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Startle Modulation During Conscious Emotion Regulation Is Arousal-Dependent

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Conscious regulation of negative emotion has been shown to affect human eyeblink startle responses, but whether these results depend on modulation of arousal- or valence-based processes is unknown. The authors presented participants with negative, neutral, and positive pictures and directed them to enhance, maintain, and suppress emotional responses. On emotional picture trials, startle responses decreased as a function of cue in the following order: enhance > maintain > suppress. Analysis of negative and positive picture trials separately revealed similar patterns of startle modulation by emotion regulation. There were no effects of emotion regulation on neutral trials. Results indicate that arousal, not valence, may be critical to startle modulation via conscious emotion regulation.

Keywords: arousal, affect, emotion regulation, startle, valence

Emotion regulation refers to the processes by which aspects of an emotional response are modulated (Gross, 1998). Because adults regulate emotions in multiple situations and ways (Gross, 1999), improved understanding of emotion regulation is important for psychological and neuroscientific models of emotional information processing. Better understanding of emotion regulation may also yield novel insights into psychopathology and psychotherapy, given that emotional dysregulation characterizes most psychopathological conditions (*Diagnostic and Statistical Manual of Mental Disorders,* 4th edition; American Psychiatric Association, 1994), and emotion regulation instruction is central to several psychotherapies (e.g., Beck, 1976). A substantial body of work with both nonhuman animals (e.g., Davis, Falls, Campeau, & Kim, 1993) and humans (e.g., Lang, 1995) has demonstrated that startle responses to acoustic probes are modulated by emotional factors. For example, startle responses are reliably potentiated when an organism is exposed to stimuli that provoke fear. Here we consider how one form of emotion regulation—cognitive change (Gross, 1998)—alters startle probe responses.

Cognitive change refers to humans' ability to alter the meaning ascribed to emotionally evocative stimuli. Jackson, Malmstadt, Larson, and Davidson (2000) demonstrated that cognitive change can affect eyeblink startle. In that study, participants viewed emotionally negative and neutral pictures. During picture presentation, participants heard cues to "enhance" (increase), "maintain" (keep constant), or "suppress" (decrease) emotional arousal elicited by the pictures. The full set of regulation cues was presented on negative trials (neutral trials always featured the maintain cue), and acoustic startle probes were presented. On negative trials, startle responses decreased as a function of cue in the following order: enhance > maintain > suppress. This paradigm has since been used in neuroimaging studies, which have shown that attempts to cognitively enhance, maintain, and decrease negative emotions lead to increased, sustained, and diminished amygdala activation, respectively (Ochsner et al., 2004; Schaefer et al., 2002).

This work provides a foundation for the cognitive neuroscientific study of emotion regulation, but there are outstanding questions. One issue concerns the role of attention and/or effort. Research conducted with cue–target paradigms demonstrates that attention-directing cues elicit activity in a fronto-parietal attentional control network (Giesbrecht, Woldorff, Song, & Mangun, 2003; Woldorff et al., 2004). This activity appears to index multiple processes, including sensory processing, cue interpretation, and execution of the cued task. By extension, it may be argued that results obtained in emotion regulation paradigms primarily reflect cue-directed attentional operations that are emotion independent. Emotion regulation researchers have addressed this issue in two ways. First, by examining multiple regulation strategies in one experiment, researchers have attempted to control for nonspecific effort associated with attempts at emotional control (Jackson et al., 2000; Ochsner et al., 2004). Second, attempts to enhance or decrease emotional responses have been contrasted with attempts to maintain or attend to emotional responses (Jackson et al., 2000; Ochsner, Bunge, Gross, & Gabrieli, 2002). To the extent that these regulation cues make similar demands on attentional resources or require equivalent effort, additional effects may be interpreted as reflecting changes in emotional state. Another way to address this issue would be to present regulation cues on neutral picture trials. If previous results reflect emotion regulation, there should be no effect of regulation cues on such trials because they feature minimal emotional arousal. However, if previous results primarily reflect emotion-independent cognitive operations related to cue processing, then effects of regulation cues might be observed on neutral trials.

A second issue concerns the relative contributions of stimulus arousal and valence to startle modulation. Arousal refers to the degree of excitation elicited by a stimulus, whereas valence refers to its degree of pleasantness or unpleasantness (Russell, 1979).

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Most recent research has focused on regulation of emotions elicited by arousing negative pictures (e.g., Ochsner et al., 2004). This approach is reasonable because the neural systems underlying negative emotional information processing are well understood and because problems with regulating negative emotions are paramount in psychopathology. However, this approach confounds arousal and valence, which make dissociable contributions to psychophysiology (Bradley, Codispoti, Cuthbert, & Lang, 2001).

Directing participants to regulate emotional experience on both negative and positive picture trials would allow examination of the contributions made by arousal and valence to startle modulation during emotion regulation. Whether similar startle modulation occurs during attempts to regulate positive emotion is unknown. A similar pattern of startle modulation (enhance > maintain > suppress) on both negative and positive trials would indicate that arousal is more critical than valence. Such a pattern might be expected, for example, if visual imagery is differentially engaged as a function of cue (e.g., more imagery in response to enhance vs. suppress cues), as increased startle is observed during imagery of highly arousing negative and positive emotional experiences (Witvliet & Vrana, 1995).

Alternatively, valence may prove more important than arousal, and the pattern of emotion regulation effects on startle may differ on negative and positive trials. This idea is supported by the fact that startle responses are reliably potentiated during negative picture viewing and tend to be attenuated during positive picture viewing (Lang, 1995). This valence-sensitive result has been explained by the motivational priming hypothesis, which states that negative pictures engage the brain's aversive motivational systems and prime defensive reflexes, including startle, whereas positive pictures do not. Therefore, if motivational priming underlies startle modulation by conscious emotion regulation, startle responses should be attenuated on positive/enhance relative to positive/maintain or positive/suppress trials, as positive affect should be strongest on positive/enhance trials, and activation of the brain's aversive motivational systems should be minimal. This would be in contrast to the result on negative trials, where enhancing (negative) affect leads to increased startle relative to maintaining or suppressing (negative) affect.

To address these issues, in the present study participants were presented with negative, neutral, and positive pictures, which were fully crossed with cues to enhance, maintain, and suppress emotional responses. This design allows assessment of general attentional factors, as regulation cues are presented on neutral trials. Furthermore, the design enables a test of the two competing hypotheses regarding arousal and valence. If valence is critical, then startle modulation as a function of regulation should show opposing patterns on negative and positive trials. If arousal is critical, then a similar pattern of startle modulation (enhance > maintain > suppress) should be observed on negative and positive trials. Finally, startle probes were presented both prior to and following regulation cues to dissociate the effects on startle of picture-induced emotion versus emotion regulation.

Method

Participants

Fifty right-handed adults participated. Data from one participant were lost because of technical error, and one participant was excused because of drowsiness. The remaining 48 participants (37 female, 11 male) had a mean age of 22 years ($SD = 3.0$). Participants were screened for history of neurologic and psychiatric illness, drug abuse, and psychotropic medication use. Participants provided written informed consent for a protocol approved by the Duke University Institutional Review Board and were either paid $20 or received class credits.

Apparatus and Procedure

Sixty-three pictures were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2001). Pictures were presented on a computer screen for 8 s. At 4 s poststimulus onset, a regulation cue ("enhance," "maintain," or "suppress") was pronounced over headphones worn by participants. Picture offset was followed by presentation (for 8 s) of a gray screen. Participants were instructed to continue regulating emotional responses during this interval. Each trial ended with on-screen presentation of the word "RELAX" (for 4 s).

Prior to the experiment, participants were told how to respond to the regulation cues. Because our goal was to replicate and extend the research protocol of Jackson et al. (2000), we used identical instructions. Briefly, participants were told that when they heard the "enhance," "maintain," and "suppress" cues, they were to try to increase, keep constant, or decrease the intensity of whatever emotional response was elicited by the picture being viewed. Participants were not directed to use specific regulation strategies and could choose whatever strategies seemed most effective, with the restrictions that strategies should be cognitive in nature and should not involve looking away from pictures or consciously changing facial expressions. This naturalistic approach allows participants to regulate emotions as they might in everyday life.

On each trial, a 100-dB, 50-ms burst of white noise with near instantaneous rise time was presented as a startle probe. Because three picture types were crossed with three regulation cues and startle probes were presented at three time points (see below), a complete within-participant design was unfeasible. Therefore, picture type and regulation cue were manipulated within participants, and the timing of startle probe presentation was manipulated between-participants. For Group 1 ($n = 24$), the probe (A) was presented 3 s posttrial onset (while pictures were on-screen but before regulation cues were delivered). For Group 2 ($n = 12$), the probe (B) was presented 7 s posttrial onset (while pictures were onscreen but after regulation cues had been delivered). For Group 3 ($n = 12$), the probe (C) was presented 12 s posttrial onset (after pictures had been replaced by the gray screen and after regulation cues had been delivered; Figure 1a).

This design allowed for separate examination of emotion elicitation and emotion regulation. Whereas Probes B and C were critical for examining emotion regulation, Probe A allowed for examination of emotion elicitation by the pictures as it was presented before regulation cues. Because of reported failures to find pleasure-attenuated startle (e.g., Cook, Hawk, Davis, & Stevenson, 1991), twice as many participants were assigned to Group 1 as to Groups 2 or 3 to maximize the ability to detect pleasure attenuation of startle responses.

A practice session familiarized participants with the regulation cues and minimized orienting responses to probes. The session consisted of nine trials: three each of negative, neutral, and positive pictures. Additional instructions addressing neutral trials were given after the practice. Participants were told that some pictures presented during the practice session were not emotionally intense, and that they could expect similar pictures during the experiment. They were told to regulate any minor emotional reactions that might be elicited on such trials, even if such reactions consisted of boredom or frustration (e.g., with the nonemotional nature of some pictures).

The 63 experimental trials were organized in two orders according to the following rules: no more than three trials involving the same picture type or regulation cue could occur consecutively. Otherwise, stimulus order was pseudo-randomized. The two orders were broken into two runs (33 and 30

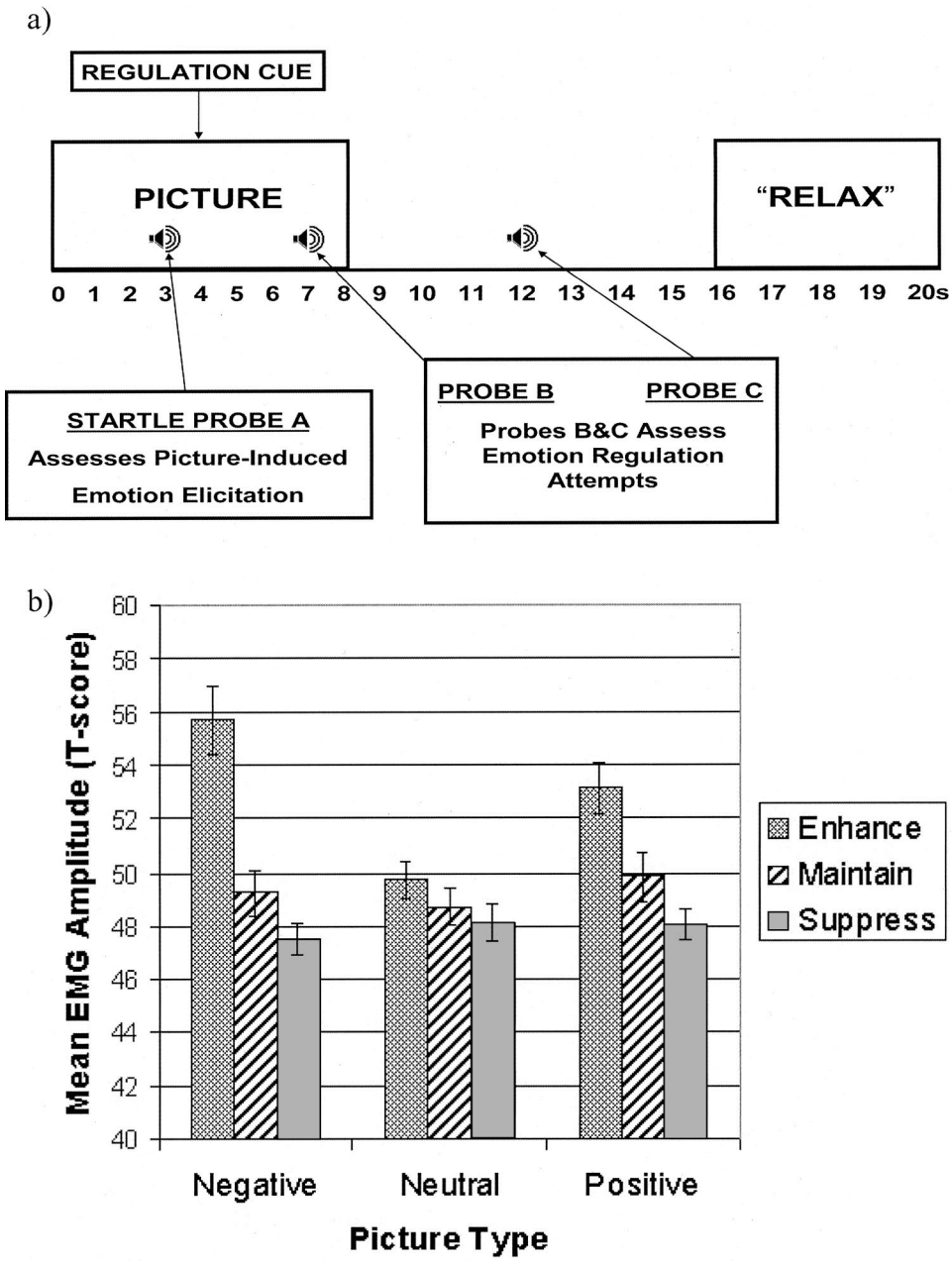

Figure 1. (a) Experimental design. Probe A, delivered prior to the onset of regulation cues, measured the effects of picture-induced emotion on eyeblink startle responses. Probes B and C, delivered after the onset of regulation cues, measured the effects of emotion regulation attempts on eyeblink startle responses. (b) Mean eyeblink startle responses (electromyography magnitude) as a function of emotion regulation cues, for negative, neutral, and positive picture trials. Data are shown for responses elicited by Probes B and C (data collapsed across Groups 2 and 3), which were presented after the onset of the regulation cues. Error bars reflect the standard error of the mean.

trials), and presentation and run orders were counterbalanced. Finally, participants viewed the pictures a second time and rated them for arousal and valence using the Self-Assessment Manikin (Bradley & Lang, 1994) with a 9-point scale for both arousal (1 = *calm*, 9 = *excited*) and valence (1 = *highly unpleasant*, 9 = *highly pleasant*) ratings. Because of technical error, picture rating data from one participant were lost.

Stimuli

There were 21 pictures each of three types: negative, neutral, and positive. We selected negative and positive picture sets that were equated for arousal on the basis of normative ratings but that differed in valence from the neutral set. In addition, 12 of the positive pictures consisted of

erotica, as pleasure attenuation is typically found with highly arousing positive pictures (Cuthbert, Bradley, & Lang, 1996). Normative mean (*SD*) valence ratings for negative, neutral, and positive pictures were 2.74 (0.90), 4.98 (0.30), and 6.93 (0.80). A one-way analysis of variance (ANOVA) revealed an effect of picture type, $F(2, 60) = 179.28$, $p < .0001$, $\eta^2 = .79$. Analysis by *t* test showed that all picture types differed significantly. Normative mean (*SD*) arousal ratings for negative, neutral, and positive pictures were 6.32 (0.64), 2.89 (0.53), and 5.79 (0.93). A one-way ANOVA revealed an effect of picture type, $F(2, 60) = 136.15$, $p < .0001$, $\eta^2 = .53$. Analysis by *t* test showed that the two emotional picture types were equally arousing and significantly more arousing than the neutral pictures. Participant and normative ratings were entered into a single data set, and correlation coefficients for both arousal and valence ratings were obtained. These coefficients were tested against the null hypothesis of zero correlation, and results revealed significant correlations between participant and normative picture ratings for both arousal and valence (both *p*s $< .0001$). This indicates that the pictures elicited the intended emotional responses.

Because of a concern that the erotic stimuli might have been regarded differently by men and women, *t* tests were used to compare male and female participants' arousal and valence ratings for both the positive picture set as a whole and the subset of erotic pictures. No test revealed a significant effect of gender (all *p*s $> .07$), indicating that the positive pictures were experienced similarly by men and women.

Startle Response Measurement

The eyeblink component of the startle response was measured by electromyogram (i.e., by electromyography [EMG]). Two Ag-AgCl electrodes with 4 mm inner diameter (BIOPAC Systems; Goleta, CA) were placed on the orbicularis oculi muscle below the left eye, and a ground electrode was attached to the medial face of the right earlobe. Signa Gel (Parker Laboratories; Fairfield, NJ) was used as a conductive electrolyte.

The raw EMG signal was sampled at 200 Hz, and the gain was amplified by 2000. High-pass (50-Hz) and low-pass (500-Hz) filters were applied to the data with AcqKnowledge software (BIOPAC Systems; Goleta, CA). EMG data were rectified and integrated in AcqKnowledge, and startle responses were defined as the difference between mean EMG activity in the 50 ms prior to the startle probe and the peak amplitude occurring within 120 ms of probe onset. Within participants, startle responses were converted to *T* scores to adjust for between-participants differences in response and baseline EMG amplitude (Funayama, Grillon, Davis, & Phelps, 2001). A startle probe was presented on each trial. As there were 21 pictures of each type (negative, neutral, and positive) and three cues (enhance, maintain, and suppress), a total of 7 startle probes was presented for each combination of picture type and cue.

Data Analysis

Startle and ratings data were analyzed by ANOVA. The Greenhouse-Geisser correction was used for repeated-measures ANOVA involving more than one degree of freedom, and corrected *p* values are reported.

Results

Emotional Modulation of Eyeblink Startle (Pre-Regulation Cues)

Mean startle responses elicited by Probe A are presented in Table 1. There was a main effect of picture type, $F(2, 46) = 10.56$, $p < .0005$, $\eta^2 = .46$. Analysis by *t* test showed that eyeblinks elicited during negative picture presentations were of greater magnitude than those elicited during presentation of either neutral or positive pictures (*p*s $< .005$), which did not differ. Because pleasure-attenuated startle is most readily found with erotic stimuli, a subanalysis was performed in which Probe A startle responses on erotic picture trials were analyzed separately. The mean (*SD*) startle response elicited by Probe A on erotic picture trials, 48.45 (3.28), was not significantly lower than that elicited by the positive picture set as a whole, 48.88 (2.90).

Table 1
Mean (Standard Deviation) Eyeblink Startle Magnitude as a Function of Emotion Regulation Cue, Group, and Picture Type

Cue	Group 1 (Probe A)	Group 2 (Probe B)	Group 3 (Probe C)
	Negative Pictures		
Enhance	N/A	56.47 (7.11)	54.98 (5.27)
Maintain	N/A	48.04 (2.71)	50.45 (5.35)
Suppress	N/A	47.79 (3.07)	47.17 (3.17)
M	51.94 (2.34)	50.77 (6.16)	50.87 (5.61)
	Neutral Pictures		
Enhance	N/A	49.96 (3.78)	49.47 (3.25)
Maintain	N/A	49.01 (3.58)	48.43 (2.85)
Suppress	N/A	47.29 (2.24)	48.91 (4.30)
M	48.56 (2.22)	48.75 (3.37)	48.94 (3.45)
	Positive Pictures		
Enhance	N/A	52.61 (4.92)	53.69 (4.39)
Maintain	N/A	50.30 (5.43)	49.32 (3.36)
Suppress	N/A	48.53 (2.23)	47.57 (3.15)
M	48.88 (2.90)	50.48 (4.61)	50.19 (4.42)

Note. Probe A was presented before the onset of the emotion regulation cues, so means from Probe A trials are given as a function of picture type only.

Emotion Regulation Effects on Eyeblink Startle

Mean startle responses elicited by Probes B and C are presented in Table 1. There were main effects of picture type, $F(2, 44) = 4.34$, $p < .02$, $\eta^2 = .03$, and regulation cue, $F(2, 44) = 22.05$, $p < .0001$, $\eta^2 = .20$. Post hoc tests conducted with the Ryan-Einot-Gabriel-Welsh (REGWQ) multiple range procedure (Howell, 2002) on the main effect of picture type showed that the magnitudes of eyeblinks elicited on negative ($M = 50.82$, $SD = 5.85$) and positive ($M = 50.34$, $SD = 4.49$) trials were statistically equivalent, but both were greater than that of eyeblinks elicited on neutral ($M = 48.85$, $SD = 3.39$) trials. Post hoc tests (REGWQ) on the main effect of regulation cue showed that eyeblinks elicited on enhance trials ($M = 52.86$, $SD = 5.40$) were of greater magnitude than those elicited on maintain ($M = 49.26$, $SD = 3.99$) or suppress ($M = 47.88$, $SD = 3.06$) trials, which did not differ from each other.

A significant Picture Type × Regulation Cue interaction, $F(4, 88) = 4.19$, $p < .01$, $\eta^2 = .06$, was also found, attributable to significant effects of regulation cue for both negative pictures, $F(2, 44) = 16.72$, $p < .0001$, $\eta^2 = .19$, and positive pictures, $F(2, 44) = 8.82$, $p < .001$, $\eta^2 = .07$, but not for neutral pictures, $F(2, 44) = 1.25$, $p = .29$ (see Figure 1b). Follow-up examination of this interaction was conducted, initially by analyzing startle responses on both negative and positive trials together. This analysis of

emotional picture trials revealed a significant effect of regulation cue, $F(2, 44) = 31.56$, $p < .0001$, $\eta^2 = .30$. Mean startle responses decreased as a function of cue in the following order: enhance ($M = 54.44$, $SD = 5.53$) > maintain ($M = 49.53$, $SD = 4.34$) > suppress ($M = 47.77$, $SD = 2.88$). Follow-up t tests showed significant differences among all three cue types (all ps $< .05$). Next, responses on negative and positive trials were analyzed separately. On negative trials, mean startle magnitude decreased in the same order: enhance > maintain > suppress. Analysis by t test revealed significant differences between enhance and suppress trials, $t(23) = 23.97$, $p < .0001$, and between enhance and maintain trials, $t(23) = 16.97$, $p < .0004$, but the maintain versus suppress comparison was not significant, $t(23) = 2.18$, $p = .15$. On positive trials, the same qualitative pattern emerged (enhance > maintain > suppress). Significant differences between enhance and suppress trials, $t(23) = 22.26$, $p < .0001$, and between enhance and maintain trials, $t(23) = 5.65$, $p < .03$, were found, but the maintain versus suppress comparison was not statistically significant, $t(23) = 2.36$, $p = .14$.

Because highly arousing, erotic pictures are known to more reliably affect startle, subanalyses of startle responses elicited by Probes B and C on erotic picture trials were performed. As no erotica were paired with the maintain cue for Group 2, we analyzed data from the enhance and suppress trials that featured erotica. For Group 2, the mean (*SD*) startle response was 52.61 (4.92) on enhance trials and 48.10 (3.61) on suppress trials that featured erotica. A paired t test comparing these values revealed a significant difference, $t(11) = 2.75$, $p < .02$. For Group 3, there were three or more erotic pictures in each cue condition. Mean (*SD*) startle was 52.87 (6.69), 49.31 (5.76), and 47.74 (4.17) for trials featuring the enhance, maintain, and suppress cues, respectively. A repeated measures ANOVA on these data failed to reveal a significant effect of cue, $F(2, 22) = 2.37$, $p = .12$, which is likely due to the low number of trials per condition. However, a planned contrast comparing responses on enhance and suppress trials was significant, $F(1, 11) = 4.81$, $p < .05$. In general, the analyses for these two groups indicate that the pattern of regulation effects was similar when either the erotic pictures alone or the positive picture set as a whole was considered.

Discussion

The primary goal of this study was to assess the contributions of arousal and valence to startle modulation by conscious emotion regulation. Three picture types (negative, neutral, positive) were crossed with three regulation cues (enhance, maintain, suppress). Significant effects of regulation cues were found on emotional trials but not on neutral trials. Because participants were encouraged to obey the cues on all trials, this finding indicates that cue-directed, emotion-independent attentional shifts alone are not sufficient for the observation of effects in this paradigm. Instead, a certain degree of emotional arousal appears to be required to observe startle modulation. This pattern of results strengthens the argument that the paradigm measures emotion regulation rather than cue-directed attentional processing per se. Nonetheless, because presumably little emotion was elicited on neutral trials, it may be that different cognitive processes were engaged by regulation attempts on these trials as opposed to emotional picture trials. Future work should therefore attempt to further delineate the contributions of attentional modulations to emotion regulation via cognitive change.

In contrast to the results from neutral picture trials, startle responses on emotional picture trials decreased as a function of cue in the following order: enhance > maintain > suppress. The same qualitative pattern of emotion regulation effects was observed on negative and positive trials, indicating that voluntary attempts to increase and decrease emotional responses had similar physiological signatures irrespective of valence.

Startle Modulation During Emotion Elicitation and Emotion Regulation

Probe A, delivered prior to regulation cues, elicited eyeblinks of greatest magnitude on negative trials. This finding is consistent with the motivational priming account (Lang, 1995), although, like previous researchers (e.g., Cook et al., 1991), we did not observe pleasure-attenuated startle. Nonetheless, we are confident that the picture set elicited positive affect, as participant ratings were highly correlated with normative ratings. Regardless, the key finding is that the pattern of responses to Probe A (negative > neutral/positive) is clearly different than that to Probes B and C (negative/positive > neutral).

For Probes B and C, the qualitative pattern of emotion regulation effects (enhance > maintain > suppress) was the same for negative and positive trials. Subanalyses conducted on erotic images alone confirmed the results from all positive stimuli combined. These results indicate that the paradigm may be more sensitive to changes in arousal than valence. Furthermore, the emotion regulation results are inconsistent with the motivational priming hypothesis. Whereas the effects of regulation cues on negative trials could be explained in terms of motivational priming (i.e., enhance trials lead to large eyeblinks because negative affect is strongest on those trials), trials on which positive affect was presumably strongest—positive/enhance—led to increased startle responses relative to those elicited on positive/maintain and positive/suppress trials, an outcome opposite that predicted by the motivational priming argument.

Lang, Bradley, and Cuthbert (1997) noted that if startle probes are presented when participants actively engage in emotional responses, the startle reflex appears to be more sensitive to arousal than valence. For example, probes presented while participants imagine themselves engaging in emotional activities elicit increased startle responses for both highly arousing positive and negative stimuli (e.g., Witvliet & Vrana, 1995). The cognitive change strategies used in the present study are active coping strategies engaged following presentation of emotion-eliciting stimuli. In accordance with Lang et al. (1997), differences in startle response as a function of cue on emotional picture trials may reflect differential use of emotional imagery across cues. Support for this idea comes from verbal reports provided by participants during debriefing. In response to the enhance cue, many participants reported imagining themselves in the scenes depicted, whereas in response to the suppress cue many participants reported cognitively distancing themselves from the scenes. Future studies should explicitly manipulate use of visual imagery during emotion regulation to further evaluate this hypothesis.

When positive and negative pictures were pooled, all three regulation cues had statistically significant effects on startle (en-

hance > maintain > suppress). However, when analyses were conducted on negative and positive trials separately, the differences on maintain and suppress trials were not statistically reliable. This result stands in contrast to Jackson et al. (2000), who reported reliable differences on maintain versus suppress trials using negative pictures. The reason for this difference is unclear, although it may be due to statistical power. Future studies should consider alternative emotion regulation instructions to determine which ones decrease emotional responses most reliably. Moreover, additional online measures, such as verbal ratings, provide complementary evidence for the effectiveness of these strategies and should be paired with physiological measures in future research.

Although no measures of neural activity were obtained in this study, the results suggest possible targets for future neuroscientific investigations of emotion regulation. The process of emotion regulation by cognitive change appears to be implemented in the brain by interactions between dorsal executive control regions and ventral frontolimbic regions that mediate emotional responding (Ochsner et al., 2004). Emotional modulations of startle are typically discussed with reference to the amygdala, because this structure plays a clear role in fear-potentiated startle (Davis, Falls, Campeau, & Kim, 1993; Hitchcock & Davis, 1986, 1987; Lang, 1995), and functional brain imaging studies of conscious regulation of negative emotions have featured modulations of amygdala function (Ochsner et al., 2002, 2004; Schaefer et al., 2002). Therefore, it may be the case that attempts to regulate negative emotions affected startle responses by modulating amygdala activity.

Because most previous research on emotion regulation has focused on negative emotions, the neural regions affected by attempts to regulate positive emotions are largely unknown. Previous research has demonstrated that the amygdala responds to highly arousing positive pictures (e.g., Dolcos, LaBar, & Cabeza, 2004; Hamann, Ely, Hoffman, & Kilts, 2002), and Beauregard, Levesque, and Bourgouin (2001) reported reductions in amygdala activity when male participants suppressed arousal elicited by erotica. Furthermore, research with nonhuman animals has found that attenuation of the startle response in the presence of appetitive cues is dependent on the integrity of the mesolimbic dopamine system (Koch, Schmid, & Schnitzler, 1996). The results presented here suggest that top-down control of reward circuitry, perhaps including the amygdala and the mesolimbic dopamine system, may be possible through cognitive emotion regulation strategies, but more work with neuroscientific techniques is necessary to test the exact mechanism.

Many of the emotion regulation strategies used in the present study and in everyday life are subserved by cognitive processes, including changes in attentional deployment, maintenance of cognitive change strategies in working memory, retrieval of emotional information from episodic and semantic memory, and the generation of narratives or mental images used to change emotional state (Gross, 1998; Ochsner & Feldman Barrett, 2001). These processes depend on a variety of dorsal prefrontal and temporo-parietal cortical regions, which may be critical for modulating emotional processing in subcortical structures, including the amygdala (Davidson, 1998, 2000; Davidson, Putnam, & Larson, 2000; Ochsner & Feldman Barrett, 2001). Results from the current study indicate that at least some regulation strategies have similar effects on physiological responses to both negative and positive stimuli. Future neuroimaging studies could vary the emotion regulation strategies used by participants in order to understand which cortical regions are engaged by various strategies, how these strategies differentially affect processing in subcortical structures, and whether some strategies have differential effects on negative and positive emotional responses (Ochsner et al., 2004).

Conclusion

By ruling out emotion-independent effects of cue processing as an alternative explanation for startle modulation and by showing the same effects of regulation cues on negative and positive trials, the present study advances knowledge regarding mechanisms underlying emotion regulation. Extending this work to clinical populations will be important for understanding emotional dysregulation in psychopathology.

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