Thinking makes it so:

A social cognitive neuroscience approach to emotion regulation

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One of the most remarkable of all human skills is our ability to flexibly adapt to nearly every imaginable circumstance. This ability arises in part from our capacity to regulate emotions that are engendered by the situations we face. Drawing upon an array of emotion regulatory strategies, we can accentuate the positive, remain calm in the face of danger, or productively channel anger. One particularly powerful emotion regulation strategy involves changing the way we think in order to change the way we feel.

Known as reappraisal, this capacity to cognitively control emotion was eloquently described by Auschwitz survivor, neurologist, and psychiatrist Viktor Frankl. In Man's Search for Meaning, Frankl wrote, "We who lived in the concentration camps can remember . . . that everything can be taken from a man but one thing: The last of his freedoms - to choose one's attitude in any given set of circumstances . . . to transform a personal tragedy into triumph, to turn one's predicament into a human achievement." (1985, 1946, p. 86, 135).

The goal of this chapter is to develop a framework for understanding the mechanisms by which reappraisal and other emotion-regulatory strategies exert their emotion-modulatory effects. Towards that end, the chapter is divided into five parts. In the first part, we briefly review common conceptions of emotion and emotion regulation. In the second and third parts, we present our approach which integrates theory and method from both social psychology and cognitive neuroscience to develop a framework for studying the capacity to cognitively control emotion. In the fourth part, we present two fMRI studies designed to probe the neural bases of reappraisal. In the fifth part, we consider implications for other forms of emotion regulation, individual and group differences in emotion and emotion regulation, the development of emotion regulation skills, and psychopathology.

The Nature of Emotion and Emotion Regulation

Lay Conceptions

In the movie/musical *Chicago*, jazz singer Velma Kelly unexpectedly discovers her sister and her husband making love in her dressing room. The amorous pair are later found shot to death and Velma is caught literally red handed, with blood on her hands. Accused of murder, Velma pleads her innocence, claiming to have been so overcome with emotion upon discovering the pair that she blacked out, only to find them shot upon awakening. Of course, the audience knows the truth: enraged by the unsuspected infidelity, Velma shot them both.

Velma's denial of responsibility for her actions reflects deeply held lay conceptions of emotion, which suggest that we occasionally encounter situations that trigger passions that in turn spark actions over which we may have little regulatory control. Indeed, the tug of war between raw feeling and reasoned control is a theme that resonates throughout the history of Western culture. According to the Hebrew Bible, our emotion regulatory struggles began with the first human beings, Adam and Eve, who knew no sin until they succumbed to their appetites and ate an apple from the Tree of Knowledge. Their children, Cain and Abel, soon followed suit: in a fit of jealous anger, Cain killed Abel after God rejected his sacrifice but accepted his brother's sacrifice.

The age-old excuse, "The devil made me do it," finds expression in these two stories and in countless others in which the protagonist is ruled by emotion rather than a ruler of it. Examples abound in great works of philosophy and literature from Plato to Dostoevsky, and continue to the present day in novels, television programs, and movies such as *Chicago*. Whatever the medium, the message is clear: within every person there is an essential tension between emotional impulses and our attempts to control them.

Experimental Psychological Approaches

Although current conceptions of emotion paint a more complex picture of our emotion-regulatory struggles than do lay conceptions, researchers still take as their starting point the tension between processes that generate emotions and those that regulate them. On the emotion generation side, a consensus has emerged that emotions are biologically-based responses that help an organism meet challenges and opportunities, and involve changes in subjective experience, behavior, and physiology (Levenson, 1994; Smith & Ellsworth, 1985). Emotions arise when something important to us is at stake, and classic work by Lazarus in the 1960's provided the first experimental demonstration that the way in which we appraise, or interpret, an emotionally evocative stimulus shapes how we respond emotionally to it (Lazarus, 1991). Subsequent work on appraisal theory has examined the way in which different specific emotions are generated by appraisals of the relevance of stimuli to different goals, and current work is attempting to specify the component processes of appraisal (Scherer, Schorr & Johnstone, 2001).

Emotion regulation occurs when an individual attempts to modify one or more aspects of an emotional response (Campos & Stenberg, 1981; Gross, 1998). Recent studies have begun addressing questions about emotion regulation including who regulates their emotions, which strategies they use, and how different emotion regulation strategies influences how we feel, think, and act. It is now clear that effective emotion regulation is essential for mental and physical health (Davidson, Putnam & Larsen, 2000; Gross, 1998), that emotion dysregulation lies at the heart of many psychiatric disorders, such as depression (Gross & Munoz, 1995), and that different regulatory strategies have very different consequences for emotional experience, behavior and physiology (Gross, 1998). For example, experimental studies of emotion regulation processes have contrasted the suppression of emotion expressive behavior and cognitive reappraisal of an event's meaning in the service of emotion down-regulation (Gross, 2001). Suppression can successfully mask facial and bodily manifestations of emotion, but it does so at a cost of boosting physiological responding and fails to diminish the emotional experience that prompted one to suppress in the first place. By contrast, reappraisal alleviates negative emotional experience and diminishes behavioral responses without any apparent physiological cost.

A Process Model Of Emotion And Emotion Regulation

A major aim of our research has been the specification of cognitive and neural processes that support emotion regulation. In this section, we sketch the simple model we use to describe how control processes may influence appraisal processes. In the following section, we then use neuroscience data to flesh out and constrain this model.

On our view, the appraisal process does not proceed from perception to emotion and then stop, but rather iterates continuously, providing updated appraisals as stimuli and events (including one's own actions and feelings) change over time (see Scherer, 1994). That being said, it is useful to consider one iteration in isolation, and then examine how different types of emotion regulation might impact different points of the appraisal process. In this way, differences between, and relationships among, regulatory strategies can be understood in terms of how they modulate the appraisal cycle.

For present purposes, five types of emotion regulation strategies may be distinguished (Gross, 2001). In the first, which we refer to as *situation selection*, a person can control the appraisal process before it ever begins by actively choosing to place oneself in particular contexts and not others. The second type of emotion regulation strategy -- *situation modification* -- involves efforts to directly change the situation so as to modify its emotional impact. Each of these first two emotion regulation strategies serve to modify appraisal inputs, thereby controlling the cues available to generate particular emotions. Once the particular context has been set, a third strategy may direct attention to environmental cues that promote desired emotions, while at the same time ignoring cues that promote undesired emotions. *Attentional deployment* gates particular cues into the reappraisal process, while excluding others from it. A fourth strategy, *cognitive change*, allows one to modify the meaning of particular cues once they have gained access to the appraisal process. For example, in the case of reappraisal, which is one kind of cognitive change, by reinterpreting the meaning of stimuli and events one can alter the ongoing trajectory of an emotional response. The fifth strategy, *response modulation,* affects only the outputs of reappraisal process. Using this strategy, control processes can suppress or augment behavioral manifestations of one's emotional state, such as smiles, frowns, or tendencies to approach or withdraw.

In the remainder of this chapter we focus on clarifying the neurocognitive mechanisms of one form of cognitive change, namely cognitive reappraisal. Other chapters in this volume deal extensively with situation selection and selective attention (e.g. MacCoon & Newman; Mischel & Ayduk; Posner et al; Rothbart et al), and elsewhere we have examined one form of response modulation, expressive suppression (e.g. Gross, 1998).

Our focus on reappraisal is motivated both by the apparent commonness of reappraisal in everyday life, and by research demonstrating that other alternative types of strategies may have serious shortcomings: It isn’t always possible to selectively avoid or modify undesirable situations, or to selectively ignore particular aspects of them, and response suppression takes both a physical toll (boosting blood pressure, heart rate, and skin conductance (Gross & Levenson, 1993; Gross, 1998b)) and a mental toll (impairing memory (Richards & Gross, 2000)). By contrast, cognitive reappraisal strategies, which influence the appraisal process itself by changing the way an event is interpreted, are widely applicable, and can successfully influence emotional experience and expression without the physiological costs (e.g., boosting blood pressure (Gross & Levenson, 1993; Gross, 1998b)) and mental costs (impairing memory (Richards & Gross, 2000)) associated with suppressing behavioral expressions of emotion.

In the following section, we develop our model of the neurocognitive mechanisms supporting reappraisal in particular, and the cognitive control of emotion more generally.

Toward a Functional Neural Architecture for the Cognitive Control of Emotion

Because very little research has addressed the topic directly, insights regarding the the neural bases of the cognitive control of emotion must be gleaned by analogy and inference from studies of emotion processing and "cold" forms of cognitive control such as working memory, response selection, and reasoning.

Current cognitive neuroscience models posit that cognitive control involves interactions between regions of prefrontal cortex that implement control processes and subcortical and posterior cortical regions that encode and represent specific kinds of information (Knight et al, 1999; Miller & Cohen, 2001; Smith & Jonides, 1999). By increasing or decreasing activation of particular representations, prefrontal regions enable an individual to selectively attend to and maintain goal-relevant information in mind and resist interference from irrelevant information (Bunge et al, 2001; Knight et al, 1999; Miller & Cohen, 2001; Smith & Jonides, 1999).

We hypothesize that similar interactions will underlie the cognitive control of emotion (Davidson & Irwin, 1999; Ochsner & Feldmann Barrett, 2001). More specifically, we hypothesize that reappraisal should modulate activation of brain systems implicated in emotional appraisal and should depend on frontal systems implicated in cognitive control. These systems are diagrammed in Figure 1. In the following sections, we first discuss the neural bases of emotional appraisal and then turn to the neural bases of cognitive emotional control. The goal here is to develop a functional architecture of the neurocognitive dynamics supporting reappraisal that can be tested using functional neuroimaging, as described in the following section.

What Does Reappraisal Influence? The Neural Bases of Emotional Appraisal

Theorists have postulated that the appraisal process involves multiple types of processing (Lazarus, 1991; LeDoux, 2000; Ochsner & Feldmann Barrett, 2001; Rolls, 2000; Smith, 2001). Although the precise nature of component appraisal processes is not yet clear, a distinction may be made between processes that 1) rapidly evaluate the affective relevance of a stimulus, determining whether it may be potentially threatening, 2) processes that encode sequences of actions or events that predict reward, or generally predict the occurrence of reinforcing stimuli, and 3) processes that provide a more elaborated, context-sensitive, evaluation that may be important for decision-making and representing stimulus value in awareness (Scherer, Schorr & Johnstone, 2001). Different brain systems may be associated with each type of process, and it is possible that reappraisal may influence activation of each one.

Amygdalae. The amygdalae play an essential role in quickly determining whether a stimulus is affectively relevant. Both neuropsychological and neuroimaging studies demonstrate that the amygdalae are important for the pre-attentive detection and recognition of affectively salient stimuli (Anderson & Phelps, 2001; Morris, Ohman & Dolan, 1999; Whalen et al, 1998), learning and generating physiological and behavioral responses to them (Bechara et al, 1999; LeDoux, 2000), and modulating their consolidation into declarative memory (Cahill et al, 1995; Hamann et al, 1999). Although the amygdalae may play a special role in fear (LeDoux, 2000), it is now clear that they respond to the arousing properties of both positive and negative stimuli (Adolphs & Tranel 1999; Hamann et al, 1999). In keeping with their role as modulators of perception and memory, amygdala lesions do not impact the everyday experience of emotions and moods (Anderson & Phelps, 2002; Cahill et al, 1995).

Striatum. The striatum plays an essential role in learning which stimuli predict rewards, and more generally which sequences of stimuli predict the presence or absence of reinforcing stimuli (Rolls, 2000). Imaging studies have shown differential striatal response during receipt of rewards, punishments, and pleasant sensations (Berns et al, 2001; Knutson et al, 2000; 2001; O'Doherty et al, 2001), as well as stimuli with acquired reinforcement value, including positive (Hamann et al, 1999) and negative photos (Canli et al, 1998, Paradiso et al, 1999), happy and sad films (Lane et al, 1997), as well as happy (Crtichley et al, 2000; Morris et al, 1996), fear (Philips et al, 1997; Schenider et al, 1997), and disgust faces (Sprengelmeyer et al, 1996). The architecture of the striatum seems particularly suited to implicitly encoding sequences of thoughts or actions that precede reinforcing stimuli, and it has been postulated that these sequences may be expressed as habits that may guide automatic behavior (Lieberman, 2000). The sensitivity of the striatum to both positive and negative stimuli may reflect its general role in encoding these predictive sequences. The ventral portion of the striatum, however, seems to play a special role in predicting the occurrence of rewarding stimuli (Knutson et al, 2001), and may be seen as a structure that allows the intuitive guidance of behavior towards rewards. Anticipation of reward activates the striatum (Knutson et al, 2001), as does viewing neutral images with positive captions (Teasdale et al, 1999), suggesting that cognitively interpreting stimuli as positive may activate reward circuitry.

Orbitofrontal cortex. The orbitofrontal cortex (OFC) has been implicated in appraisal processes that evaluate the emotional meaning of stimuli in context, and determine the appropriateness of possible responses to them (Lazarus, 1991; Scherer et al, 2001). OFC is important for emotional experience and social behavior (Hornak et al, 1996; Rolls et al, 1994; Zald & Kim, 1996), as well as the perception (Beauregard et al, 1998; Blair et al, 1999; Paradiso et al, 1999;) sensation (Francis et al, 1999), generation (Crosson et al, 1999), imagery (Shin et al, 1997), and recall (Pardo et al, 1993; Reiman et al, 1997) of pleasant and unpleasant stimuli across sensory modalities. Recently it has been suggested that medial OFC may play a particularly important role in emotional appraisal (Elliott et al, 2000; Ongur & Price, 2000), given the high level of connectivity of medial OFC and amygdalae (Ongur & Price, 2000). Medial OFC (along with the adjacent ventromedial prefrontal cortex) may be important for representing the pleasant or unpleasant affective value of a stimulus (Davidson & Irwin, 1999; Elliott et al, 1997; Knutson et al, 2001; O'Doherty et al, 2001) in a flexible format that is sensitive to momentary changes in social and motivational context (Bechara et al, 2000; Ochsner & Feldmann Barrett, 2001; Rolls, 2000). Together, the amygdala and MOFC are thought to differentially encode and represent the affective properties of stimuli (Bechara et al, 1999; Schoenbaum et al, 1999).

What Implements Reappraisal? The Neural Bases of Cognitive Reappraisal

Reappraisal involves complex strategic processing, and seems unlikely to be represented by a single, unitary process. However, we hypothesize that the component processes upon which reappraisal depends may involve: 1) the active generation of a strategy for cognitively reframing an emotional event as well as the maintenance of that strategy over time, 2) the mediation of interference between the newly constructed top-down interpretation of an event (as more or less emotional) and a bottom-up appraisal that may continue to generate the initial affective impulse, and 3) the reinterpretation of the meaning of internal states with respect to the stimuli that elicited them. These functions have been associated with a network of four interconnected brain structures, which working together support the reappraisal process.

Lateral prefrontal cortex. Both neuropsychological and functional imaging studies have implicated lateral prefrontal cortex in the first of these functions: lateral prefrontal lesions impair working memory, reasoning, problem solving, and the ability to generate and organize plans of action (Barcelo & Knight, 2002; Miller & Cohen, 2001), and tasks tapping these abilities reliably activate PFC in both functional imaging (Cabeza & Nyberg, 2000; Smith & Jonides, 1999) and electrophysiological (Barcelo et al, 2000; Nielsen-Bohlman & Knight, 2000) studies. Although lateral prefrontal cortex is commonly activated in studies of emotion, its functional relationship to emotion-processing brain systems, such as the amygdalae, is unclear. Consider, for example, that during the perception, recall or learning of affective stimuli, studies have found activation of prefrontal cortex but not amygdalae (Canli et al, 1998; Mayberg et al, 1999; O'Doherty et al, 2001; Paradiso et al, 1999; Teasdale et al, 1999), amygdalae but not prefrontal cortex (e.g. Buchel et al, 1998, LaBar et al, 1998; Morris et al, 1996; 1999; Reiman et al, 1997; Taylor et al, 2000), both prefrontal cortex and amygdalae (Crosson et al, 1999; Damasio et al, 2000; Phillips et al, 1997) or activation of prefrontal cortex and deactivation of amygdalae (Critchley et al, 2000; Hariri et al, 2000; Liberzon et al, 2000). Lateral prefrontal activations also have been associated with induced (Baker et al, 1997; Chua et al, 1999) or endogenous moods (Davidson & Irwin, 1999). Unfortunately, it is difficult to determine the regulatory significance of these activations, because most studies have used uninstructed viewing conditions that do not take into account the possible spontaneous regulation of emotional responses in which participants tend to engage (Erber, 1996), employed stimulus judgments unrelated to emotional appraisal or reappraisal, or used stimuli that do not elicit strong emotional responses (such as faces). In line with our predictions, however, some have suggested that prefrontal cortex may represent emotion-related goals (Davidson & Irwin, 1999), although this hypothesis has yet to be systematically tested in the context of emotion regulation.

Anterior cingulate cortex. The dorsal anterior cingulate cortex (ACC) may be essential for mediating interference between top-down regulation and bottom-up appraisals that generate competing emotional response tendencies (Botvinick et al, 2001; Ochsner & Feldman Barrett, 2001). Dorsal cingulate activity consistently has been found in a variety of conditions that involve response conflict (Barch et al, 2001; Botvinick et al, 1999; for reviews see Botvinick et al, 2001; Bush et al, 2000), including tasks that require over-riding prepotent response tendencies (Carter et al, 2000; Peterson et al, 1999). It has been suggested that dorsal ACC works hand-in-hand with PFC during cognitive control: whereas PFC implements control processes, ACC monitors the degree of response conflict or error and signals the need for control to continue (Botvinick et al, 2001; Gehring & Knight, 2000; MacDonald et al, 2000; Miller & Cohen, 2000). Unfortunately, just as in the literature on prefrontal cortex, it is difficult to interpret the regulatory significance of dorsal ACC activation in studies of the perception (e.g. Beauregard et al, 1998; Francis et al, 1999; O'Doherty et al, 2001b; Teasdale et al, 1999), recall (Damasio et al, 2000) or learning (Fredrikson et al, 1998) of emotional stimuli.

Orbitofrontal cortex. For many of the same reasons that orbitofrontal cortex may play an important role in the initial appraisal of emotional stimuli, evidence suggests that it may play an important role in reappraisal as well. In supporting the contextual evaluation of stimuli, the OFC may participate in updating the meaning of emotional stimuli as they change over time (Bechara et al, 2000; Ochsner & Feldmann Barrett, 2001; Rolls, 2000), which is essential to altering stimulus meaning during reappraisal. For example, orbitofrontal lesions in humans can result in the inability to select appropriate behavioral and emotional responses across varying social contexts (Bechara et al, 2000; Hornak et al, 1996; Zald & Kim, 1996), and monkeys can impair reversals of stimulus-reward mappings (Butter, 1969; Dias et al, 1996; Iversen and Mishkin, 1970) and cause perseveration of responding to a previously rewarded stimulus for a few trials after this reversal is made (Dias et al 1996). In humans, neuroimaging studies have shown activation of lateral orbitofrontal cortex when stimulus-reward mappings are changed (O'Doherty et al, 2003). Some have suggested that lateral OFC is necessary for inhibiting prepotent responses or mediating interference between conflicting responses more generally (see Ongur & Price, 2000; Roberts & Wallis, 2000), which is consistent with neuroimaging studies showing activation of lateral OFC and related areas of ventral lateral frontal cortex when participants are performing the Stroop task (Bench et al, 1993), preparing but not executing a finger movement (Krams et al, 1998), making a finger or speech response in the direction opposite of that indicated by a cue (Paus et al, 1993), inhibiting an attentional shift when a stimulus appears in an invalidly cued location (Nobre et al, 1999), changing well-learned response mappings (Taylor et al, 1994), or reasoning deductively or inductively (Goel et al, 1997).

Medial prefrontal cortex. Recent functional imaging work suggests that dorsal regions of medial prefrontal cortex (including rostral portions of the anterior cingulate implicated in emotion (Bush et al,1999; Lane et al,1999)) may play an important role in reappraising the relationship between internal states and external events. Medial prefrontal activation has been observed when evaluating one’s own (Lane et al, 1997; Paradiso et al, 1999) or another person’s (Gallagher et al, 2000; Happe et al, 1996) emotional state, when judging the self-relevance of stimuli (Craik et al, 1999; Kelley et al, 2002) and during viewing of emotional films (Beauregard et al, 1998; Lane et al, 1997b; Reiman et al, 1997). Importantly, activation of MPFC when anticipating painful shock (Chua et al, 1999; Hsieh et al, 1999) may be inversely correlated with the experience of anxiety (Simpson et al, 2001), and in rats medial prefrontal lesions increase freezing in response to an aversive CS (Morgan & Ledoux, 1995), suggesting impairment of regulatory control.

Testing Our Working Model of Reappraisal Using fMRI

To test predictions drawn from our literature review, we conducted two fMRI studies of reappraisal whose design allowed us to make direct inferences regarding the roles that cognitive and emotion processing systems play in the reappraisal process.

Using fMRI to Examine Reappraisal

Before describing how fMRI might be used to test our reappraisal model, it is important to emphasize two interrelated points about the use of fMRI in particular, and neuroscience methods more generally, to address psychological questions (for a more complete discussion of these points, see Kosslyn, 1999 and Ochsner & Lieberman, 2001).

First, neuroscience techniques should be seen as tools in a researcher's methodological toolbox that can be used to provide, along with many other tools, converging evidence concerning a question of interest. This means that neuroscience data are not special in the sense that they provide a "magic window" on the mind that tells us what "really" is going on. No matter what technique is employed, whether neuroscientific or behavioral, researchers must draw inferences about what a given dependent measure tells us about the psychological processes under investigation, which in turn depends upon considering a given result in the context of related findings.

This leads to the second point: neuroscience data *are* special in so far as they more directly reflect the participation in a behavior of a given neural information processing system than do purely behavioral methods that measure only the inputs to, and outputs of, such systems. As illustrated below, neuroscience studies can tell us when and how particular information processing systems are engaged in a task, while also deepening our understanding of the functions carried out by particular brain systems.

The Neural Bases of Cognitive Reappraisal: An Initial Study

With these considerations in mind, in an initial study, we sought to use fMRI to address the general question of how reappraisal exerts its emotion modulatory effects. More specifically, we asked first, what types of cognitive processes support reappraisal, and second, what types of emotion processing does reappraisal modulate (Ochsner et al, 2002).

Using the model of reappraisal described above, we formulated concrete predictions about the psychological and neural processes involved in the cognitive control of emotion that could be tested using fMRI. On the one hand, reappraisal should activate prefrontal and cingulate regions implicated in cognitive control, and on the other hand, reappraisal should involve modulation of one or more emotion processing systems, such as the orbitofrontal cortex and the amygdalae.

The logic of our approach was to use the presence or absence of activation in particular cognitive and emotion processing systems as markers of the engagement or disengagement of particular psychological processes. Thus, by determining whether and how prefrontal regions are activated during reappraisal, we could draw inferences about how systems involved in implementing cognitive control strategies enable individuals to reinterpret the meaning of an affectively charged event. Similarly, by determining whether and how emotion processing systems are more or less activated during reappraisal, we could infer that reappraisal modulates either the low-level processes associated with the amygdala, and/or the complex contextual processes associated with the orbitofrontal cortex.

In this study we asked 15 female participants to view a series of negative and neutral photos for eight seconds each. Drawing on a paradigm used by Jackson et al, (2000), we had participants simply view the image for the first four seconds. At the four second mark, participants were cued either to reappraise the image in such a way that they no longer felt negative in response to it, or on baseline trials they were cued to attend to their feelings and let themselves respond naturally. In a pre-scan session, participants received substantial prior training in reappraisal, which involved imagining less negative outcomes or dispositions for pictured individuals. For example, an image of women weeping outside a church might initially be appraised as a sad scene of women at a funeral. Reappraisal training helped participants to view the scene either as a wedding rather than a funeral, or if appraised as a funeral, to see weeping as a natural and healthy way of grieving the passing of an individual who had lived a long and fulfilling life.

Two contrasts were performed to identify brain regions involved in, and modulated by, reappraisal: in the *cognitive control contrast*, regions more active on reappraise than on attend trials should be involved in the cognitive control of emotion, which we could infer support the reappraisal process; in the *emotion processing contrast*, regions more active on attend than on reappraise trials should be involved in the generation of an emotional response, which we could infer are modulated by reappraisal.

As shown in Figure 2, results were generally consistent with our expectations. The cognitive control contrast showed activation primarily in left prefrontal regions implicated in working memory and response selection. The left lateralized nature of these activations is consistent with the idea that participants use verbal strategic processes to construct novel reframes of the evocative photos they viewed. The emotion processing contrast showed modulation of left medial orbitofrontal cortex, and in a region of interest analysis (see Figure 2), modulation of the amygdala as well. These findings are consistent with the idea that reappraisal can influence low-level emotion processes involved in the initial detection and recognition of arousing stimuli as well as high level emotion processes involved in the translation of arousal into a context appropriate sense of positive or negative affect. As our working model of the neural bases of reappraisal would predict, reappraisal-related activations of prefrontal cortex correlated with concomitant modulations of amygdala and orbitofrontal cortex (see Figure 2), suggesting a sensitive regulatory relationship between them.

Interestingly, in the cognitive control contrast, we did not observe activation in the anterior cingulate cortex. Sometimes the failure to observe activation in an overall group contrast occurs because a given brain region is not consistently recruited in all participants. Some participants might recruit the region a great deal, whereas others might not recruit that region at all, and when averaged together, no activation is observed. In such cases, one can correlate a performance measure with brain activation to determine whether individuals who perform well or poorly on the task recruit particular brain regions more or less. When we correlated a measure of reappraisal success with brain activation during reappraisal, only two brain regions were identified. One was a region of parietal cortex involved in semantic analysis, and the other was a region of right anterior cingulate cortex, shown in Figure 3. Increasing activation in this region was coupled with greater reappraisal efficacy. Given the cingulate's role in monitoring and evaluating the success of cognitive control, this finding may suggest that individuals who more closely monitor the selection and application of reappraisal strategies are able to more successfully regulate their negative emotions.

The Neural Bases of Cognitive Reappraisal: Up- and Down-Regulation of Emotion

In the initial fMRI experiment described above, we examined the use of reappraisal only to attenuate, or down-regulate, negative emotion. This seemed like a reasonable starting point because attenuation is commonly employed to neutralize negative reactions, as when one interprets a hurtful remark as unintended and inconsequential. However, reappraisal also may be used to dampen positive reactions as well, as when a researcher tries not to get carried away by an initial positive finding.

One important question is whether reappraisal that enhances rather than diminishes the emotional impact of a situation engages similar neural systems. After all, reappraisal can be used to interpret an evocative stimulus in terms that not only diminish but also increase, or enhance, its emotional impact, whether negative or positive. For example, reappraisal may be used either to augment a response that already is under way, as when one enhances joy at a wedding, or to generate an emotional response to a stimulus that initially was appraised as neutral, as when one imagines that an innocuous creak signals an intruder in the next room (Langston, 1994). The use of attenuation and enhancement have been shown to play an important role in subjective well-being and adaptation to stress (Diener, 1984; Folkman, 1984; Gross, 1998a; Nolen-Hoeksema & Morrow, 1991; Parrott, 1993).

In a second study, therefore, we use fMRI to directly compare the use of reappraisal to either down or up-regulate negative emotional responses. The goals of this study were twofold: first, we sought to determine whether the down and up regulation of emotion depend upon similar control systems, and second, we sought to determine whether these two different uses of reappraisal might divergently modulate activation in emotion processing systems such as the amygdala (Ochsner et al, 2003).

Turning first to the control side of the reappraisal equation, our basic hypothesis was that changing the goal of reappraisal from the down regulation of emotion to the up regulation of emotion should not change many of the essential processes used to generate a verbal strategy for reinterpreting an event. In either case, participants would be telling stories about pictured events. In one case the stories would make them feel better, and in the other cases the stories would make them feel worse, about what they're reviewing. But in both cases, a common set of control systems used to generate the stories should be recruited.

However, generating stories that make us feel worse or better about negative events may also recruit some distinct control systems as well. We hypothesized that using reappraisal to up regulate negative emotion would uniquely recruit prefrontal systems implicated in the self generation of emotional content. For example, when viewing an image of a sick individual in the hospital, one could up regulate negative affect by generating negative descriptions of the emotions, dispositions, or outcomes experienced by that individual. This is, in fact, what we instructed participants to do. Participants could imagine that a sick individual was in great pain, had a weak constitution, and would be likely to get sicker and perhaps even die in the future. By contrast, we hypothesized that using reappraisal to down regulate negative emotion would uniquely recruit lateral orbitofrontal systems implicated in updating and altering the affective value of stimuli. When down regulating, we instructed participants to once again focus on the emotions, dispositions, or outcomes experienced by pictured individuals, but this time to imagine that things are getting better for that person. Participants could imagine that a sick individual was not in great pain, was hearty, and would be getting better in the future. The application of this neutralizing top-down reinterpretation of an otherwise negative event should require a reversal of that event’s meaning.

On the emotions side of the reappraisal equation, we hypothesized that down regulating negative affect should once again decrease activation in the amygdala, but that up regulating negative affect should increase activation in the amygdala. This prediction followed from our first study, which showed activation of the amygdala when generating a negative emotion, and attenuation of that response during reappraisal. Our reasoning was that cognitive control may modulate low-level emotion processes that encode the emotionally salient properties of a stimulus. These properties should become more or less salient as one up or down regulates negative affect. With respect to medial orbitofrontal cortex, which also was modulated in our initial study, we also hypothesized that activation in this region should increase or decrease in concordance with the up or down regulatory goal of reappraisal. Our reasoning was that cognitive control may modulate high level emotion processes as one cognitively restructures the mental context in which an event's meaning is being appraised.

To test these hypotheses we employed a variant of the experimental method employed in our initial study. This time, on each trial participants first were cued to either increase or decrease their negative affect in response to a subsequently presented photo. In the baseline condition, participants were instructed simply to look at each photo and let themselves respond naturally. To identify regions associated with the up or down regulation of negative emotion, we contrasted activation on increase or decrease trials with activation on look baseline trials. As shown in Figure 4, results provided support for our hypothesis that these two uses of reappraisal should involve some common and some distinct control systems. Both up and down regulating negative emotion engaged left lateral prefrontal control systems implicated in verbal strategic processes such as the maintenance and manipulation of verbal information in working memory-processes essential to reappraisal.

Regions unique to each form of reappraisal were identified by directly comparing activation on increase and decrease trials. In keeping with predictions, up regulating negative affect uniquely recruited a region of left rostral lateral prefrontal cortex previously implicated in self generating negative words to emotional category cues (Crosson et al, 1999), whereas down regulating negative affect recruited right lateral prefrontal and lateral orbitofrontal regions previously implicated in inhibiting prepotent responses and altering emotional associations (Bechara et al, 2000; Dias et al 1996; Hornak et al, 1996; O'Doherty et al, 2003; Rolls, 2000; Zald & Kim, 1996).

Two intriguing aspects of these results should be noted. First, we now observed bilateral activation of prefrontal cortex when down regulating negative emotion as compared to the left sided activation that was observed in our initial study. The reason for this difference is very likely due to an increase in the power in our second study: this study employed 24 as compared to 15 participants, used a more powerful fMRI pulse sequence to acquire data, and involved numerous procedural improvements over the initial study designed to better train participants to reappraise stimuli that were pre-selected to be even more strongly negative. This conclusion is further supported by examining activation in our initial study at a more liberal threshold, which reveals a bilateral pattern of prefrontal activation when regulating negative emotion that is essentially identical to the pattern observed in our second study.

A second intriguing aspect of these results is the lateralization of prefrontal activations associated with up and down regulating emotion. Davidson and colleagues (Davidson & Irwin, 1999; Davidson et al 2000) have marshaled evidence supporting the hypothesis that left prefrontal systems are associated with approach motivation whereas right prefrontal systems are associated with withdrawal motivation. In this study, we observed an association between left prefrontal activation and increasing negative affect on the one hand, and right prefrontal activation and a decrease in negative affect on the other. Our results may be consistent with Davidson's hypothesis to the extent that increasing negative affect involves increasing closeness or approach to an event, whereas decreasing negative affect involves withdrawal from an event.

Also in keeping with our predictions we found that up or down regulating negative affect resulted in increases or decreases in amygdala activation, respectively. Furthermore, the extent to which amygdala activation increased or decreased was correlated with activation in prefrontal cortex. When up regulating negative affect, prefrontal activation correlated positively with amygdala activation, and when down regulating negative affect, prefrontal activation correlated negatively with amygdala activation. These results suggest a sensitive relationship between prefrontal cortex and amygdala, further support the findings of our initial study, and indicate that cognitive control influences low-level emotion processes.

We did not observe modulations of the medial orbitofrontal cortex, however, which contrasts with the results of our initial study. When considered in light of procedural modifications that included changes in instructions on baseline trials, the failure to observe medial orbitofrontal modulations to reappraisal may not be altogether surprising. In our initial study, participants were instructed to attend to, but not to try to change, their emotions on baseline trials. One concern we had with this instruction is that asking participants to attend to their emotional responses may have selectively amplified medial orbitofrontal responses to aversive photographs on baseline trials. This concern led us to modify our baseline instructions in the second study, eliminating the instruction to attend to one's emotional state, and simply asking participants to look at a stimulus and let themselves respond naturally. Interestingly, our concern seems to have had some merit, as relatively increased activation on baseline as compared to down regulation reappraisal trials was no longer observed.

Summary and Conclusions

In summary, these two studies of the neurocognitive bases of reappraisal converge to support two inferences. The first is that reappraisal depends upon prefrontal systems implicated in other forms of cognitive control, such as working memory and response selection. Depending upon the goal of reappraisal, to up or down regulate negative emotion, similar and overlapping but distinct networks of prefrontal control systems will be recruited to make one feel better or worse. The second is that reappraisal modulates low-level emotion processing systems such as the amygdala. Whether and when reappraisal modulates higher level emotion processing systems is less clear.

Since we began this work, other investigators have begun investigating reappraisal and related forms of attentional regulation of emotion processing. Work by Beauregard and colleagues, for example, has investigated the use of reappraisal to modulate feelings of sexual arousal (2002) or sadness (2003). Their findings generally dovetail with ours: regions of lateral prefrontal cortex showed greater activation when participants reappraise, whereas emotion processing systems such as the amygdala, in the case of sexual arousal, or the insula, in the case of sadness, show decreased activation. As described below, an important goal for future work will be to determine how different types of reappraisal strategies, and other forms of self regulation more generally, involve the same kinds of interactions we've observed here.

Implications And Future Directions

Our working model of the cognitive control of emotion necessarily simplifies matters, and much work remains to be done to further test the model and extend it to other types of emotion regulatory phenomena. In this section, we use the model to help generate hypotheses concerning emotion and emotion regulation in a series of domains to illustrate one way in which neurocognitive analyses could develop our model and deepen our understanding of emotion regulation across levels of analysis.

Relations to Other Forms of Reappraisal and Self-Regulation

In developing our working model of the cognitive control of emotion, our goal was to create a framework for understanding not just reappraisal in the service of the down-regulation of negative emotion, but also other forms of reappraisal, and even other forms of self-regulation. One important next step, therefore, will be to apply this framework to other kinds of reappraisal, and to other important forms of self-regulation.

In our initial fMRI studies described above, we examined the use of reappraisal only in the context of negative emotion. This seemed like a reasonable starting point because reappraisal is often used to neutralize negative reactions, as when one interprets a hurtful remark as unintended and inconsequential. However, reappraisal also may be used to manage positive or appetitive reactions as well, as when a researcher tries not to get carried away by an initial positive finding, or a child attempts to delay gratification (Mischel & Ayduk, this volume). One important question, therefore, is whether the findings of our initial study will generalize to the down-regulation of positive emotion. It is possible, for example, that reappraisal of appetitive reactions will engage prefrontal control systems that overlap highly with those used to regulate negative reactions, but that these prefrontal systems will modulate structures specifically involved in generating appetitive reactions, such as the striatum.

How might our work on cognitive regulation of emotion relate to other important forms of self-regulation? Chapters in this volume by MacCoon & Newman, Rothbart et al, and Rueda et al all deal with mechanisms of selective attention, which is one of the five strategies for regulating emotion that we outlined in a preceding section. Work by Posner and colleagues reviewed in Rueda et al has supported the notion that cingulate and prefrontal systems are essential for supporting attention to target stimuli and ignoring irrelevant distracters, as well as the sustained maintenance of attention over time. As discussed above, cingulate and prefrontal control systems also figure prominently in our model of reappraisal. Cognitive neuroscience research suggests that these systems may participate in multiple forms of cognitive control, but it is not yet clear whether control systems supporting selective attention are distinct from those supporting the maintenance and manipulation of cognitive strategies that are part and parcel of reappraisal.

Some studies have addressed the way in which full or divided attention to affectively salient stimuli influences their processing by the amygdala. Amygdala responses to fear faces seem to be unaffected by attentional manipulations (e.g. Anderson et al 2003; Vuillumier et al, 2001, cf. however Pessoa et al, 2002). Other studies have examined the way in which processing of fear faces is influenced by direct or indirect judgments of their affective properties. Amygdala activation has been shown to be greater when participants indirectly process affective content, for example by judging the gender of a fear face, as compared to when participants must directly process affective content, for example by rating the degree of negative affect expressed (e.g. Critchley et al, 2000; Hariri et al, 2000; Winston et al, 2002). These studies have not investigated the regulation of emotional experience or responses per se, and instead have investigated processing of social cues to emotional experience in others that may have evolutionarily conserved significance (for example, alerting us to the presence of threats that have been detected by conspecifics). Nonetheless, in the context of our reappraisal studies, they suggest that there may be important differences between the cognitive restructuring of emotional experience and simple inattention to, or superficial processing of, stimuli with some affective relevance.

An important goal for future research is differentiating control systems important for reappraisal as opposed to selective attention or other forms of cognitive self-regulation, and the way in which they interact with emotion processing systems.

Individual Differences in Emotion and Emotion Regulation

Individuals differ both in their emotional responding and in their use of reappraisal. Our working model could be used to characterize and test hypotheses about the neurocognitive bases of these differences. Such investigations would be important for at least two reasons. First, studies of emotion regulation that explicitly consider these two important sources of variation among individuals may have increased power to detect the cognitive and neural mechanisms of emotion regulation. Second, differences in emotional responding and regulation also may help to account for gender differences in emotional experience and brain activation (George et al, 1996; Kring et al, 1998).

Individual differences in emotional responding. Individual differences in emotional responding arise -- at least in part -- from early-appearing, biologically based differences among individuals. The dimensions of extraversion and neuroticism have been found to be associated with positive and negative emotional experience, respectively (Costa & McCrae, 1980; Eysenck, 1990; John, 1990; Meyer & Shack, 1989). Individuals who exhibit a high degree of extraversion -- the tendency to be upbeat, to be optimistic, and to enjoy social contact -- report more positive emotions in everyday life than less extraverted individuals (Costa & McCrae, 1980). Individuals who exhibit a high degree of neuroticism -- the tendency to worry, to be anxious, and to be apprehensive -- report more negative emotions in everyday life than less neurotic individuals (Costa & McCrae, 1980). Experimental manipulations of emotion have likewise documented strong personality-emotion level/reactivity relations (Gross et al, 1998) whose neural basis is suggested by Canli et al (2001), who showed that extraversion predicts right amygdala, striatum, cingulate and prefrontal activation to positive photos, whereas neuroticism predicts right prefrontal deactivation to negative photos. These data are consistent with the hypothesis that extraverts use prefrontal regions to enhance positive emotion whereas neurotics fail to regulate negative emotion using these same regions. This hypothesis needs to be tested in future work.

Individual differences in reappraisal. Less is known about individual differences in emotion regulation than about individual or group differences in emotional responding. However, recent research has shown that individuals do differ in their typical use of reappraisal (Gross & John, in press). Such individual differences in the use of reappraisal can be measured reliably and validly, and predict self- and peer-reports of (a) greater positive emotion and (b) lesser negative emotion. Future work may determine whether typical use of reappraisal in the real world is related to reappraisal efficacy as measured in the functional imaging laboratory. Such analyses could reveal ways in which life experience tunes cognitive control systems to better support the reappraisal process.

Emotion Regulation Across the Lifespan

Emotion regulation processes play an important role throughout the lifespan. There are indications, however, that the use of cognitive reappraisal as an emotion regulation strategy may vary across the lifespan.

Emotion regulation in childhood. One crucial step in the life-long acquisition of emotion regulation skills is the development of the capacity to cognitively reappraise emotion-eliciting situations. As early as the preschool years, children understand that emotions can be caused by internal (mental) events as well as external (physical) events (Harris, 1989). However, it is not until age 10 or so that children start to explain changes in their own or others' emotions by invoking mental events (Saarni, 1993). At about the same age, children report using more cognitively-oriented emotion regulation strategies to change their emotions. Thus, in contrast to younger children (age 6), older children (age 10) at boarding school said that they tried to alleviate negative emotions such as sadness and homesickness by using cognitive strategies such as distraction and reappraisal (Harris & Lipian, 1989). Although little is currently known about the frequency of use of cognitive reappraisal from late childhood through adulthood, it appears that there may be an increase in the use of cognitive reappraisal not only through adolescence (Harris, 1989), but even through adulthood (Gross et al, 1997).

The emergence of reappraisal capacity around age 10 is striking given 1) that we have found that reappraisal depends upon prefrontal cognitive control systems in adults, 2) that cold forms of cognitive control such as working memory develop between the ages of 6 and 12 years (Dempster, 1981; Swanson, 1996), 3) that the development of these control abilities is thought to depend upon delayed maturation of prefrontal cortex that continues into adolescence (Casey et al, 2000; Diamond, 2002), and 4) that amygdala responses to fear relevant stimuli in children 10 years of age may be indistinguishable from those of adults (Baird et al, 1999; Thomas et al, 2001a), suggesting adult-like functioning of at least one emotion processing system at a time when prefrontal cortex is still maturing. Given these facts, we have hypothesized that the development of prefrontal cortex may undergird the development of cognitive reappraisal as children mature into adolescence and young adulthood. We recently have begun studies directly addressing these hypothesis using modified versions of our reappraisal paradigm described above.

Emotion regulation in later life. As we age, many of our cognitive and physical abilities decline. By contrast, both field and laboratory evidence suggest that emotional well-being may actually improve with age. How can these apparently discrepant findings be reconciled? We have hypothesized that as people age, they become increasingly skilled at using effective emotion regulation strategies such as cognitive reappraisal (Gross et al, 1997). This hypothesis derives from two related observations. On one hand, data from experience sampling (Carstensen et al, 2000), longitudinal (Charles et al, 2001), and cross-cultural (Diener & Suh, 1998) field studies demonstrate that whereas the frequency and duration of positive emotions remains constant across adulthood, negative emotions decline in frequency and duration. And in the lab, older people experience induced negative emotions as intensely as younger adults (Malatesta & Kalnok, 1984). Taken together, these data suggest that the capacity to generate emotion does not decline with age. On the other hand, older adults report greater control over emotion (Gross et al, 1997) as shown by their ability to limit the escalation of negative affect in social interactions (Carstensen et al, 2000) and expression of diminished physiological activation when recalling emotional autobiographical events (Levenson, 1994).

Although there may be many factors contributing to an improvement in emotion regulation in older adults, including a relative prioritization of affect regulatory goals (as posited by socioemotional selectivity theory, (Carstensen et al, 1999)), at present the contextual factors and processing mechanisms responsible are not clear. In the context of our neurocognitive model of reappraisal, we might hypothesize that older adults may be better able to attenuate negative emotions and/or enhance positive emotions, which could be tested in functional imaging studies contrasting these two forms of reappraisal in the same participants.

Interestingly, it is known that some of the prefrontal neural machinery supporting cognitive control declines with age (DeCarli et al, 1994; Raz et al, 1997; Reuter-Lorenz et al, 2000; Rypma & D'Esposito, 2000), which might suggest that older adults employ more efficient strategies and/or recruit additional systems to support emotion regulation not used by younger individuals (Reuter-Lorenz et al, 2000).

Concluding Comment

In Aristotle's *Nichomachean Ethics*, he argued that emotions are useful only when they are about the right things, are expressed in the right way, arise at the right time, and last the right amount of time. This formulation points to -- but does not address -- a fundamental question that has intrigued scientists since Aristotle: How can individuals regulate their emotions so as to maximize their emotions' adaptive value? This question motivates our own work as well as that of many other contributors to this volume. As this volume shows, many different answers can be provided for this question. In our chapter, we have taken a few steps towards providing an answer of a very particular kind. This answer has to do with reappraisal, and makes heavy use of neuroscience methods and findings in order to identify neural information processing systems that support reappraisal, and are in turn modulated by it. We hope that both our process model of emotion regulation and the empirical findings it has generated have helped to clarify the neural bases of emotion regulation. In particular, we hope to have shed some light on what Frankl memorably called "the last freedom," namely the capacity to tailor how one responds emotionally to a given situation by using cognitive reappraisal.

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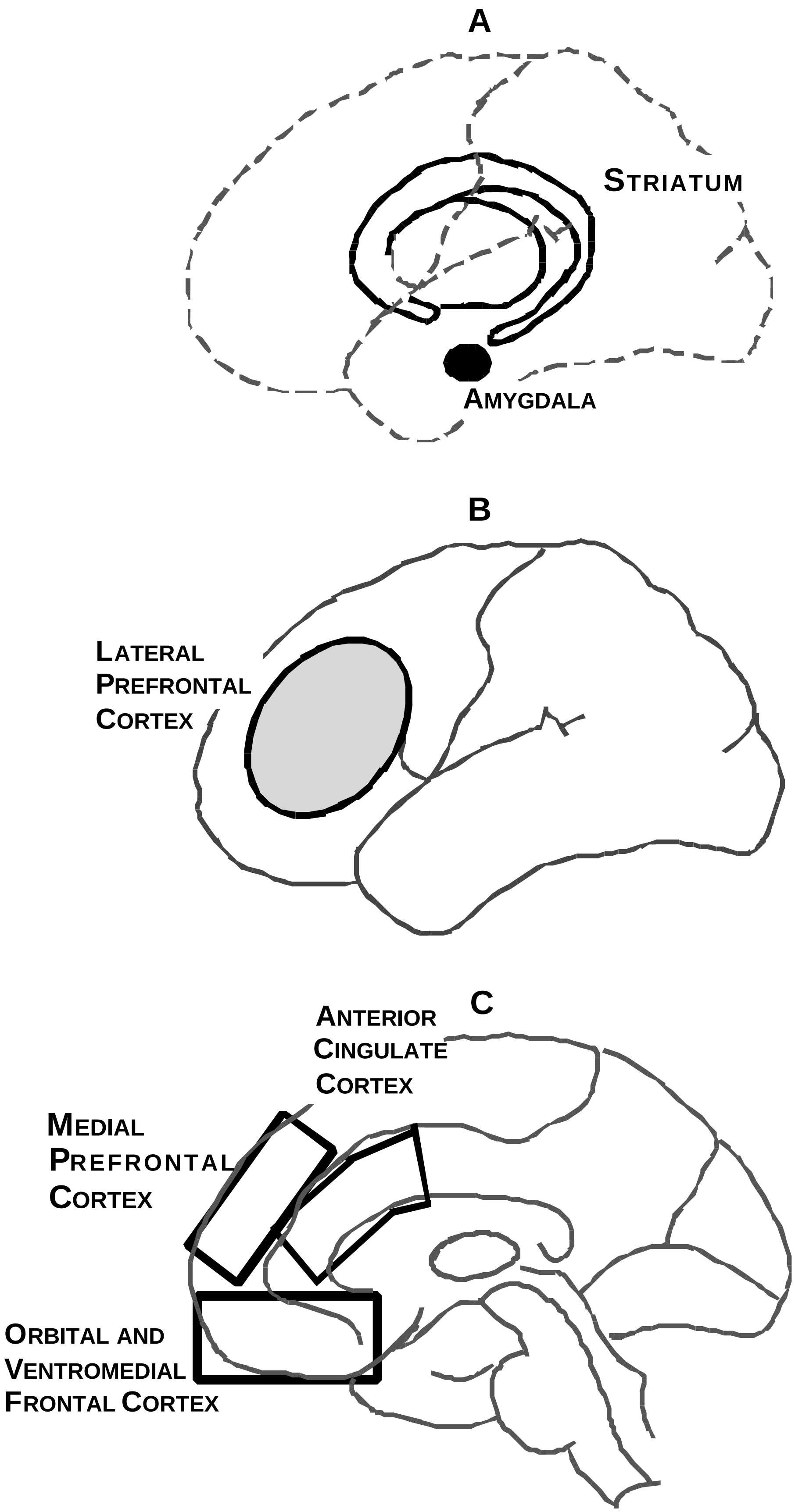
Figure Captions

Figure 1. Schematic overview of brain systems involved in the cognitive regulation of emotion. A. Two subcortical brain systems implicated in appraising the emotional significance of stimuli, viewed through a transparent image of the left hemisphere. The amygdala is implicated in the rapid detection and encoding of arousing stimuli including potential threats; the striatum is implicated in the encoding and representation of sequences of thoughts and actions that lead to reinforcing outcomes, including rewards. B. The lateral prefrontal cortex, shown here on a lateral view of the left hemisphere, has been implicated in the generation, maintenance, and strategic selection of control strategies used to regulate emotion. C. Medial view of the right hemisphere showing two brain systems implicated in cognitive control and one brain system implicated in emotion generation. The anterior cingulate cortex and medial prefrontal cortex are involved in the online monitoring of control strategies and drawing inferences about internal states, respectively. The orbitofrontal and ventromedial frontal cortex is important for placing emotional responses in their appropriate social context, which may be important both for the appraisal and cognitive reappraisal of emotional responses.

Figure 2. Lateral prefrontal and amygdala regions activated in our first study (Ochsner et al, 2002). A. Lateral prefrontal (LPFC) and medial orbitofrontal (MOFC) cortical regions activated (green) or deactivated (red) by reappraisal used to down-regulate negative emotion. B. Group averages for parameter estimates of activation across trial types in right amygdala ROI. Activation decreased significantly ($p < .05$) on Reappraise as compared to Attend trials with negative photos and was not significantly different from activation on Attend trials with neutral photos. Right panel shows representative ROI for one participant.

Figure 3. Top panel shows region of right anterior cingulate cortex whose level of activation across participants predicted their drop in negative affect on reappraise as compared to attend trials. Bottom panel plots activation against drop in negative affect. Each point represents one participant's level of cingulate activation and the corresponding magnitude of affect change.

Figure 4. Prefrontal regions activated when increasing (Panel A) or decreasing (Panel B) negative emotion via reappraisal. A. Lateral views of the right and left hemisphere showing regions activated when participants cognitively increased their negative affect. Note that activations are primarily left sided. B. Lateral views of the right and left hemisphere showing regions activated when participants cognitively decreased their negative affect. Note that activations are substantially bilateral. Common activation of left lateral prefrontal systems by both the cognitive increase and decrease of negative emotion suggests that these two types of reappraisal rely upon a common set of verbal strategic control processes associated with these left lateralized regions. Selective recruitment of right prefrontal regions when decreasing negative affect is consistent with the involvement of these regions in behavioral inhibition and withdrawal more generally. See text for details.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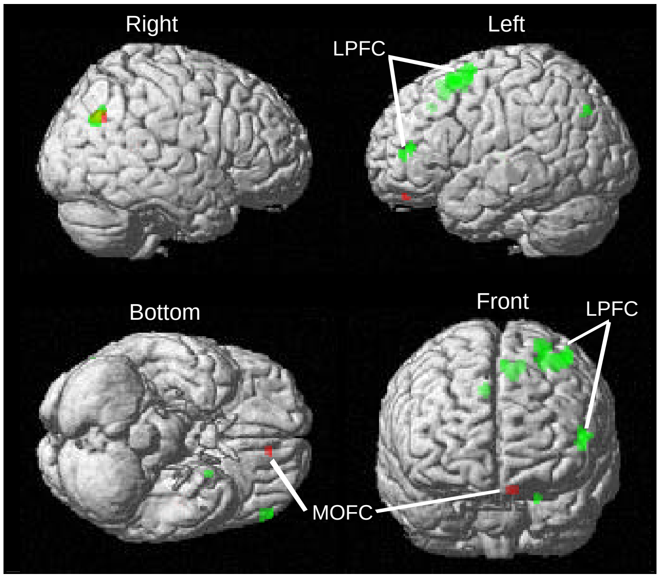
A.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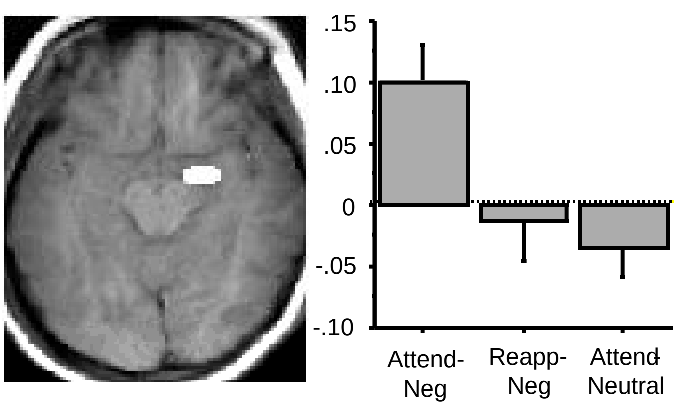
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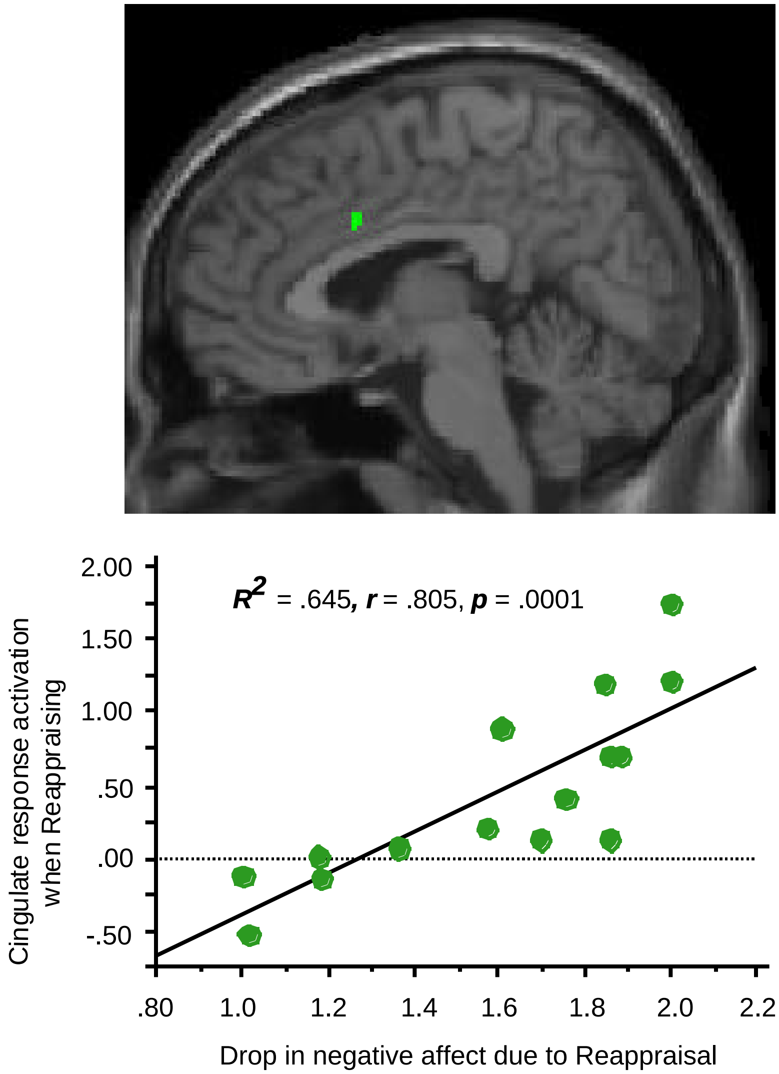
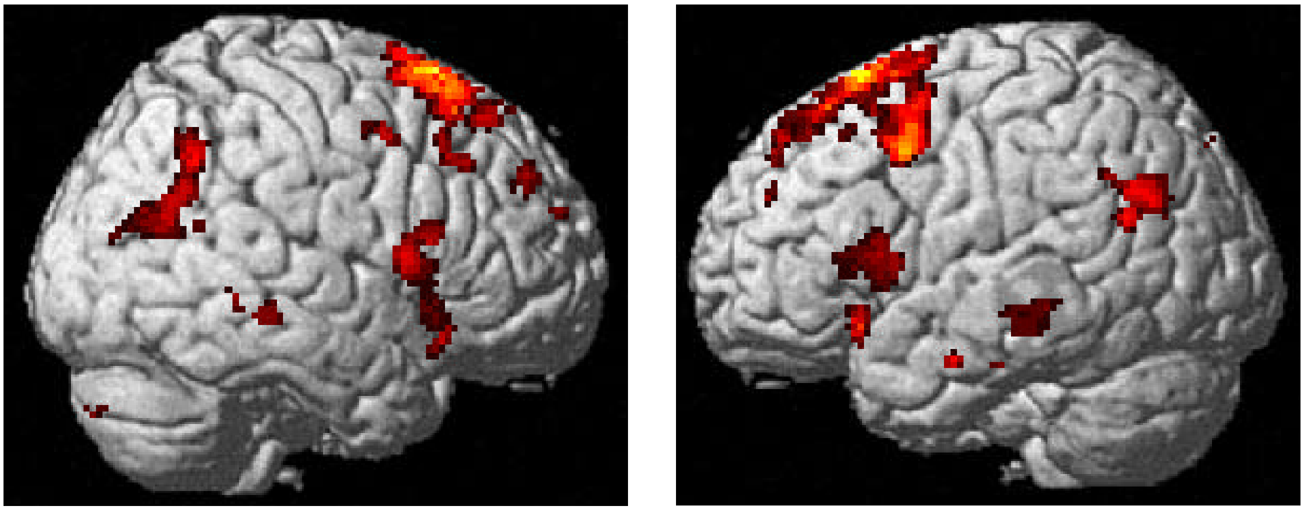


R2 = .645, r = .805, p = .0001
2.00
1.50
1.00
.50
.00
-.50
Cingulate response activation when Reappraising
.80
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Drop in negative affect due to Reappraisal

A.



B.