleasant clusters separately, bars that share no letters are significantly different. For valence, mean response for pleasant and unpleasant are greater than neutral. For instructional cure, both enhance and suppress have greater mean response than view.

Time \times Instruction, $F(4,55) = 3.73$, $p < .009$, interactions. Subsequent analyses thus looked at each time point separately.

In the one-way ANOVA for Valence in the view condition alone, the two early probe times (300 and 800 msec) produced no significant effects; similarly, early probe times yielded no significant Instruction or Instruction \times Valence effects in the 2-way ANOVA.

For startle probes presented at 3–5 sec post-picture onset, there was a significant omnibus main effect for Valence in the view condition. Significant linear contrast results indicated that startle blink magnitude was greater while viewing unpleasant pictures than while viewing pleasant pictures. Two-way ANOVA results for later probe times (3–5 sec) indicated a significant omnibus main effect for Instruction. Results of a linear contrast showed that startle blink magnitude was increased during the enhance relative to the suppress condition for both unpleasant and pleasant pictures.

Heart rate (HR). The one-way ANOVA within the view condition yielded a significant omnibus main effect of Valence, with pleasant pictures evoking greater peak HR acceleration than unpleasant pictures. The 2-level Valence term (excluding the neutral-view condition) also evidenced significantly greater acceleration for pleasant versus unpleasant pictures. Cognitive control of emotional responses was best depicted in a significant omnibus main effect and linear contrast for the Instruction term. Average peak HR acceleration was greatest during the

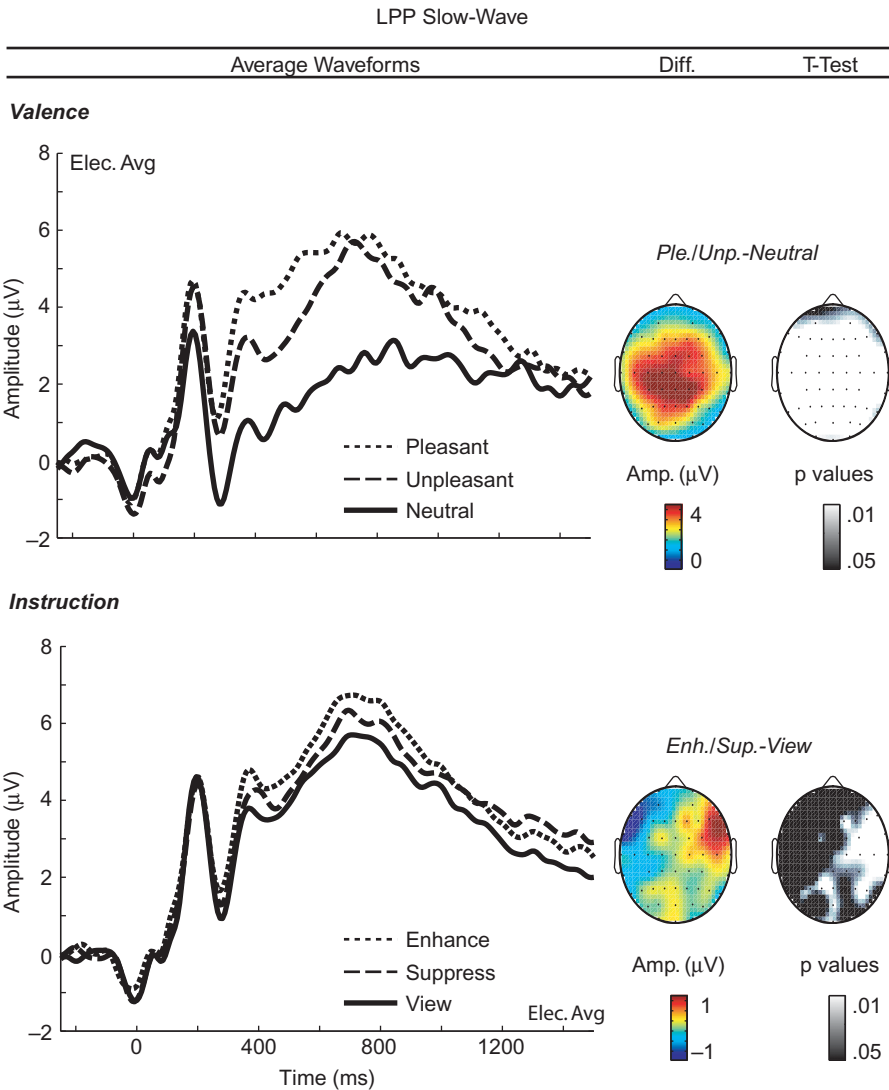


FIGURE 4 Grand average waveforms (across electrodes) and topographical distributions of the late positive potential (LPP)/slow-wave measures are depicted for both valence (upper panel) and instructional (lower panel) effects. For valence, increases for pleasant and unpleasant relative to neutral are readily apparent in the waveforms. Topographical distribution of the mean difference is depicted in the color topographic map, which indicates that this effect has a centro-parietal distribution. Topographical distribution of the statistical evaluation (t -tests) is given in the black and white topographic map, which indicates that this effect was significant across most of the recorded sites. For instructional cue, increases for enhance and suppress relative to view are apparent in the waveforms. Topographic distribution of the differences indicate that the differences are maximal over right-frontal regions. Topographic distribution of statistical evaluation indicates that differences are significant primarily in these same right-frontal areas. (color figure available online)

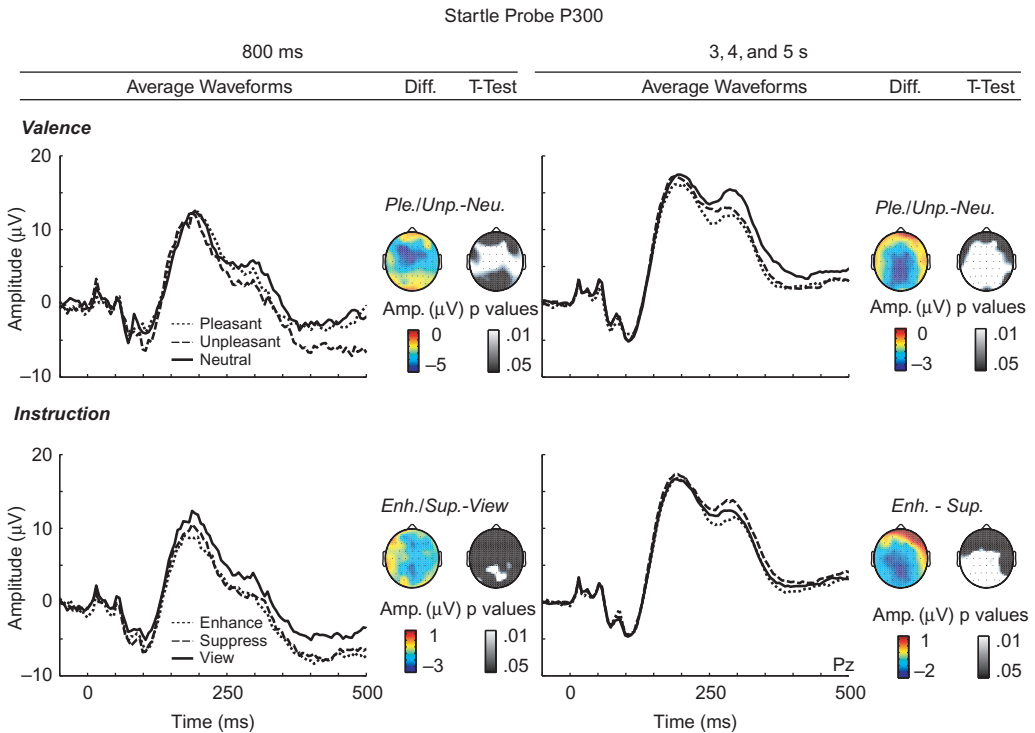


FIGURE 5 Grand average waveforms (across electrodes) and topographical distributions of the startle probe P300 measures are depicted for the early probe time (800 msec) in the left column and for the later probe times (3, 4, and 5 sec) in the right column. These are divided into valence effects (upper row) and instructional cue effects (lower panel). For valence, pleasant and unpleasant stimuli were associated with reduced mean startle probe P300 amplitudes for both the early and later probe times, as can be seen in the average waveforms. This difference is more anterior for the early probe time and more centro-parietal for the later probe time as can be seen in the difference and statistical topographic maps. For instructional cue, enhance and suppress instructions are associated with reduced mean amplitude at the early probe time, although isolated to the parietal region around the Pz site. For the later probe times, on the other hand, enhance produced reductions in mean amplitude while suppress produced increases in mean amplitude, which was distributed broadly across centro-parietal areas. (color figure available online)

enhance condition and smallest in the suppress condition for both pleasant and unpleasant pictures.

Arousal Measures

Arousal ratings. For the one-way ANOVA conducted within the view condition, there was a significant omnibus main effect of the 3-level Valence term within the view condition that was

mainly characterized by the quadratic effect, with both pleasant ($M = 4.88$, $SD = 1.27$) and unpleasant pictures ($M = 5.59$, $SD = 1.13$) being rated as more arousing than neutral pictures ($M = 3.44$, $SD = 1.35$). Unpleasant-neutral differences were significantly larger than pleasant-neutral differences when directly compared, $F(1,59) = 13.37$, $p < .001$, although this difference was small relative to the highly significant unpleasant-neutral, $F(1,59) = 112.51$, $p < .001$, and pleasant-neutral, $F(1,59) = 68.96$, $p < .001$, differences.

For the 2-way ANOVA, a significant omnibus main effect was evident for Instruction, suggesting that arousal ratings varied across conditions of cognitive control. There was a significant linear trend for this main effect, such that ratings were higher under the enhance condition and lower under the suppress condition for both pleasant (enhance: $M = 5.83$, $SD = 1.25$; suppress: $M = 4.71$, $SD = .99$) and unpleasant pictures (enhance: $M = 6.06$, $SD = 1.06$; suppress: $M = 5.54$, $SD = 1.18$).

Skin conductance. The omnibus main effect of Valence in the view condition reached only trend-level significance, but a significant quadratic contrast indicated that combined pleasant and unpleasant pictures evoked greater skin conductance than neutral pictures. In the 2-way ANOVA, the omnibus main effect and quadratic contrast for the Instruction term were significant. This indicates that skin conductance was increased during both enhance and suppress conditions relative to view when averaging responses across pleasant and unpleasant pictures.

LPP amplitude. A significant omnibus main effect of Valence in the view condition was found for the LPP component (see Figure 4). The quadratic contrast was significant, while the linear was not. This reflects greater overall amplitude for pleasant and unpleasant pictures relative to neutral, with no differences between pleasant and unpleasant stimuli. In the 2-way ANOVA, a significant omnibus main effect of Instruction was observed (see Figure 4), along with a significant quadratic contrast, indicating that greater overall LPP amplitudes were produced while enhancing and suppressing relative to viewing across pleasant and unpleasant picture presentations.

Attentional Processing

Startle probe P300. The initial repeated measures 2-way ANOVA revealed a significant Time main effect, $F(2,58) = 89.43$, $p < .001$, and Instruction \times Time interaction, $F(4,56) = 2.70$, $p < .04$; subsequent analyses thus assessed each time point separately. There were no significant effects found for P300 amplitudes to startle probes presented at 300 msec post-picture onset, and these were not assessed further. P300 amplitudes to startle probes presented at 800 msec post-picture onset evidenced a trend-level effect for Valence (quadratic contrast, Pleasant/Unpleasant $>$ Neutral) at the assessed electrode (Pz), as presented in Table 1. However, anterior regions evidenced broad significance for this effect (see Figure 5), indicating that both affective stimulus types produced decreases during the P300 at anterior sites. Next, a significant omnibus main effect and quadratic contrast for the Instruction term revealed that P300 amplitude was smaller within both suppress and enhance conditions than in the view condition across pleasant and unpleasant pictures, at the 800 msec probe time. P300s at later probe times (3–5 sec) were significantly modulated by picture valence in the same directions as those at early probes (see Table 1), but with a more parietal topographical distribution (see Figure 5). A significant

omnibus main effect for Instruction was characterized by a significant linear trend indicating that P300 amplitudes were smaller under the enhance condition than the suppress condition across pleasant and unpleasant contents.

DISCUSSION

The current study goals were to replicate and extend findings observed in emotion-regulation tasks (cf. Jackson et al., 2000; Dillon & Labar, 2005) by including a variety of physiological measures, both pleasant and unpleasant stimulus conditions, and both enhance and suppress instructions in a fully randomized design. Measures of subjective and physiological responding were categorized into valence, arousal, and attentional indices, providing a way to assess coordinated patterns associated with control efforts during the experimental task. Responses on most measures were modulated based on instruction-related regulation efforts. However, hypothesized valence by instruction interactions (which would support inferences that regulation efforts modulated underlying affective responses) were limited to more superficial systems: subjective ratings and expressive facial muscle measures. Thus, findings from the current study suggest that modulation of “bottom up” emotion processes either did not occur, or only occurred at the level of overall activation. Findings were consistent with the idea that modulations in arousal or effort involved in implementing the regulation instructions were observed, rather than core systems indexing bipolar, valenced, affective reactivity (e.g. fear/defense for startle).

Summary of Results

Findings regarding overall affective responding (i.e., comparison of responses to pleasant, neutral, and unpleasant stimuli in the View condition) were consistent with previous work. Specifically, stimulus hedonic valence was associated with predicted differences in self-reported experience of valence (pleasant < neutral < unpleasant), corrugator EMG (unpleasant > neutral > pleasant), startle reflex (unpleasant > neutral > pleasant), and HR acceleration (pleasant > neutral > unpleasant). The zygomatic EMG response increased as expected during viewing of pleasant relative to neutral pictures; unexpectedly, unpleasant pictures evoked modest increases as well. While this change was not in the predicted direction, it is consistent with findings from past research of small increases in zygomatic EMG responses to unpleasant pictures (Greenwald, Cook, & Lang, 1989; Lang et al., 1993) reflecting globally increased muscle tension during unpleasant experiences that includes some zygomatic activation while grimacing. Stimulus arousal level was associated with predicted differences in self-reported experience of arousal (unpleasant/pleasant > neutral), skin conductance (unpleasant/pleasant > neutral), and LPP (unpleasant/pleasant > neutral). Finally, as previously reported, startle probe P300 was associated with decreased attention toward the startle probe during processing of emotional stimuli (unpleasant/pleasant < neutral). Together, these effects support the conclusion that affective modulation of the measures included in this study was operating in a typical manner.

The effects of control efforts (instructional cue) were not uniform across the assessed measures. The present findings thus provide new information about relationships between these efforts and affective responding, as indexed by both valence-based and arousal-based measures. Because effective regulation of responses on valence-based measures is hypothesized to produce

Valence \times Instruction interactions, significant interactions provide a basis for inferences that control efforts effectively modulated affective responding. Results for subjective valence ratings were consistent with such inferences. Specifically, on the nine-point bipolar valence scale, increase instructions were associated with ratings farther from neutral (higher for unpleasant and lower for pleasant), than those for decrease instructions, which were associated with pleasant and unpleasant ratings that were closer to neutral.

Findings for the corrugator EMG paralleled those of the subjective valence ratings. Corrugator activity evidenced hypothesized, significant, and inverse instruction effects for pleasant and unpleasant stimuli (an Instruction by Valence interaction), suggesting that corrugator activity robustly reflects affective modulation due to emotion regulation efforts. Activity of the zygomatic EMG was also consistent with an inference of cognitive control of affective response, given that the increase/decrease cue was associated with increased and decreased activity, respectively, if only for pleasant stimuli. Thus, particularly for the appropriate valence (unpleasant for corrugator and pleasant for zygomatic), both EMG channels provided evidence suggesting that cognitive control of affective responding did occur.

The startle blink reflex and HR measures also represent valence-based indices of affective responding, where startle is typically increased for unpleasant stimuli, and HR for pleasant stimuli. However, hypothesized Valence \times Instruction interactions were not observed for either of these measures. Instead, only main effects were observed, for Instruction and Valence. For both measures, increase instructions produced greater responses while decrease instructions produced smaller responses, relative to the view instruction. This pattern of findings supports the view that responses during these measures were affected by control efforts; however, this modulation was consistent across stimulus valence types. We will return to this point, particularly for the startle reflex, which has been central to research about cognitive control of affect.

Arousal-based measures all evidenced main effects related to control efforts, with no Instruction by Valence interactions. Both increase and decrease instructions were associated with increased skin conductance and LPP relative to view instructions, regardless of picture type. The absence of interaction effects necessitates more tentative inferences about affective modulation due to control efforts than those for valence measures; the uniformity of responses within instruction sets across picture valence raises the possibility that affective modulation was driven by processes other than affect (e.g., attention). For self-reported arousal, attempts to enhance responses to both pleasant and unpleasant stimuli led to increased ratings, whereas ratings decreased during suppression of affective responding. Skin conductance activity and amplitude of the LPP component (including right frontal regions) were increased during attempts to both enhance and suppress both types of affective responses. We suggest that arousal ratings represent an outcome of successful control efforts, whereas skin conductance and right-frontal slow-wave (LPP) differences represent constituent processes of regulation, such as effort or attention.

Attention allocation, assessed via P300 amplitude to startle-noise probes, differed across cognitive control instructions. This modulation varied as a function of time, but not as a function of stimulus valence. P300 amplitude was decreased while implementing both types of cognitive control strategies, relative to viewing, during the early probe time (i.e., 800 msec), whereas P300 amplitude differed between up and down regulation (enhance < view < suppress) during later probe times (3–5 sec).

Implications

Overall, cognitive control showed significant relationships to responses on all affective measures. However, the nature of these relationships varied across affective output domains. Subjective emotional experience (ratings), as well as expressive emotion indicators (facial EMG), both changed in concordance with attempts to implement cognitive control. This is consistent with previous research demonstrating both modulation of corrugator EMG during aversive picture viewing based on regulation instructions (Jackson et al., 2000), and inhibition of affective experience and overt expressive behavior following instructions to reinterpret emotional stimuli as less emotional (Gross & Levenson, 1993, 1997; Gross, 1998b).

The pattern of results for startle and HR measures differed from those for facial EMG and valence ratings. Specifically, identical rather than opposing effects of instructional cue were found for pleasant and unpleasant pictures: the enhance instruction increased startle and HR responses and the suppress instruction attenuated startle and HR responses for *both* unpleasant and pleasant pictures. These findings replicate results from earlier work that assessed startle blink responses during both pleasant and unpleasant picture stimuli (Dillon & Labar, 2005), and extend these findings to include HR.

The effects for HR and startle suggest differential effects of enhance and suppress instructions on some component of activation distinct from sympathetic and cortical activation. Consistent with Lacey's (1967) observation of similar directional fractionation between cardiac and sympathetic reactions in situations involving inner-focused mental effort versus outer-directed perceptual processing, the effects for HR in the current study could reflect assumption of a deep mentative set involving elaborative imaginal processing of picture content during increase trials and adoption of a more externally focused, perceptual scanning set during suppress trials. Results from the startle-probe P300 (3–5 sec) are also consistent with this idea. Enhance instructions were associated with smaller probe P300 (indicating attention was less available for probe processing and presumably engaged by the stimulus) relative to suppress instructions, which were associated with larger probe P300 (indicating more attention was available to process the probe).

Earlier research has shown that imagery of affective material, whether pleasant or unpleasant, produces increases in startle (as well as HR) response compared with imagery of neutral material (e.g., Miller et al., 2004). Similarly, increases in mental effort lead to progressive increases in both startle response and HR activity levels (Panayiotou & Vrana, 1998), and activity in neural regions implicated in emotion or fear (e.g., the amygdala) also emerges during cognitive processes including working memory (Schaefer et al., 2006) and learning (Holland & Gallagher, 1999). Indeed, some theorists now suggest that the amygdala may best be understood as a system for general, rather than fear-specific, relevance detection (Sander, Grafman, & Zalla, 2003). Taken together, these bodies of research provide a foundation for speculation that changes in both the startle reflex and HR reflect the modulation of cognitive variables, such as engagement and response mobilization, as a function of cognitive control, rather than changes in bipolar affective valence.

Cognitive control modulated both skin conductance and electrocortical activity (i.e., the LPP/slow-wave) in a similar fashion, such that both measures showed increased amplitude during attempts to both enhance and suppress affective responding. The increased skin conductance observed in the current study during affect suppression is consistent with past research (Gross &

Levenson, 1993, 1997). The findings for the LPP, however, contrast with those of Moser et al. (2006, 2009), who found that LPP decrease instructions produced decreased amplitude, and responses increased for increase instructions.

Clarification of differences between the present study and those of Moser and colleagues may help resolve this apparent inconsistency. First, while the LPP effects in the current study were weakly present at the parietal electrode Pz, the effects were primarily located over right-frontal brain regions. This suggests that cognitive control effects in the current study did not modulate the primary LPP effect generally measured in response to affective pictures (cf. Cuthbert et al., 2000), which is observed centro-parietally. Rather, a slow-wave increase over right-frontal areas is more consistent with lateral PFC engagement related to the control efforts (discussed further below).

A second difference is that earlier LPP studies utilized blocked, rather than fully randomized, designs, due to concerns that trial-to-trial changes between increase and decrease instructions could complicate effects via additional processes such as task switching (cf. Monsell, 2003). A primary issue with block designs is that effects that develop due to the repeated exposure across a block can be confounded with trial by trial modulations, complicating inferences. In an attempt to control block effects in earlier studies, Moser et al. (2009) mixed together only decrease and view or increase and view trials within a block (unpleasant and neutral were randomly presented within each block). However, average responding within the view condition was nominally higher in the increase than decrease blocks. This raises the possibility that participants may have adopted a “set” or otherwise become oriented towards one instruction during the course of the block.

This procedural discrepancy points to an important under-assessed source of variance in emotion-regulation paradigms: what aspects of regulation happen rapidly on a trial by trial basis, and what effects emerge across a number of combined trials or minutes? It may be, for example, that low-level affective modulation in response to control efforts is not effective in a trial-by-trial manner, and a more sustained effort is required to produce a change in affective state. The current study’s fully random design eliminated potential confounding block effects; however, effects that take longer to develop, as well as any additional effects of continual switching, cannot be readily evaluated. Perhaps the current findings and those of Moser et al. (2009) would be more consistent if such procedural differences were controlled.

The pattern of LPP effects in the right frontal area is consistent with earlier fMRI work, in that increases in LPP/slow-wave amplitude during both up and down regulation occurred within brain areas associated with cognitive control (e.g., the right lateral PFC). A number of fMRI studies have demonstrated increased activity in the right PFC and ACC during voluntary regulation of emotion (Ochsner et al., 2002, 2004; Schaefer et al., 2002; Beauregard et al., 2001; Hariri et al., 2003; Levesque, 2003). The right PFC is also known to be involved in inhibitory control (Aron, Robbins, & Poldrack, 2004; Garavan, Ross, & Stein, 1999) and cognitive set shifting (Konishi et al., 1999). The current findings lend further support to the supposition that brain regions associated with cognitive control are recruited during attempts to regulate emotional experiences.

Taken together, changes in skin conductance and LPP/slow-wave amplitude seem to represent the overall mobilization of autonomic and cortical systems during efforts to modulate an emotional experience. Interestingly, these changes do not parallel those seen in HR or the startle reflex. Lacey (1967) suggested that there are differential systems of arousal (i.e., autonomic,

behavioral, electrocortical), that do not always operate in a unitary fashion. The distinctive effects of cognitive control on these different measures further support the idea that distinct arousal systems may act independently. In other words, the current findings suggest that cognitive control mechanisms may differentially recruit various aspects of arousal systems in the body during attempts to modulate emotion.

The analysis of the probe P300 measure revealed a number of interesting effects. First, in general, probe P300 amplitudes were markedly smaller at the earliest (800 msec) probe time than at later (3–5 sec) times. This reflects the early impact of picture presentation as a “prepulse” on the processing of the acoustic probe stimulus (cf. Bradley et al., 1993; Bradley, Codispoti, & Lang, 2006); elaborative processing of the probe (as reflected in P300 amplitude) is diminished due to strong initial allocation of attention to the picture stimulus, which lessens across time. In conjunction with this early prepulse effect at 800 msec, a main effect of instructional cue was evident, with P300 amplitude reduced for both enhance and suppress conditions relative to view. The implication is that at this early time point, the recruitment of resources for enhancing/suppressing emotion drew attention away from the noise probe stimulus. A significant effect of emotional valence on probe P300 amplitude at this earlier (800 msec) probe time was also evident, but not at the parietal Pz site, only at more anterior sites.

In contrast, at later (3–5 sec) times—in conjunction with generally increased P300 amplitude as initial prepulse effects subsided—significant main effects of both valence and instructional cue were evident. The effect of emotional valence replicated that reported in prior picture viewing studies: P300 amplitude was attenuated for both pleasant and unpleasant relative to neutral pictures, reflecting greater allocation of attentional resources to the processing of affective material (Cuthbert et al., 1998; Schupp et al., 2004). For instructional cue, the enhance instruction increased this P300-dampening effect relative to the suppress condition—indicating greater recruitment of attentional resources in the enhance condition. This result converges with startle and HR results, in that the enhance instruction may have led to a deeper (mentative-imaginal) processing of the affective pictures than the suppress instruction. Under this interpretation, enhance instruction implementation was associated with inner-focused, elaborative processing (reflected in augmented HR and startle reactivity) that entailed greater attentional resource allocation (reflected in greater dampening of the P300 response to the noise probe).

Previous studies have concluded that the startle probe P3 is an indicator of the amount of attention allocated to picture processing, such that smaller startle probe P300 amplitude reflects greater attention to the emotional pictures as a result of less residual attention to process the auditory probe (e.g., Schupp et al., 2004). Accordingly, the smaller P300 amplitudes seen to the probe presented earlier in the picture presentation (i.e., 800 msec post-onset) indicate an initial increased engagement with the foreground picture during cognitive control attempts. Interestingly, the P300 to the startle probes that occurred later in the picture presentation (i.e., 3–5 sec post-onset) differentiated between up and down regulation strategies, with the smallest amplitudes during the enhance condition and the greatest during the suppress condition. This suggests increased engagement with the foreground picture during attempts to enhance the emotion and decreased engagement during attempts to suppress.

Modulation of attention allocated toward an affective stimulus may thus constitute one mechanism underlying up versus down regulation of emotion, consistent with earlier suggestions that attentional control is a mechanism of emotion regulation. For example, studies have shown that limiting attention to emotional stimuli can diminish responses in affective appraisal structures,

such as the amygdala (see Ochsner & Gross, 2005 for review) and cortical response systems (Dunning & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009).

Limitations and Future Directions

Evidence suggests that modulation of affective systems in the current study was limited to superficial response systems, and that “bottom up” processes underlying the bipolar valence dimension were not significantly modulated. At the same time, inferences about modulation of processes underlying an arousal affective dimension were supported. However, inferences about modulation of emotional arousal are more difficult to make, because arousal can be confounded with other processes such as attention or internal mentative processing (cf. Lacey, 1967).

The fully randomized design allows the current study to examine trial-by-trial outcomes of control efforts. Our results indicate that control efforts across randomized trials do not readily produce clear modulation in the “bottom-up” systems indexed by startle and HR. However, there are reasons to believe that short duration trial-by-trial tasks are the least likely to produce such modulation with sufficient strength to be detected. For example, as Moser et al. (2009) suggest, the act of switching modulation strategies at each trial may carry its own overhead, and may in fact create a strong task-switching effect that could dominate the response systems measured. A good test of this possibility would be to evaluate startle blink and other valence-based measures for valence by instruction interactions under a blocked design. Such effects could indicate that the fully random approach either did not allow enough time for deeper affective modulation, or that task-switching effects dominated or obscured other effects.

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