



Effects of emotion regulation strategy on brain responses to the valence and social content of visual scenes

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ABSTRACT

Emotion Regulation (ER) includes different mechanisms aiming at volitionally modulating emotional responses, including cognitive re-evaluation (re-appraisal; REAP) or inhibition of emotion expression and behavior (expressive suppression; ESUP). However, despite the importance of these ER strategies, previous functional magnetic resonance imaging (fMRI) studies have not sufficiently disentangled the specific neural impact of REAP versus ESUP on brain responses to different kinds of emotion-eliciting events. Moreover, although different effects have been reported for stimulus valence (positive vs. negative), no study has systematically investigated how ER may change emotional processing as a function of particular stimulus content variables (i.e., social vs. nonsocial). Our fMRI study directly compared brain activation to visual scenes during the use of different ER strategies, relative to a “natural” viewing condition, but also examined the effects of ER as a function of the social versus nonsocial content of scenes, in addition to their negative versus positive valence (by manipulating these factors orthogonally in a 2×2 factorial design). Our data revealed that several prefrontal cortical areas were differentially recruited during either REAP or ESUP, independent of the valence and content of images. In addition, selective modulations by either REAP or ESUP were found depending on the negative valence of scenes (medial fusiform gyrus, anterior insula, dmPFC), and on their nonsocial (middle insula) or social (bilateral amygdala, mPFC, posterior cingulate) significance. Furthermore, we observed a significant lateralization in the amygdala for the effect of the two different ER strategies, with a predominant modulation by REAP on the left side but by ESUP on the right side. Taken together, these results do not only highlight the distributed nature of neural changes induced by ER, but also reveal the specific impact of different strategies (REAP or ESUP), and the specific sites implicated by different dimensions of emotional information (social or negative).

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1. Introduction

Emotions play a vital role in human life, shaping many personal and social processes. However, besides being influenced by emotions in our actions, we in turn have the ability to modulate our emotional responses by different mechanisms. The importance of emotion regulation (ER) capacities can be observed in various domains or situations, either in terms of increasing pos-

itive health outcomes when used appropriately, or by promoting mood disorders and anxiety when malfunctioning (Gross, 2002; Jackson, Malmstadt, Larson, & Davidson, 2000). Uncovering the neural mechanisms that can regulate affect and their influence on the processing of emotionally significant information is therefore of great importance, not only to gain insight into the determinants of well-being and adaptive emotional processing, but also to better understand the predispositions to affective disorders and the effect of specific therapeutic interventions.

Behavioral research on ER (Gross, 1998) has highlighted two major kinds of ER strategies, which are conceptualized to have their impact at distinct stages during emotion processing.

On the one hand, *cognitive reappraisal* (REAP) is thought to intervene at a relatively early stage of emotion processing by modulating the meaning of an emotional event. This typically involves the intentional (conscious) generation of alternative interpretations in response to an event, allowing one to modify (e.g., minimize)

Abbreviations: BASE, baseline; CON, control; ER, emotion regulation; ESUP, expressive suppression; INST, viewing instruction; INT, intensity; NAT, natural viewing; NEG, negative; NSN, nonsocial negative; NSOC, nonsocial; NSP, nonsocial positive; PLN, pleasantness; POS, positive; REAP, re-appraisal; SC, social content; SN, social negative; SOC, social; SP, social positive; VAL, valence.

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its emotional significance. Accordingly, REAP has been shown to alter subjective emotion experience (as measured by physiological arousal and verbal reports) to both negative and positive emotional stimuli, and for both up- and down-regulation of affect (Kim & Hamann, 2007). Moreover, studies using functional magnetic resonance imaging (fMRI) during REAP have shown increased activity in a widespread network of cortical frontal regions, together with simultaneous decreases in areas critical for emotion elicitation, such as the amygdala, the posterior cingulate cortex (PCC), and insula (Goldin, McRae, Ramel, & Gross, 2008; Kim & Hamann, 2007; Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner, Ray et al., 2004).

On the other hand, *suppression of behavioral expression* (ESUP) is thought to operate only after emotion elicitation, and is directed towards the inhibition of emotional responses (e.g., facial expressions or physiological changes). Thus, the triggering event is typically appraised and elicits an emotion, but the overt behavioral manifestations are voluntarily suppressed. Unlike REAP, ESUP has been found to increase sympathetic activation, to produce little effect on negative emotion experience, and to even decrease positive affect and interfere with cognitive processes such as memory (Gross, 1998; Richards & Gross, 2000). Although brain imaging data on ESUP are still scarce, one study has reported an increase in prefrontal cortical activity during ESUP of negative emotions (either sadness or disgust; (Goldin et al., 2008)). The same investigation also found increased amygdala and insula responses during ESUP, but only in a late period of prolonged exposure to disgusting film-clips, contrasting with the decreases observed in these regions during REAP (Kim & Hamann, 2007; Ochsner et al., 2002; Ochsner, Ray et al., 2004). Finally, whereas the use of REAP has been linked to enhanced control of emotion, better interpersonal functioning, and higher psychological and physical well-being, the frequent use of ESUP is thought to result in diminished control of emotion, worse interpersonal functioning, and greater risks for depression (Gross & John, 2003).

Despite the fact that our knowledge regarding the neural correlates of ER has steadily increased during the last decade, several important issues still remain largely unresolved. Firstly, most of the previous brain imaging studies on ER have investigated only one type of ER strategy at a time (Beauregard, Levesque, & Bourgouin, 2001; Kim & Hamann, 2007; Koenigsberg et al., 2010; Levesque et al., 2003; Ochsner et al., 2002; Ochsner, Ray et al., 2004), except for one study (Goldin et al., 2008) that compared REAP and ESUP in a single experimental design but focused on difference in the time-course of ER effects. Hence, still very little is known about the *differential* impact of REAP and ESUP on brain activity during emotional processing, particularly in relation to different stimulus types. This does not only concern cortical brain areas exerting top-down control during ER, predominantly located within prefrontal cortex, where a functional segregation between behavioral (ESUP) and cognitive (REAP) control has already been suggested (Goldin et al., 2008); but also the lower-level areas in sensory cortices and subcortical regions that are crucially involved in emotional responses, such as the amygdala, striatum, or insula. Thus, it still remains to be elucidated whether insula activity during down-regulation of affect only decreases through REAP but increases during ESUP, as would be predicted by ER theory (Gross, 1998; Gross & John, 2003), or whether it can also be down-regulated during ESUP just like during REAP. Therefore, in our study, we examined both cognitive (REAP) as well as behavioral (ESUP) strategies of ER, in addition to a “natural” emotion experience condition (NAT; see Section 2) that served as a baseline condition.

Secondly, most previous fMRI experiments on ER only differentiated modulatory effects as a function of the valence (VAL; positive vs. negative) and/or arousal values (low vs. high intensity) attributed to emotional stimuli (Kim & Hamann, 2007; Mak, Hu, Zhang, Xiao, & Lee, 2009), but did not consider other important

aspects of the latter, such as their social versus nonsocial features. One exception is a recent investigation by Koenigsberg and colleagues where the authors used social negative images exclusively in a cognitive re-evaluation (REAP) paradigm (Koenigsberg et al., 2010). Yet, this study did not compare brain activations elicited by social negative to comparable nonsocial negative scenes. This lack of systematic investigation of ER as a function of the content of emotion-eliciting stimuli is regrettable given many other findings which point to major differences in emotional reactions (and their corresponding neural signatures) depending on the social versus nonsocial nature of information (Britton et al., 2006; Frewen et al., 2010; Goossens et al., 2009; Hariri, Tessitore, Mattay, Fera, & Weinberger, 2002; Norris, Chen, Zhu, Small, & Cacioppo, 2004; Sander, Koenig, Georgieff, Terra, & Franck, 2005; Scharpf, Wendt, Lotze, & Hamm, 2010). In addition, there is evidence that the activation of some limbic brain areas (e.g., the amygdala) is more sensitive to social and thus interpersonal aspects rather than to nonsocial dimensions of emotion-eliciting situations (Killgore & Yurgelun-Todd, 2005; Vrtička, Andersson, Grandjean, Sander, & Vuilleumier, 2008). Likewise, the medial prefrontal cortex has also been linked with both emotion recognition and social cognition (Gilbert et al., 2007; Lane & McRae, 2004; Mitchell, Macrae, & Banaji, 2006; Peelen, Atkinson, & Vuilleumier, 2010). These differences in social and emotional content are likely to imply different mechanisms for successful ER strategies. As a consequence, in our study, emotional images were systematically varied according to both their affective valence (VAL: positive vs. negative) and their social content (SC: social vs. nonsocial), as separate experimental factors in a 2×2 design.

To this aim, our study used a systematic approach combining whole-brain imaging with analysis of functionally defined regions of interest (ROIs) while participants were instructed to apply different ER strategies for different stimulus types. In previous work, activation differences related to ER have typically been derived from comparisons between REAP versus baseline or ESUP versus baseline, and this for a single emotional dimension (i.e., negative stimuli) (Goldin et al., 2008; Ochsner, Ray et al., 2004). To our knowledge, only two imaging studies so far also compared the *relative differences* in brain responses to positive versus negative images during ER (Kim & Hamann, 2007; Mak et al., 2009). Here, we set out to identify brain areas that were not only involved in processing a specific stimulus attribute (i.e., VAL or SC), but also significantly modulated by the different ER instructions (INST; either NAT, REAP, or ESUP). Therefore, we specifically tested for regions showing a significant $INST \times VAL$ or $INST \times SC$ interaction. To restrain our analysis to regions showing reliable effects of interest but ensure sufficient sensitivity across the different conditions, we first used a whole-brain random-effects (RFX) analysis to determine functional networks whose activity was significantly modulated by either VAL or SC, and then computed an additional second-level RFX analysis (using a paired *t*-test design in SPM) to identify voxels within these networks that displayed significant effects due to the different ER strategies (see Section 2). This approach allowed us to define regions of interest (ROIs) where the processing of specific affective cues (VAL or SC) was selectively modulated by the different kinds of ER.

We predicted changes in activations related to the differential encoding of valence (negative vs. positive) and/or stimulus content (social vs. nonsocial) in brain networks that are selectively tuned to social and affective information (Lieberman, 2007), including in particular the amygdala which has previously been shown to be sensitive to social cues (Britton et al., 2006; Frewen et al., 2010; Goossens et al., 2009; Hariri et al., 2002; Norris et al., 2004; Sander et al., 2005; Scharpf et al., 2010; Vrtička et al., 2008) and modulated by different ER strategies (Killgore & Yurgelun-Todd, 2005; Kim & Hamann, 2007; Koenigsberg et al., 2010; Levesque et al.,

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