CHAPTER 5

The Neural Architecture of Emotion Regulation

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Churchill once said of Russia that it was "a riddle wrapped in a mystery inside an enigma." He could as easily have been describing the topic of emotion regulation. Emotions are nothing if not a riddle, at once substantial and fleeting and always the subject of much debate. Our capacity to regulate emotions is something of a mystery, at once ubiquitous and deeply puzzling, particularly when our ability to regulate emotion fails us. And emotion and emotion regulation involve social, psychological, and biological factors, whose interplay can be somewhat enigmatic. In this chapter, we draw on recent human neuroimaging studies to offer a framework for analyzing the neural systems that give rise to our emotion regulatory abilities.

Toward that end, our chapter is divided into five parts. The first part provides an initial working model for understanding the brain bases of emotion and cognitive control that integrates insights from both human and animal research. The second and third parts review recent functional imaging research that examines the use of two different types of cognitive control to regulate emotional responses. The fourth part uses this review to update and elaborate the initial model, and the final section explores how it can be used as a foundation for future research.

MODELS OF THE BRAIN BASES OF EMOTION AND EMOTION REGULATION

A century of animal research has examined the neural bases of emotion and emotional learning (Davidson, Fox, & Kalin, this volume; Quirk, this volume). However, it has only been in the past decade that human research has begun to examine the neural bases of our emotion regulatory abilities. As a consequence, until recently models of the brain systems involved in emotion and emotion regulation were derived from a bottom-up approach to understanding emotion that emphasizes the affective properties of stimuli and gives relatively short shrift to higher-level cognitive processes and individual differences in emotion and regulatory abilities.

The Bottom-Up Approach

The bottom-up approach characterizes emotion as a response to stimuli with intrinsic or learned reinforcing properties (e.g., Rolls, 1999). This view has roots in both common sense and academic theories of emotion that treat emotions as the inevitable consequence of perceiving specific kinds of stimuli. This view was memorably propounded by William James (1890) who wrote, "The organism is like a lock to which is matched certain parts of the environment as if they are keys. And among these 'nervous anticipations' are the emotions which are such that they are 'called forth directly by the perception of certain facts' " (p. 250).

Early nonhuman research on the brain systems involved in emotion seemed to support this view. Numerous experiments suggested that both aggressive and prosocial behaviors could be triggered by direct electrical stimulation of either subcortical brain structures, such as the hypothalamus and amygdala, or the "limbic" cortical systems with which they were connected (Cannon, 1915; Kaada, 1967; Maclean, 1955). Modern lesion and recording studies have built on these early studies by elaborating complementary roles for subcortical and cortical systems in emotional learning. For example, research has shown that the amygdala is important for learning initially which events predict the occurrence of intrinsically unpleasant stimuli (e.g., electric shock), whereas the medial and orbital frontal cortex support extinction and alteration of these stimulus–reinforcer associations (LeDoux, 2000; Quirk & Gehlert, 2003; Rolls, 1999). Taken together, both past and present nonhuman work is motivated by the view that emotions are generated by bottom-up processes that encode two kinds of associations: those between actions and the pleasant or unpleasant outcomes that are a consequence of them (as in operant conditioning) and those between stimuli and the pleasant or unpleasant responses they evoke (as in classical conditioning).

This view was echoed by the first cognitive neuroscience studies of emotion in healthy humans, which followed the advent of functional imaging research in the early 1990s. These initial studies treated emotion as a response to stimulus properties that could be perceived directly and encoded in a bottom-up fashion. Participants were simply asked to passively view, hear, smell, taste, or touch purportedly affective stimuli while brain responses were recorded in a scanner. This approach reflected the influence of successful prior nonhuman research. But it also reflected the influence on human imaging work of vision and memory research that involved passive perception of words and objects whose processing was thought to be driven by the bottom-up encoding of stimulus properties such as shape, size, and color.

Although the emotion-as-stimulus-property view was sensible given prior work, problems with this view soon became apparent as imaging studies failed to consistently confirm predictions based on studies with nonhuman populations. For example, amygdala activation in response to emotional stimuli was found inconsistently (Phan, Wager, Taylor, & Liberzon, 2002), and prefrontal systems not important in animal work were often activated in human studies (for review, see Ochsner & Gross, 2004). As described in the next section, studying emotion in humans involves something more than mapping the neural correlates of bottom-up processing of affective stimuli.

The Top-Down Approach

That something more was explained by appraisal theories of emotion. Such theories describe emotion as the product of cognitive processes that interpret the meaning of stimuli in the context of an individual's current goals, wants and needs (Scherer, Schorr, & Johnstone, 2001). A critical feature of appraisal theories is that the same stimulus can be appraised as threatening or not, or rewarding or not, depending on the circumstances. For example, seeing someone draw his fist back and prepare to strike might elicit fear or anger if appraised as aggressive but might elicit laughter if appraised as playful and harmless.

Although appraisals may be generated automatically by bottom-up processes, they may also be controlled by top-down control processes that enable one to deliberately attend to and appraise a situation in different ways. Unlike rodents and perhaps many other primates, humans possess the capacity to make conscious choices about the way they construe and respond to emotionally evocative situations. Rather than responding on the basis of automatically activated stimulus–response linkages, humans can regulate their emotions by relying on higher cognitive processes such as, selective attention, working memory, language, and long-term memory. It should be noted that for many appraisal theorists, bottom-up appraisal processes are not rigid reflexes, but flexible interpretations may be influenced by situational factors and individual differences in personality and emotion. Top-down processes do allow an individual, however, to actively control the appraisal process using various kinds of higher cognitive processes.

These higher cognitive processes have been associated with regions of lateral and medial prefrontal cortex (PFC) thought to implement processes important for regulatory control, and regions of dorsal anterior cingulate cortex (ACC) thought to monitor the extent to which control processes are achieving their desired goals (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miller & Cohen, 2001). The use of top-down control processes may help explain some of the apparent inconsistency of the early emotion imaging literature. The spontaneous use of cognitive regulatory strategies by participants is quite common in behavioral research (Erber, 1996) and may be as common in imaging studies. If participants are controlling their attention to, and appraisal of, emotionally evocative stimuli, that could explain at least some instances of PFC activity, and potentially failures to observe amygdala activity as well. This hypothesis provided a springboard for developing our working model of the cognitive control of emotion.

Integrating Bottom-Up and Top-Down Approaches

Building on prior findings and integrating previous approaches, we have formulated an initial working model of the cognitive control of emotion. According to this model, emotion generation and regulation involve the interaction of appraisal systems, such as the amygdala, that encode the affective properties of stimuli in a bottom-up fashion, with control systems implemented in prefrontal and cingulate cortex that support controlled top-down stimulus appraisals (Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner & Gross, 2005; Ochsner et al., 2004b). It should be emphasized that the distinction between top-down and bottom-up processing is relative and not absolute. It is likely, for example, that there is a continuum along which processes can be arrayed with bottom-up and top-down as the end-point extremes. Nonetheless, this distinction serves a heuristic function for guiding thinking about the way in which different types of processes interact and combine during emotion regulation.

Our model posits that emotions can be generated and modulated either by bottom-up or top-down processes. Top-down processes can be used to place particular stimuli in the focus of attention and, in so doing, have the capacity to generate and regulate emotions by determining which stimuli have access to bottom-up processes that generate emotions. Once bottom-up generation has begun (and sometimes even before, if one anticipates a negative event), top-down processes can regulate, redirect, and alter the way in which triggering stimuli are being (or will be) appraised. Top-down processes also can initiate emotion generation directly, as beliefs, expectations, and memories guide the appraisal and interpretation of stimuli. In many cases, no external stimulus need be present—an individual can generate an emotion using top-down-generated memories of past experiences or the construction of possible future events.

Figure 5.1 illustrates the interaction between bottom-up and top-down processes in emotion generation and regulation. As shown in Figure 5.1a, the bottom-up generation of an emotional response may be triggered by the perception of stimuli with intrinsic or learned affective value. Appraisal systems such as the amygdala, ventral portions of the striatum (also known as the nucleus accumbens), and insula encode the affective properties of stimuli (Calder, Lawrence, & Young, 2001; Ochsner, Feldman, & Barrett, 2001; Phillips, Drevets, Rauch, & Lane, 2003). These systems then send outputs to hypothalamic and brainstem nuclei that control autonomic and behavioral responses, and also to cortical systems that may represent in awareness the various features of an emotional response. The top-down generation of an emotional response begins with the perception of situational cues that lead an individual either to anticipate the occurrence of a stimulus with particular kinds of emotional properties (e.g., shock) or, as shown in Figure 5.1b, to have the goal of thinking about a neutral stimulus in emotional (in this case negative) terms. At this point, an anticipatory or a manufactured emotional response may be generated. In either case, top-down beliefs alter the way in which the stimulus is appraised and subsequently experienced (e.g., leading one to experience something neutral as emotional). The top-down regulation of an emotional response is triggered by the perception (or anticipation) of an affective stimulus but transforms the initial affective appraisal through the use of cognitive control. As shown in Figure 5.1c, the active generation and application of a cognitive frame alters the way in which a stimulus is appraised. In this way, emotional responses are altered in accordance with one's current goals.

To ground this process account of emotion regulation in the brain, we have found it useful to draw on models of cognitive control in humans (e.g., Beer, Shimamura, & Knight, 2004; Miller & Cohen, 2001) and animal models of emotion (e.g., LeDoux, 2000; Quirk & Gehlert, 2003; Schultz, 2004). As illustrated in Figure 5.2, emotion regulation is thought to follow from interactions between prefrontal and cingulate systems that implement control processes and subcortical systems such as the amygdala and basal ganglia that implement various types of affective appraisal processes (Ochsner & Gross, 2004, 2005).

Five principles form the foundation of this model. The first is that emotional responses arise from interactions between multiple types of bottom-up and top-down appraisal processes, each of which may be associated with different neural systems. For example, there are debates about the putative regulatory functions of dorsal versus ventral PFC (D'Esposito, Postle, Ballard, & Lease, 1999; Roberts & Wallis, 2000) or lateral

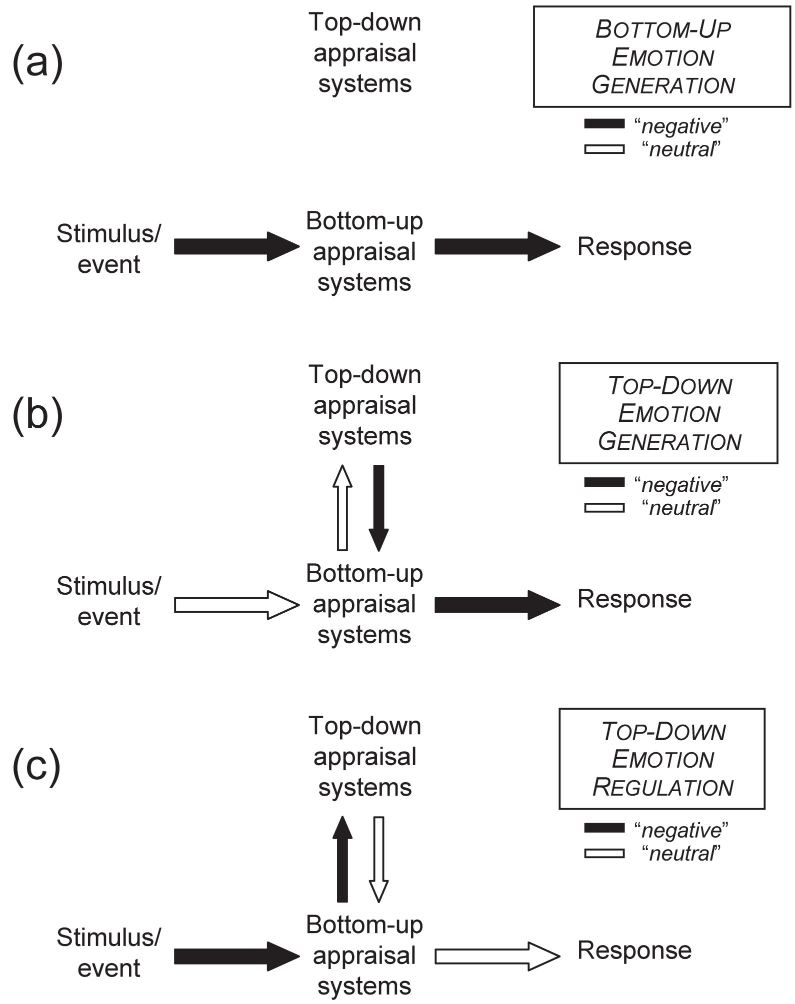

FIGURE 5.1. Schematic diagram of processes implicated in our initial model of emotion regulation. Three panels illustrate how emotional responses may evolve out of interactions between processes involved in the bottom-up and top-down generation and regulation of emotion. Although the diagram illustrates the processes involved in generating/regulating negative emotions, the processes may work in much the same way for positive emotions as well. (a) The bottom-up generation of an emotional response is triggered by the perception of stimuli with intrinsic or learned affective value. (b) In the top-down generation of an emotional response, beliefs lead one to appraise an otherwise neutral stimulus as emotionally evocative, in this case as negative. (c) In the top-down regulation of an emotional response, one actively generates and applies a cognitive frame that alters the way in which the stimulus is appraised, in this case transforming a negative appraisal into a neutral one. See text for details.

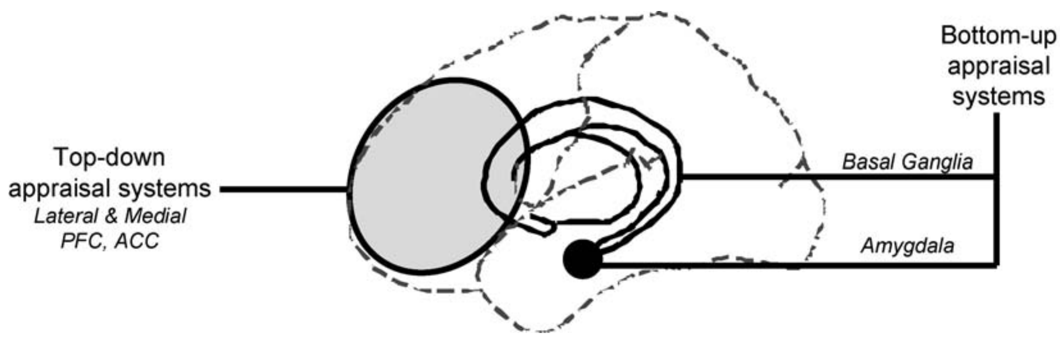

FIGURE 5.2. Schematic illustration of brain systems implicated in our initial model of emotion regulation. Each brain system shown here can be associated with a different kind of processing shown in Figure 5.1. According to this model, emotions evolve out of interactions between prefrontal and cingulate systems (not shown) that implement top-down appraisal processes, which in turn control bottom-up appraisals generated by subcortical systems like the amygdala (which may signal the affective salience of both negative and positive stimuli) and basal ganglia/striatum (which may be particularly important for learning about rewarding stimuli). Other brain systems, such as the insula (which lies underneath the junction of the frontal and temporal lobes), also may play important roles in encoding the affective properties of stimuli but are not shown here. See text for details.

and medial orbitofrontal cortex (Elliott, Dolan, & Frith, 2000; Roberts & Wallis, 2000), and there are likely different, if overlapping, sets of neural systems implicated in primarily negative emotion (e.g., the insula), positive emotion (e.g., the basal ganglia) or both (e.g., the amygdala) (for reviews see Calder et al., 2001; Ochsner & Barrett, 2001). The second is that emotional responses are defined by their valence, degree of intensity, and potential to initiate changes across multiple response systems (Cacioppo & Berntson, 1999; Feldman Barrett, Ochsner, & Gross, in press). Third, following definitions of regulation or control in the cognitive neuroscience literature (e.g., Miller & Cohen, 2001), emotion regulation occurs when the use of goal-directed controlled processing alters one's emotional response. Importantly, this means that emotion regulation may occur in two different ways: (1) when one has the explicit goal of changing one's emotional state—as when attempting to reduce stress by actively reinterpreting an aversive situation in unemotional terms (this is known as reappraisal, as described in a following section)—and (2) when one is engaging control processes to achieve some other type of task-related goal, and emotion regulation occurs as a consequence—as when attempting to predict when a potentially painful event will occur generates anxiety in anticipation of it. Fourth, when considering how control processes may shape the appraisal process, it is important to understand what type of response (experiential, physiological, or behavioral) is being changed, in what way (whether it is to start, stop, or alter a response) and which appraisal systems are being modulated to achieve that effect. Fifth, regulatory strategies differ in the extent to which they rely on different types of control processes instantiated in different parts of PFC and ACC. An understanding of all five principles is necessary for building a model of the functional architecture supporting emotion regulation.

The remainder of this chapter uses this initial model as its starting point for organizing a review of current and potential future directions for research. Our focus is on studies that investigate *attentional deployment* or *cognitive change* (see Gross & Thompson, this volume). This focus is motivated by the facts that these two types of emotion control are quite common and to date have received the greatest amount of empirical attention. Because work on the neural bases of emotion regulation per se has only begun to appear, this review also considers studies involving the regulation of other types of valenced responses as well, including affective evaluations and motivational impulses such as pain (for discussion of relationship between different types of affective impulses, see Gross & Thompson, this volume).

ATTENTIONAL DEPLOYMENT

Attention is one of the most fundamental cognitive processes, acting as an all-purpose "gatekeeper," that allows passage of goal-relevant information for further processing. By definition, processes unaffected by attentional manipulations are deemed automatic, and those influenced by attention generate enhanced behavioral and neural responses when attention is directed toward them. Although numerous cortical and subcortical systems participate in appraising the affective properties of stimuli (see, e.g., Ochsner & Barrett, 2001), to date most cognitive neuroscience research has focused on the amygdala.

According to our model, attentional deployment in the context of emotion should work in much the same way it works in "cold" cognitive contexts. For example, directing attention to photographs of faces enhances activation in the cortical systems supporting processing of them (i.e., the fusiform face area), whereas directing attention to other stimuli decreases activation in these systems (e.g., Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003). In the case of emotion, the question is whether directing attention to emotionally evocative stimuli influences amygdala activity. The underlying assumption of many studies is that attention should not impact the amygdala, which would suggest that its processing is automatic. Two ways in which controlled attention can be used to regulate emotion have been investigated.

Selective Attention

Selective attention can be used to select some stimuli or stimulus features for further processing while limiting the processing of other stimuli or stimulus features. For example, while in line at the airport, one's emotions can be controlled by paying attention to the smiling face and familiar voice of a traveling companion and ignoring the ranting and raving of an irate traveler standing nearby. To date, neuroimaging studies have been concerned primarily with the impact of attention on the perception of negatively valenced stimuli, which typically are faces that do not elicit strong emotional responses when presented in isolation (as has been typical in studies done to date).

Unfortunately, results have shown contradictory patterns of amygdala response when participants pay attention to the emotional features of stimuli. For example, some studies have reported amygdala activity decreases when participants pay greater attention to emotional properties of stimuli and process them with a greater degree of cognitive elaboration. Thus, amygdala activity is diminished by judging the facial expression rather than gender of fearful, angry, or happy faces (Critchley et al., 2000), matching emotional faces or scenes based on semantic labels rather than perceptual features (Hariri, Bookheimer, & Mazziotta, 2000; Lieberman, Hariri, Jarcho, Eisenberger, & Bookheimer, 2005), viewing supra- as compared to subliminal presentations of African American faces (Cunningham, Raye, & Johnson, 2004), or rating one's emotional response to aversive scenes rather than passively viewing them (Taylor, Phan, Decker, & Liberzon, 2003). By contrast, other studies have found amygdala activity to be *invariant* with respect to attention to emotional stimulus features. In these studies, amygdala responses were unchanged when participants attended to and judged the gender of fearful faces and ignored simultaneously presented houses (Anderson et al., 2003; Vuilleumier, Armony, Driver, & Dolan, 2001); judged the gender as compared to expression of happy and disgust (Gorno-Tempini et al., 2001) or happy, sad, disgusted, and fearful faces (Winston, O'Doherty, & Dolan, 2003); judged either the age or trustworthiness of normatively untrustworthy faces (Winston, Strange, O'Doherty, & Dolan, 2002); or judged whether photos showed individuals from the past or present as compared to judging whether they were good (e.g., Martin Luther King) versus bad people (e.g., Osama bin Laden) (Cunningham, Johnson, Gatenby, Gore, & Banaji, 2003).

Although the precise reasons for the discrepant results of these studies are not clear, there appear to be at least three methodological possibilities. First, because most studies seems to implicitly assume that emotion is a stimulus property that can be perceived bottom-up, like shape size or color, they failed to provide behavioral (e.g., subjective reports of experience or facial expression) or physiological measures (e.g., measures of heart rate, respiration, or skin conductance) that could be used to verify that emotional responses were, in fact, generated. Instead, they relied only on brain activation changes to support the inference that modulation of an emotional response has taken place, which provides little leverage for understanding why activation of an appraisal system was or was not observed.

Second, the studies typically used face stimuli presented in isolation, devoid of important contextual information that may determine their emotional power. In everyday encounters, facial expressions may have the capacity to trigger emotions in large part because of additional situational and contextual information available to a perceiver that supports inferences about why a person is smiling (he or she is in love), frowning (he or she failed an exam), or looks angry (I just insulted them). Behavioral research suggests that contextual information plays a key role in determining what emotion is attributed to facial expression in the first place (Carroll & Russell, 1996), and a recent imaging study indicates that manipulations of context can determine whether or not a face is perceived as expressing surprise or fear, with amygdala activation evident only if the face is perceived as expressing fear (cf. Kim, Somerville, Johnstone, Alexander, & Whalen, 2003).

A third problem also stems from the tendency to treat emotion as a stimulus property perceived directly like color. From this strongly bottom-up perspective, it makes sense to examine how diminished attention impacts emotion, which essentially becomes a form of perceptual processing. If this view of emotion is correct, then the results reviewed previously could fail to cohere because they each used a different attentional manipulation, each of which may impose a differing degree of (as of yet unquantified) attentional load. However, if emotion results from an often very rapid—but partially controllable—appraisal process, then manipulations of attention may impact not only what perceptual features are encoded but what kinds of controlled top-down appraisal processes are engaged (Erber, 1996). In keeping with this suggestion, Cunningham, Raye, and Johnson (2004) found right ventral lateral activation (LPFC) when making good/bad evaluations of attitude targets (e.g., abortion) on trials where they reported in postscan ratings that they had exerted control. Although many of the studies described earlier did not report PFC activations, some did report an inverse relationship between PFC and amygdala activity (e.g., Hariri et al., 2000; Lieberman et al., 2005; Taylor et al., 2003). This suggests that in some cases (e.g., when explicitly paying attention to emotional stimulus features), participants may be using available cognitive resources to actively reappraise stimuli. As discussed later, reappraisal is thought to involve PFC–amygdala interactions.

Attentional Distraction

Attentional distraction refers to the engagement of a secondary task that diverts attention from processing a primary target stimulus. It differs from selective attention in that it does not involve screening out unwanted distractions per se, but involves managing the competing demands of doing two things at once. Most studies using this approach have examined the impact of performing a cognitive task on responses to aversive painful stimulation. These studies avoid some of the methodological problems described earlier because they use a highly arousing stimulus that can elicit strong changes in multiple response channels, and they collect subjective reports to confirm that distraction has impacted pain experience.

Studies have shown that while experiencing painful stimulation, performing a verbal fluency task (Frankenstein, Richter, McIntyre, & Remy, 2001), the Stroop task (Bantick et al., 2002; Valet et al., 2004), or simply being asked to "think of something else" (Tracey et al., 2002) diminishes the aversiveness of pain and may reduce activity in cortical and subcortical pain-related regions, including mid-cingulate cortex, insula, thalamus, and periacqueductal gray. Regions of orbitofrontal cortex (OFC), medial PFC (MPFC), ACC, and dorsolateral PFC (dlPFC) may be more active during distraction (Frankenstein et al., 2001; Tracey et al., 2002; Valet et al., 2004), although it is not yet clear whether these activations reflect processes supporting performance of the secondary task, active attempts to regulate pain, or both. To date, no studies have attempted to address this issue directly.

Only one distraction study has used fear faces as stimuli, and it found results compatible with the pain studies: Amygdala responses dropped when participants performed a line orientation judgment task (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002).

Summary and Critique

Studies examining how attentional control regulates emotional responses have provided mixed results. On one hand, studies of *selective attention* suggest ambiguously that paying attention to, and making judgments about, emotional stimulus features either does or does not have an impact on amygdala response. On the other hand, studies of *attentional distraction* demonstrate more consistently that responses in appraisal systems may drop when participants devote attention to performing a concurrent cognitive task. Thus, these studies do provide support for the hypothesis that prefrontal and cingulate control systems may modulate activity in appraisal systems, but this support is somewhat inconsistent. In addition to the problems noted previously, because *selective attention* and *attentional distraction* studies have tended to use such different kinds of stimuli—faces and photos as compared to pain—it is difficult to know how much the discrepant results are attributable to variability in the emotional responses elicited by stimuli. It will be important for future work to use comparable emotionally evocative stimuli, manipulate or measure the way in which stimuli are being appraised, and assess behavioral and physiological changes in emotional response to verify that emotion regulation has taken place.

COGNITIVE CHANGE

If attention is the "gatekeeper" for an information-processing kingdom, then our capacities for higher cognitive function are the engineers and architects that keep the kingdom functioning. Various higher cognitive abilities, such as working memory, language, and mental imagery, enable us to think about the past, plan for the future, and reason about problems more generally. As described earlier, all these abilities are thought to depend on interactions of prefrontal and cingulate control systems with posterior cortical systems that encode, represent, and store various types of perceptual information (McClure, Botvinick, Yeung, Greene, & Cohen, this volume; Zelazo & Cunningham, this volume).

In the context of emotion regulation, studies have begun to examine whether and how these control systems may modulate activity in emotional appraisal systems by enabling one to *cognitively change* the meaning of a stimulus or event. For example, one might transform anger into compassion by judging that the apparently aggressive behavior of a drunk partygoer is the unintended consequence of an attempt to drown his sorrows after receiving bad news. *Cognitive change* can be used either to generate an emotional response in the absence of an external trigger, as when one feels eagerness or anxiety in anticipation of an event, or to alter a response that was triggered by an external stimulus, as when one reinterprets the meaning of the drunken partygoer's actions. According to our model, cognitive change should depend on prefrontal and cingulate control systems that use top-down processes to modulate bottom-up activity in emotional appraisal systems such as the amygdala or striatum.

Controlled Generation

Cognitive control processes can be used to form beliefs and expectations about the emotional properties of stimuli. Four different approaches have been taken to studying how these expectations and beliefs generate emotional responses from the top down.

The first approach concerns the emotional impact of beliefs about the nature of upcoming events. If we believe that a pleasant or unpleasant event is about to occur, we may generate a pleasant or unpleasant emotion in anticipation of it. This emotion may reflect either fears or worries about the upcoming event or adaptive attempts to prepare for it. The maintenance of these pleasant or unpleasant expectations has been associated with activation of dorsal mPFC regions (Hsieh, Meyerson, & Ingvar, 1999; Knutson, Fong, Adams, Varner, & Hommer, 2001; Ploghaus et al., 1999; Porro et al., 2002) that have been implicated in making inferences about one's own or other people's emotional states (Ochsner et al., 2004a). Recruitment of MPFC during the anticipation of a pleasant or unpleasant experience may reflect beliefs about how one will feel or could feel when the expected event occurs. Also activated during anticipation are regions important for appraising the affective properties of stimuli, which might differ for positive and negative stimuli. For example, anticipating primary reinforcers that elicit pain activates regions implicated in appraising painful and aversive stimuli, including cingulate, insula, and amygdala (Hsieh et al., 1999; Jensen et al., 2003; Phelps et al., 2001; Ploghaus et al., 1999). Similarly, anticipating either pleasant primary (e.g., a sweet taste) or secondary (e.g., money) reinforcers activates some combination of amygdala, NAcc, cingulate, insula, and/or OFC (Knutson et al., 2001; O'Doherty, Deichmann, Critchley, & Dolan, 2002). It remains to be clarified how activation of each of the systems contributes to the generation of a pleasant or unpleasant emotion. However, it is clear that anticipatory activation may reflect priming of systems to more rapidly encode expected stimulus properties, which is a function of top-down processes in vision and spatial attention (Kosslyn, Ganis, & Thompson, 2001). In some cases this priming may contribute directly to the experience of anxiety, eagerness, or other anticipatory emotions.

The second approach also concerns the emotional impact of beliefs about upcoming events but instead of examining an anticipatory interval focuses on how we respond to the stimulus when it appears. To date, this issue has been addressed only in studies of expectations about potentially painful stimuli. When participants expect a painful stimulus will be delivered but receive only a nonpainful one, they nonetheless show activation of pain-related regions of midcingulate cortex (Sawamoto et al., 2000), rostral cingulate/MPFC regions likely related to expectations about how it might feel, and medial temporal regions related to memory (Ploghaus et al., 2001).

The third approach is not concerned with expectations per se but, rather, with contrasting the use of beliefs to generate emotion in a top-down fashion with the generation of emotion via the bottom-up encoding of intrinsically affective stimuli. To date, only a single study has investigated this issue. Participants were asked either to passively perceive highly arousing aversive images—a bottom-up route to emotion generation—or to actively appraise neutral images as conveying an aversive meaning—a top-down route to emotion generation. Although both routes to emotion generation activated the amygdala, only top-down generation activated systems associated with cognitive control, such as ACC, LPFC, and MPFC (Ochsner & Gross, 2004). This suggests that appraisal systems participate in both types of emotion generation, but that higher cognitive processes come into play when generation proceeds top-down.

The fourth approach concerns appraisals of one's ability to control one's response to a stimulus. The perception that one may exert control over a situation can have an important impact on one's emotional response to it (Sapolsky, this volume). To date, only a single imaging study has investigated the neural correlates of top-down beliefs about the ability to control (Salomons, Johnstone, Backonja, & Davidson, 2004). This study found that when painful stimuli were presented, the perception one could limit the duration of pain diminished activation of systems (such as the midcingulate cortex) related to the experience of pain and controlling behavioral responses to it.

Controlled Regulation

In contrast to *controlled generation*, which concerns the initiation of an emotional response in the absence of affective cues, *controlled regulation* refers to the use of higher cognitive processes to alter or change a response triggered by a stimulus with innate or acquired emotional properties. Broadly speaking, higher cognitive processes may be used to regulate emotion in two ways—by either (1) using top-down processes to change the way one mentally describes a stimulus, which leads appraisal systems to respond to this new description, or (2) directly experiencing a change in the emotional outcomes associated with an action or stimulus event and subsequently using top-down processes to update these predictive relationships. In both cases, top-down processes change the way in which one represents the relationship between a stimulus and one's emotional response to it.

The first type of cognitive regulation is exemplified by *reappraisal*, which entails actively reinterpreting the meaning of an emotionally evocative stimulus in ways that lessen its emotional punch. Colloquially, reappraisal involves "looking on the bright side," by cognitively reframing the meaning of an aversive event in more positive terms. For instance, one can reappraise an initially sad image of a sick individual in the hospital as depicting a hearty person who is temporarily ill and soon will be well. A growing number of studies are using functional imaging to investigate the neural bases of reappraisal and in general have provided consistent results. Reappraisal activates dorsal ACC and PFC systems that presumably support the working memory, linguistic, and long-term memory processes used to select and apply reappraisal strategies. Activation of these control systems leads to decreases, increases, or sustained activity in appraisal systems such as the amygdala and/or insula in accordance with the goal of reappraisal to decrease, increase, or maintain negative affect (Beauregard, Levesque, & Bourgouin, 2001; Levesque et al., 2003; Ochsner et al., 2002, 2004b; Phan et al., 2005; Schaefer et al., 2002). Some of the variability in activation of prefrontal and appraisal systems may be attributable to differences in the types of stimuli employed, which have ranged from sexually arousing or sad film clips to disgusting and disturbing photos.

Perhaps more interestingly, some of the variability also may be attributable to differences in the kinds of reappraisal strategies used in each study. Most studies have left relatively unconstrained the way in which participants are asked to reappraise, which leaves open the possibility that different strategies depend on different types of controlled processes. To date, only a single study has investigated this possibility, by systematically instructing participants to reappraise stimuli using either a self-focused or a situation-focused reappraisal strategy to decrease negative emotion (Ochsner et al., 2004b). Self-focused reappraisal involves decreasing the sense of personal relevance of an image by becoming a detached, distant, objective observer. Situation-focused reappraisal involves reinterpreting the affects, dispositions, and outcomes of pictured persons in a more positive way. Although both strategies recruited overlapping PFC and cingulate systems, self-focused reappraisal more strongly activated MPFC whereas a situation-focused reappraisal more strongly activated LPFC. This pattern may reflect the use of systems that track the personal motivational significance of the stimulus, as compared to accessing alternative meanings for an event in memory.

The placebo effect is another form of controlled regulation that may involve mentally redescribing the meaning of a stimulus. In a typical placebo study, participants are led to believe that creams or pills will exert a regulatory effect on experience when, in fact, they contain no active drug compounds that could have an impact on bottom-up appraisal. Thus far, this has been studied only in the context of pain. Three studies have led participants to believe that placebos should blunt pain experience and have observed that stimuli elicit less pain and produce decreased activation of amygdala and pain-related cingulate, insula, and thalamic regions (Lieberman et al., 2004; Petrovic, Kalso, Petersson, & Ingvar, 2002; Wager et al., 2004). Although the precise nature of the cognitive processes mediating placebo effects is not yet clear, it is noteworthy that placebo effects are associated with activation of lateral prefrontal regions related to cognitive control and implicated in reappraisal, including ACC and right LPFC (Lieberman et al., 2004; Wager et al., 2004). This suggests that like reappraisal, placebo effects involve the active maintenance of beliefs about placebo compounds that in turn change the way in which stimuli are appraised top-down (Wager et al., 2004).

The second type of cognitive regulation concerns changes in the emotional value of a stimulus as a function of learning that associations between stimuli and emotional outcomes have changed. This work employs classical and instrumental conditioning techniques like those used in animal models of emotion. Perhaps not surprisingly, the results of the studies are very consistent with results from the animal literature. For example, as was the case for animal studies (e.g., LeDoux, 2000; Quirk & Gehlert, 2003; Rolls, 1999), instrumental avoidance of aversive stimuli (Jensen et al., 2003), extinction of classically conditioned fear responses (Gottfried & Dolan, 2004; Phelps, Delgado, Nearing, & LeDoux, 2004), and reversal of stimulus–reward associations (Cools, Clark, Owen, & Robbins, 2002; Kringelbach & Rolls, 2003; Morris & Dolan, 2004; Rogers, Andrews, Grasby, Brooks, & Robbins, 2000) depend on interactions between the amygdala, NAcc, and ventral PFC, OFC, and/or ACC. Consistent with these findings, neuropsychological studies have shown impairments of stimulus-reinforcer reversal learning in patients with lesions of ventral and orbital but not dorsolateral PFC (Fellows & Farah, 2003, 2004; Hornak et al., 2004).

Although this general pattern of interaction between control and appraisal systems has been consistent, there has been significant interstudy variability in the specific prefrontal systems activated and the particular ways in which appraisal systems are modulated. For example, amygdala activation may either drop (Phelps et al., 2004) or increase (Gottfried & Dolan, 2004) during extinction, and both striatal (Cools et al., 2002) and amygdala activation have been observed during reversal learning (Morris & Dolan, 2004). Some of these discrepancies may result from differences in the way that emotional associations initially were learned. But some discrepancies may follow from problems of methodology noted earlier for studies of attentional control. Just as many studies of attentional control failed to manipulate or measure the way in which stimuli were appraised, classical and instrumental conditioning paradigms do not control the way in which a participant appraises the meaning of a stimulus. Although this is likely not a problem when the participant is a rodent, it may very well be a problem when the participant is a human. During reversal or extinction a participant may form expectations about whether and when choosing a stimulus will lead to a reward or a conditioned stimulus (CS) will be followed by an unconditioned stimulus (US), which could involve the cognitive generation of an emotional response. In addition, in some cases participants may reappraise the meaning of undesired outcomes, such as picking the wrong stimulus during reversal or receiving an unexpected shock during extinction. These factors may influence whether or not participants use the mechanisms of classical instrumental conditioning to regulate their emotions, or whether they use the mechanisms supporting description-based reappraisal of the meaning of a stimulus. As argued in the next section, these two forms of cognitive change may depend differentially on ventral and dorsal PFC, respectively.

Summary and Critique

Studies examining the use of cognitive change consistently have demonstrated that (1) regions of lateral and medial prefrontal cortex as well as anterior cingulate are activated when participants generate or regulate emotional responses top-down, and (2) that top-down control may modulate activity in a variety of appraisal systems, including the amygdala, midcingulate cortex, and insula. These data are more consistent than the results described for studies of attentional deployment in part because cognitive change studies consistently employ strongly emotionally evocative stimuli, provide behavioral indices of emotional response, and explicitly manipulate the way in which participants appraise stimuli. That being said, there are at least two noteworthy ambiguities in this literature. First, the strategy used and the time course over which it is deployed are confounded for studies of cognitive regulation: Effects of reappraisal or placebo are studied only in the short-term, whereas the effects of reversal learning or extinction are measured over longer spans of time. In principle, both types of strategies can be employed in both the short and long term, although descriptive strategies such as reappraisal may be more easily and flexibly deployed as immediate needs arise. It remains to be seen, therefore, whether some of the differences in brain activation across the two types of studies reflect differences in training, learning, and even automaticity in the application of regulatory strategies that only emerge long term. The second ambiguity also concerns the use of strategies and the fact that even within studies examining a single type of strategy, such as reappraisal, different control systems often are activated. Part of this variability may be attributable to differences in participants and analysis, but a more important factor may be differences in the way each strategy may be implemented. Whether it is reappraisal, extinction, or reversal, there may be multiple ways in which cognitive control may achieve the goal of describing differently an emotional event or learning to place different emotional value on a given outcome. Unpacking these differences will be an important focus for future research.

SPECIFYING A FUNCTIONAL ARCHITECTURE FOR THE COGNITIVE CONTROL OF EMOTION

We began with an initial working model of the cognitive control of emotion derived from prior human and animal work. Although the preceding review supports the general model of interactions between control and appraisal systems, it also suggests some important ways in which the model can be elaborated in greater detail. Here we describe one way in which our initial model can be elaborated and acknowledge that there may be many additions and modifications to the working model that may depend on the nature of the regulatory strategy in question, emotion to be regulated, or other variables to be identified in future work.

Taken together, studies examining attentional control and cognitive change converge to suggest that two different types of systems are involved in the cognitive control of emotion (Figure 5.3). The first may be termed the top-down “description-based appraisal system” (DBAS), which consists of dorsal PFC and cingulate regions important for generating mental descriptions of one’s emotional states and the emotional properties and associations of a stimulus. These descriptions re-represent nonspecific feeling states in a symbolic format that often is verbalizable. Top-down appraisals, expectations, and beliefs are composed in large part of these descriptions, which allow us to categorize the nature and kind of emotional response we are experiencing or wish to experience. The controlled generation of emotion via expectation, and the controlled regulation of emotion via reappraisal and placebo all tend to strongly recruit this system. Importantly, the DBAS has few direct reciprocal connections with (subcortical) emotional appraisal systems. As illustrated in Figure 5.3, it must influence bottom-up appraisal systems indirectly by either (1) using working memory, mental imagery, and long-term memory to generate alternative representations in perceptual appraisal systems that then send neutralizing inputs to affective appraisal systems, or (2) communicating directly with the top-down Outcome-Based Appraisal System.

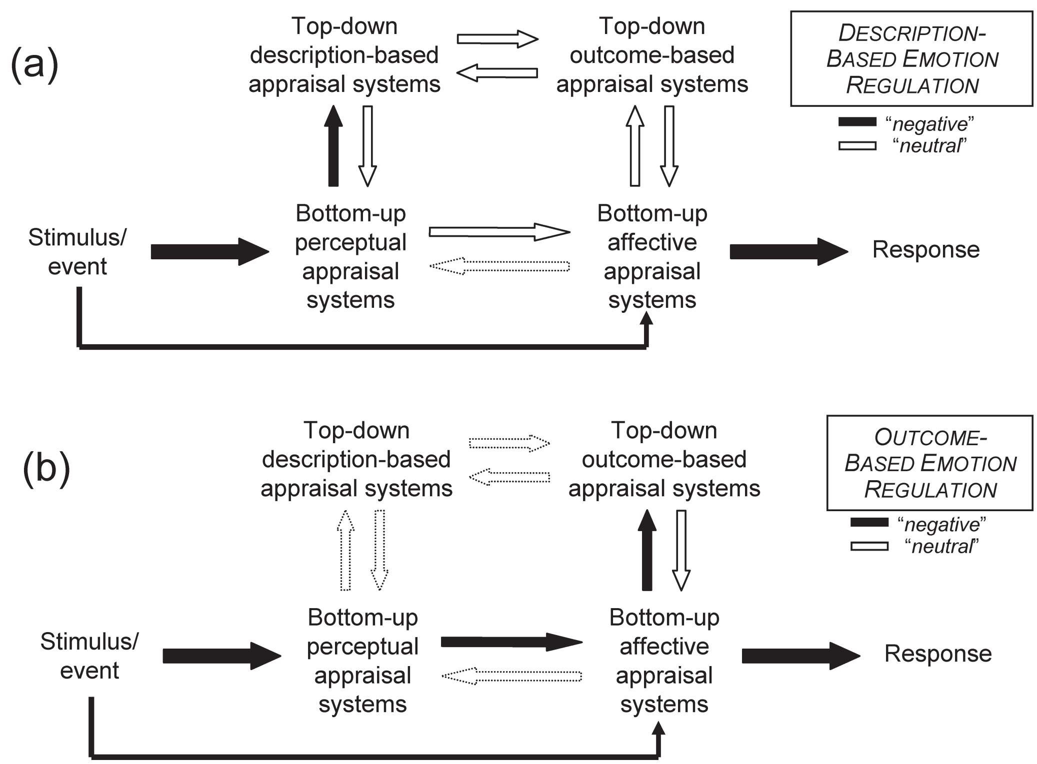

FIGURE 5.3. Schematic diagram of processes implicated in an elaborated model of emotion regulation that expands the initial model shown in Figure 5.1 based on review of the current imaging literature. This figure illustrates two different types of top-down appraisal systems that may be involved in generating and regulating emotion via interactions with multiple types of posterior cortical systems that represent different types of auditory, visual, linguistic, or spatial information. For simplicity, and because the current literature provides the strongest support for this model only in the case of emotion regulation, this figure expands only panel c of Figure 5.1 to show how each type of top-down appraisal system may be involved in emotion regulation. (a) The *top-down description-based appraisal system* consists of dorsal medial and lateral prefrontal systems important for generating mental descriptions of one's emotional states and the emotional properties and associations of a stimulus. This system is implicated in the use of controlled appraisals and reappraisals, top-down expectations, and beliefs to regulate emotion. (b) The *top-down outcome-based appraisal system* consists of orbital and ventral prefrontal regions important for learning associations between emotional outcomes and the choices or percepts that predict their occurrence. This system is implicated in the use of extinction or stimulus-reinforcer reversal learning to alter emotional associations. See text for details.

The top-down "outcome-based appraisal system" (OBAS) consists of orbitofrontal and ventral PFC and cingulate regions important for representing associations between emotional outcomes and the choices or percepts that predict their occurrence. Various types of classically conditioned and instrumental learning depend on these stimulus-reinforcer associations, which are acquired as an organism experiences the reinforcing contingencies of their environment through direct experience. The controlled regulation of emotion by extinction or stimulus-reinforcer reversal learning both tend to strongly recruit the OBAS. Figure 5.3b diagrams the direct path by which representations of alternative affective outcomes may bias appraisal systems.

Working together, the DBAS and OBAS enable us to exert various types of control over our emotional responses. Figure 5.4 illustrates the neural bases for each type of regulatory system. The DBAS supports the use of higher cognitive functions to regulate emotion, and most of our knowledge concerning its function comes from human imaging studies. By contrast, the OBAS supports the regulation of emotional responses through passive conditioning and instrumental choice, and many components of the OBAS appear to function similarly in humans and nonhuman primates and rodents. It will be important for future research to investigate how different components of each system implement different types of cognitive control processes, how these systems interact with one another, how they are involved with nonemotional forms of "cold" cognitive control, and how they come into play for the regulation of positive emotion, which has been comparatively understudied.

IMPLICATIONS FOR DEVELOPMENT, INDIVIDUAL DIFFERENCES, AND PSYCHOPATHOLOGY

According to the functional architecture we have developed in this chapter, variability in emotion regulation can be accounted for by differences in the relative strength of bottom-up emotional responses and/or in the capacity to control them using top-down processes.

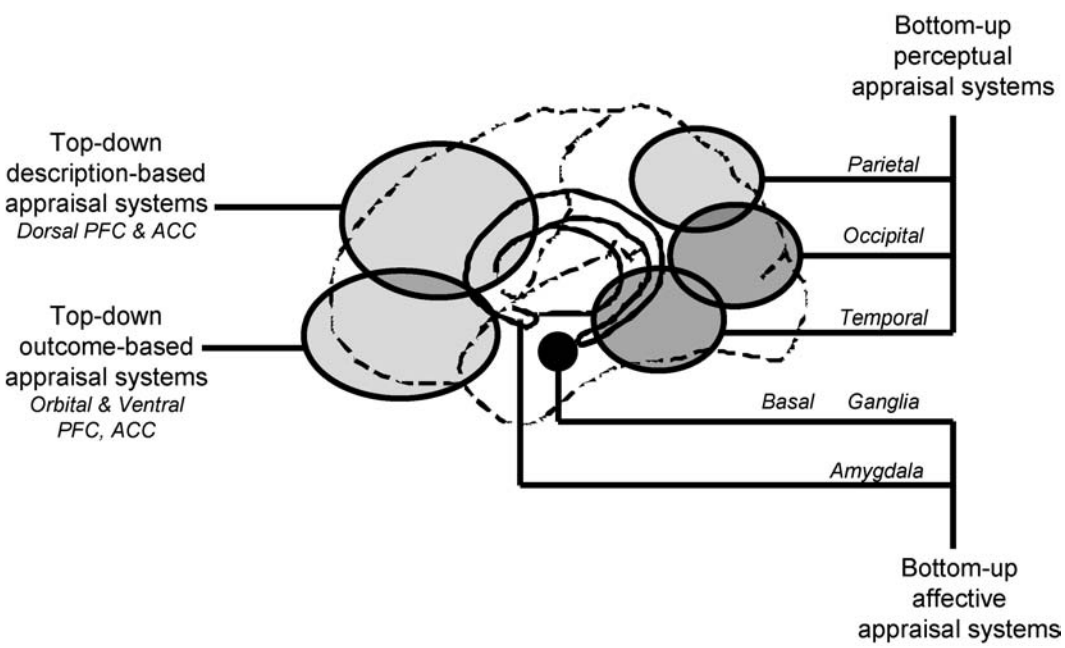

FIGURE 5.4. Schematic illustration of brain systems implicated in our elaborated model of emotion regulation. Each brain system shown here can be associated with a different kind of processing shown in Figure 5.3. This figure indicates the relative locations of the description-based appraisal system in dorsal medial and lateral prefrontal cortex, the outcome-based appraisal system in ventral and orbital prefrontal cortex, and the bottom-up perceptual and affective processing systems in posterior cortical and subcortical regions. See text for details.

Development

Developmental changes in emotion and emotion regulation across the lifespan can be analyzed in terms of differences between the strength of bottom-up emotional impulses and the top-down capacity to control them. Biological components of temperament, as well as early epigenetic influences such as quality of maternal care early in life, may exert an important influence on the ease with which negative emotional responses are generated in adulthood. For example, children at 2 years of age may be characterized as having an inhibited temperament characterized by strong and negative emotional responses to potentially threatening novel stimuli. A recent study has shown that as adults these children show greater amygdala responses to novel as compared to familiar faces (Schwartz, Wright, Shin, Kagan, & Rauch, 2003), suggesting that temperament may have an impact on responsivity in bottom-up affective appraisal systems. One's environment may shape amygdala sensitivity as well. An absence of positive social interactions early in life, especially those involving physical contact with caregivers, helps set a low threshold for activating the amygdala in response to potential threats that may persist throughout the lifespan (Meaney, 2001). Imaging studies have not yet investigated maternal shaping of the amygdala response in humans.

These and other affective predispositions may interact with the emotion regulatory norms prevalent in one's dominant culture, which may prescribe—and provide de facto training in—the use of specific kinds of emotion regulatory strategies. For example, in Asian cultures social norms dictate the regular restraint of facial expressions of emotion and the experience of particular social emotions, such as shame (Tsai, Levenson, & Carstensen, 2000). It is possible that these norms reflect themselves in the tendency to generate certain emotions bottom up, and the capacity to use particular top-down regulatory strategies with greater efficacy.

The ability to implement any given regulatory strategy may initially depend on development of prefrontal regions that implement control processes. PFC is known to undergo a rapid growth spurt between the ages of 8 and 12 that continues into one's late 20s (Luna et al., 2001), and behavioral development of "cold" forms of cognitive control is known to track these structural developments (Casey, Giedd, & Thomas, 2000). This suggests that the development of emotion control may show a similar relationship, although this question remains to be explored. Changes in cortical structure and function later in life may also impact the capacity to regulate emotion. It is known, for example, that older adults tend to experience a greater proportion of positive, and a smaller proportion of negative, emotions as they age (Carstensen, Isaacowitz, & Charles, 1999). It is not yet clear, however, whether these differences relate to changes in the tendency to generate positive emotions bottom-up (Mather et al., 2004) or whether they represent an enhanced ability to generate or regulate them top down.

Individual Differences

People may differ in the strength of bottom-up processing in a number of ways. Some of these are reflected in the broad personality dimensions such as extraversion and neuroticism (Barrett, 1997; Costa & McCrae, 1980). Recent imaging work suggests that these personality differences may reflect differences in the tendency to generate emotions bottom-up, as indicated by enhanced reactivity in structures such as the amygdala to positively and negatively valenced stimuli (Hamann & Canli, 2004; Kim et al., 2003).

The top-down capacity to control or shape appraisal processes also may differ across individuals in numerous ways. Some differences may derive from the knowledge an individual possesses about how and when their emotions can be regulated. These differences in emotion knowledge may be reflected in differing beliefs about whether emotions are controllable in the first place and the different strategies that may to be deployed in different circumstances. Assuming a given strategy is available, individuals may differ in their ability to implement it. One of the most important determinants of performance on "cold" cognitive control tasks is working-memory capacity (Barrett, Tugade, & Engle, 2004), and it is possible that individual differences in this capacity may determine one's ability to reappraise or distract oneself from an aversive experience. Individuals may also differ in their tendencies to use specific types of regulatory strategies, which may in turn affect their ability to regulate activation in bottom-up appraisal systems. For example, individual differences in the ability to identify and describe one's emotions may be useful for deciding how to regulate them (Barrett, Gross, Christensen, & Benvenuto, 2001), and the habitual tendency to reappraise emotional events in everyday life (as compared, for example, to suppressing one's behavioral responses to them) may affect the efficacy with which prefrontal systems implement descriptive regulatory strategies and downregulate activation in appraisal systems (Gross & John, 2003). In support of this hypothesis, we observed that individuals who tend to ruminate about negative life events, turning them over and over in their mind, showing greater ability to regulate activation of the amygdala up or down using reappraisal (Ray et al., 2005). Interestingly, this ability was not associated with differences in prefrontal activation, suggesting that ruminators may get "more affective bang for their regulatory buck" when attempting to control their emotions.

Psychopathology

One important extension of our heuristic framework for understanding the normative functional architecture for emotion control is to clinical populations suffering from various kinds of emotional disorders. More than half of the clinical disorders described in DSM-IV are characterized by emotion dysregulation. What is more, resting metabolic and structural imaging studies have suggested abnormalities in emotional appraisal and cognitive control systems in numerous disorders, ranging from depression and anxiety to posttraumatic stress disorder and sociopathy (Drevets, 2000; Rauch, Savage, Alpert, Fischman, & Jenike, 1997).

Each of these disorders may be characterized as reflecting an imbalance, or dysregulation, of interactions between bottom-up and top-down processes involved in emotion control. For example, resting brain metabolic studies of depressed individuals often show relative hyper activation of the amygdala and hypoactivation of left prefrontal cortex (Drevets, 2000). Strikingly, this pattern is the opposite of the pattern of brain activation shown when normal participants effectively downregulate negative emotion using reappraisal (Ochsner et al., 2002, 2004b). Future work may determine whether depression reflects an increased strength of bottom-up negative responses, weakened capacity to regulate these responses top down, or some combination of the two.

Bottom-up and top-down processing in depression also may differ qualitatively. Thus, depressed individuals may not differ in the strength of bottom-up, or the capacity to use top-down, processes but in the way in which they use specific kinds of top-down control to modulate negative emotion. For example, the capacity to reappraise may be normal in depression. But depressed individuals may typically use reappraisal to upregulate negative emotion using self-focused strategies rather than downregulating negative emotion using situation-focused strategies. This hypothesis is supported by a recent finding that was described earlier: Normal variability in the tendency to ruminate, which is a risk factor for depression, is associated with greater ability to upregulate and downregulate the amygdala using situation-focused reappraisal strategies (Ray et al., 2005).

CONCLUDING COMMENT

Any model of the neural architecture of emotion regulation depends on the quality of the data available to use as construction material. The preceding review highlighted a number of conceptual and methodological problems in the existing literature. With these in mind, we conclude by offering five recommendations for future research on emotion regulation.

It is important (1) to recognize that emotional responses are driven in part by the bottom-up encoding of affective stimulus properties and in part by top-down processes that can guide, shape, and alter the phase of initial stimulus-driven encoding. This means that investigators (2) should manipulate and/or measure, as much as possible, the way in which stimuli are being appraised, and not assume that emotions are driven by the passive encoding of stimulus properties. This will help track the extent to which participants spontaneously choose to regulate their emotional responses and more generally appraise stimuli in emotional versus unemotional terms. Because emotions are valenced responses that may include changes in experience, behavior, and physiology, researchers should be sure (3) to employ stimuli that elicit strong emotional responses and (4) to measure changes in one or more of these response channels to verify that emotion regulation has taken place *independent* of observed changes in brain activity. Finally, experiments (5) should be guided by a theoretical conception of the way in which specific types of cognitive control may interact with different kinds of emotional appraisal processes. For example, different types of emotionally evocative stimuli (e.g., those that elicit sadness as compared to fear) may involve different types of appraisal processes (Scherer et al., 2001), and different psychological operations may be involved when an individual uses different types of reappraisal strategies to regulate emotions generated in different stimulus contexts.

As we see it, one of the major goals for future research should be to refine our methods and our experiments in ways that will allow us to determine exactly how, when, and with the support of which brain systems we are able to effectively regulate different types of emotions.

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