CHAPTER 2

The Neural Bases of Emotion and Emotion Regulation: A Valuation Perspective

Kevin N. Ochsner
James J. Gross

The observation that emotions can be powerful forces for good and for ill has motivated researchers' efforts to understand how emotions arise and how they are regulated (Gross, 2007; Kalisch, 2009; Ochsner & Gross, 2005, 2008; Phillips, Ladouceur, & Drevets, 2008; Quirk & Beer, 2006). In particular, neuroscience research recently has made great strides in describing the neural systems that give rise to emotional responses and that permit their regulation. At the same time, parallel progress has been made in delineating the neural bases of related abilities, including affective learning, affective decision making, and expectancies, beliefs, and placebo effects (Cunningham & Zelazo, 2007; Hartley & Phelps, 2010; Murray, O'Doherty, & Schoenbaum, 2007; Pessoa, 2008; Rangel, Camerer, & Mon- tague, 2008). It is becoming evident that the neural systems implicated across these various literatures—including those concerned with emotion and emotion regulation—are strikingly similar. This suggests that any account of the neural bases of emotion and its regulation—or related abilities—should be informed by these similarities. Such an integrated framework would be both more robust and more translatable to multiple basic and clinical contexts. Our goal in this chapter is to provide such a framework.

Our starting point is the assertion that goal-directed (motivated) behavior may be defined as behavior that aims to decrease the probability of states of either our bodies or of the world that have negative value for us (e.g., putting on a sweater when we are cold; picking up trash in the park), or increase the probability of states that have positive value for us (e.g., opening a can of soup to eat when we are hungry; arranging to have coffee with a friend).

The determination of value occurs dynamically at many levels of the brain, at different time scales, and with respect to many features in the environment (Leventhal, 1984; Rangel et al., 2008; Scherer, 2001). A sudden loss of blood pressure may occasion a valuation, as may the smell of dinner being prepared, an aggressive driver cutting one off, or a new way of thinking about a poem. If valuations are assessments of what is bad for me (negative value) or good for me (positive value), computed for many different objects, then different types of valuation might be expected to give rise to different types of responses, and indeed, they do (Urry, Clay, & Collins, 1988;
The Functional Architecture of Valuation

According to the framework we propose here, valuation can be schematized as the three-stage processing cycle outlined in Figure 2.1A. As detailed below, a perception stage takes various kinds of stimuli as inputs; a valuation stage dynamically appraises the value of these stimuli given current goals, contexts, and prior experience with similar stimuli; and an action stage comprises valuation-appropriate responses ranging from covert adjustments of low-level sensory (e.g., increased pupil dilation) or higher-level cognitive processes (e.g., shifts in effortful attention) to overt adjustments of a wide range of response systems (e.g., facial behavior, postural adjustments, sympathetic nervous system activation). This perception–valuation–action (PVA) sequence repeats as the new state of the world, resulting from the action, becomes the input for the next PVA sequence, thus setting in motion a new PVA cycle. Because multiple PVA cycles are typically running at any given time, these cycles interact, and it is these processing dynamics that give rise to behavior.

PVA Components: The Perception Stage

A PVA sequence is initiated by an external or internal stimulus that can vary in complexity from low-level perceptual features (like eye whites or initial spatial frequencies) or physiological responses (e.g., a racing heart) to organized perceptual exemplars (e.g., objects or scenes) to abstract constructs such as the self. In this initial perception stage of the sequence, sensory systems (e.g., thalamus plus primary and secondary sensory cortices) encode these types of sensory inputs and pass them along to systems for computing value (Kravitz, Saleem, Baker, & Mishkin, 2011).

PVA Components: The Valuation Stage

Valuations are subserved by an overlapping set of interacting brain systems that compute the badness or goodness of perceptual inputs (Hamann, Zyl, Hoffman, & Kline, 2002; Ochsner & Barrett, 2001; Rangel et al., 2008; Rolls, 1999), thereby providing a common currency for comparing various objects and events (Levy & Glimcher, 2011). In this chapter we use valuation as an umbrella term to connote the same kinds of underlying processes that emotion theorists would describe using the term appraisal and attitude researchers would describe using the term evaluation. Targets of valuation range from primary reinforcers—objects that are innately seen as “bad” or “good,” such as a sweet drink, to secondary reinforcers—objects that derive their negative or positive value from their association with primary reinforcers, such as an A+ written at the top of one’s term paper (Rangel et al., 2008; Rolls, 1999). Figure 2.2A shows the brain regions associated with valuation processes. Multiple valuations are computed for a given stimulus, and these vary along a continuum of representational complexity, with more complex valuations typically taking
without conscious intent, and are implicit in how they are not directly accessible to awareness, although one can be aware of the actions they trigger, and thereby become aware of them indirectly. Core valuations are typically linked to stereotyped action impulses (Kober et al., 2008; Le Doux, 2000; Rolls, 1999; Russell & Barrett, 1999), and as such, can provide the basis for stimulus-response (S-R) links of the sort that underlie Pavlovian conditioning and other basic forms of appetitive responding that involve pleasure and pain (Rangel et al., 2008).

At an intermediate level, contextual valuations evaluate inputs that represent combinations of S-R links and at least three types of contextual information: the historical as well as current social and motivational contexts of the person (for an illustrative example, see the "PVA Sequence"). This computational step involves at least three regions. The first comprises the orbitofrontal cortex (OFC) and ventromedial prefrontal cortex (vmPFC) (Ongur, Ferry, & Price, 2003; Price, 1999), whose outputs include the output of both the core valuation level and the medial temporal lobe (MTL) and the cortical associative memory systems, which provide temporal and spatial context (Davachi, 2006; Murray et al., 2007). Second is the superior temporal sulcus and parietooccipital junction (STS/TOJ), which itself is a multisensory zone that integrates expectancies with feedback, and contextual attention accordingly, including when expectations must be adjusted about the beliefs, actions, and intentions of others (Saxe, 2006; Camprodon, Hauser, Pascual-Leone, & Saxe, 2010). Third is the anterior insula (AI), which integrates and makes available to awareness information about current body states, especially as they pertain to one's current affective state (Craig, 2003; Harrison, Gray, Gianaros, & Critchley, 2010; Kuch, Zilles, Fox, Laird, & Eckhoff, 2010; Zaki, Davis, & Ochsner, 2012). Contextual valuations indicate whether an object is good or bad in the present context, and therefore whether it should be sought or avoided. These beliefs, and the resulting choices, might be described as representing an aversive outcome (and was therefore negatively valued) no longer does so (and in the present temporal context, can be valued less negatively; Quiet & Beer, 2006). Moreover, generally, contextual valuations play key roles in other forms of affective learning, in determining whether the value of stimuli changes across contexts, and in subjective awareness of one's affective states (Craig, 2009; Cunningham, Raye, & Johnson, 2004; Holland & Gallagher, 2004; Lieberman, Jarche, & Sartore, 2004; Rangel et al., 2008; Schoenbaum, Dillenschneider, & Stalnaker, 2007). Contextual valuations influence behavior either by activating action impulses themselves or—as detailed below in the section on emotion regulation—by influencing which core valuations are expressed via actions (Ochsner, Ray, et al., 2009).

At the highest level of this continuum, conceptual valuations represent appraisals of stimuli that are abstract and therefore more readily verbalizable. By this we mean representations of evaluations and affective states that abstracted across exemplars and contexts and are accessible to awareness in the form of "beliefs-desire" language. For example, a conceptual valuation of a snake may involve activation of a conceptual representation of "fear," which one can verbalize using that word.

We propose that this level involves at least four regions. First, the rostromedial (rnPFC) and ventromedial prefrontal (vPFC) regions involved in attending to and explicitly judging the value of stimuli and use of categories and belief-desire language to elabo- rate semantically the affective value of a wide range of stimuli, from simple objects to the self (Cato et al., 2004; Lindquist, Wager, Barrett, 2008; Lindquist, Wager, Barrett, 2012; Mitchell, 2009; Olsnes & Olsnes, 2008; Zysset, Jongen, Ferstl, & von Cramon, 2002). An unresolved question about medial PFC (mPFC) is whether different subregions are involved in making judgments (whether evaluative or not) about others, the self, and/or stimuli in general (Denny, Wager, Olsnes, & Olsnes, 2012; Ferstl & von Cramon, 2002; Zysset, Huber, Samson, Ferstl, & von Cramon, 2002). For our present purposes, we consider mPFC to be critical for using conceptual information to elaborate the affective meaning of stimuli, whether the stimulus triggering the valuation and emotion is the self, another person, or some other object/
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PVA Operating Principles: Processing Dynamics

As multiple valuations are computed at different levels and time scales—each with its own set of action impulses—only a subset of the possible actions associated with a percept and its sensations can be evaluated. What determines which actions are expressed, whether mental (e.g., thoughts and feelings) or physical (e.g., smiling and hugging)?

One factor is the existing structure of the PVA sequences an individual possesses at any given moment in time. This factor has been addressed primarily in psychological and computational models of associative memory networks that suggest the Ps, Vs, and As of all currently activated PVAs mutually excite and inhibit each other. In such a way that the most activated action tendency or a set of equally activated tendencies "win" and are manifested as mental and/or physical actions (Deatman & Duncan, 1995; Barrett, Ochsner, & Gross, 2007; Maas, 2010; Miller & Cohen, 2001). The schematic PVA sequences of Figure 2.1A illustrate some possible kinds of links that may exist between P, V, and A nodes.

PVA Components: The Action Stage

At any given level of valuation, the action impulses associated with a PVA sequence can be either mental (e.g., retrieving information from memory, forming a mental image, or introspecting about one’s mood) or physical (e.g., including overt behaviors such as shifts of gaze or starting to run, and autonomic/gas stress responses such as heart rate increases or the release of stress hormones; Leventhal, 1999). Although elaborating the brain systems supporting the action stage is not the focus of this chapter, it likely involves subcortical and cortical regions involved in selecting motor actions, as well as initiating automatic responses (e.g., the PAG, primary motor and supplementary motor areas, circulat motor regions, and insula) (Buhle et al., 2012; Crichley, 2005; Dun, Levinthal, & Strick, 2009; Mobbs et al., 2009).

Valuation and Emotion Regulation

PVA Operating Principles: Interacting Networks

As our process-level description makes clear, the PVA sequence is continually unfolding in real time for multiple stimuli at multiple levels of analysis. This means that network structures of interacting brain systems underlie each stage of the PVA sequence, as well as the interactions among stages. This follows from the fact that an individual's affective response comprises the profile of activation across all PVAs, at all levels, which in turn follows from the idea that the P, V, and A stages all involve multiple brain systems working together to compute the perceptual, evaluative, and action components of one's response to a given stimulus.

Thus, the totality of one’s valuation of a stimulus cannot be understood in terms of the activation of a single brain system. That said, most of what we know about the functions of brain systems implicated in the P, V, and A stages comes from studies employing analytic techniques (e.g., simple contrasts) designed to isolate the contributions to behavior of single regions rather than integrated networks. Increasingly, however, various kinds of connectivity, network, and multivoxel pattern analyses are being used to describe the task-activating functional relationships among regions that define them as critical for aspects of the P, V, and A stages (Kober et al., 2008). For example, we and others have used mediation and structural equation modeling to describe the ways in which prefrontal control regions regulate emotional response via their impact on subcortical regions that trigger affective responses (Johnstone, van Reekum, Ury, Kalin, & Davidson, 2007; Kober et al., 2010; Ury et al., 2006; Wagner, Barrett, et al., 2008; for review, see Ochsner, Silvers, & Buhle, 2012). As such analytic techniques mature, we expect that our framework will be able to describe more precisely the functional interactions governing the P, V, and A stages, as well as their interactions.

A Valuation Perspective on Emotion and Emotion Regulation

Emotions are particular types of valuation that (1) have a well-specified object (i.e., one is angry about something), (2) unfold over seconds to minutes, and (3) involve coordinated changes in subjective experience, behavior, and physiology (Barrett et al., 2007; Mauss et al., 2005; Scherer et al., 2001). In keeping with our overall goal of showing how the valuation framework is broadly applicable, in the sections that follow we employ an expansive view of emotion.

Emotion as a Type of PVA Sequence

Imagine you are a commuter in a crowded New York subway car. Across from you sits a sleepy-eyed old man, a muscular teen, and an attractive woman. As the subway rattles toward your stop, the teen removes a knife from his pocket, shifting it from hand to hand.

In our framework, emotional reactions to the knife-wielding teen may be understood as specific kinds of PVA sequences derived from particular perceptions, valuations, and associated action impulses (Ortony et al., 1988; Scherer et al., 2001). Thus, an initial response may reflect a core-level valuation of the teen and his knife as potentially threatening by the amygdala and related regions, which triggers corresponding action impulses that mobilize you to avoid harm (e.g., increased heart rate, behavioral readiness to fight or flee; LaDoux, 2000; Phelps, 2006). At the contextual level, the action outputs of core-level PVA sequences become perceptual inputs that are integrated with other inputs (e.g., increased heart rate, behavioral readiness to fight or flee) to the social context of multiple other passengers being present (via STS/TP inputs), and the motivational context of current stress and bodily complaints (via AI and other subcortical inputs). As time passes, activation of the contextual-level PVAs and other core-level PVAs may begin to build, and the initial valuation may evolve dynamically into valuations of the teen as relatively innocuous or potentially dangerous, depending on whether the teen previously indicated he has a role as a thug in a school play or is on medication for an emotional disorder (historical context), whether he elicits calm or anxious reactions from
other passengers (social context), or whether you are stressed from work or just had a great day (motivational context). Then, the action outputs of activated contextual-level PVAs are taken as inputs to systems (vmPFC, and/ or dLPFC) that compute a valuation of the teen in belief—desire terms that can—at the action stage—be introspectively accessed or reported to others as the thoughts and feelings you attribute to yourself or others, including, for example, the thoughts that you yourself are brave, that the knife-wielding looks aggressive, and that the old man and young woman seem calm. The order in which these valuation systems is activated, and their interplay, is not fixed and depends on the circumstances of your encounter with a stimulus. For example, if you are sitting on the subway, and the teen enters from the opposite end of the car and does not pose an immediate threat, then conceptual valuation systems might evaluate its intentions (“Is he dangerous?”) and your own level of fear (“I’m not scared—yet”). As the teen moves closer, contextual systems might be most active as you evaluate the goodness or badness of potential courses of action based on your changing motivational state (increasing anxiety), history (the teen recently seemed angry, and you recalled that the last time you saw the teen was at a bus stop), and the apparent anxiety of your fellow passengers (who look increasingly anxious and afraid). Finally, as the teen moves even closer and the threat level is very high, activation in core valuation systems may escalate to promote defensive action, such as freezing, escape or fight (Mobbs et al., 2007).

The key idea is that, taken together, all of these PVAs, however they were activated, and each with their associated mental and physical action tendencies, comprise an emotional response.

**Emotion Regulation as a Type of Cognitive Sequence**

As noted earlier, emotions themselves are sometimes the target of valuation. For example, in the previous subway example, we might wish to protect our view of ourselves as brave and, as a consequence, desire to decrease our fear responses. To do this, we can take as objects of valuation the action outputs of PVAs that comprise a fear response. When we do this—thereby activating a goal to influence the nature of the emotional response—we are engaging in emotion regulation. As described below, this involves interactions among regions implicated in cognitive control (i.e., regulated and/or valuation).

In our framework, emotion regulation is initiated when a PVA cycle that gives rise to emotion becomes the object of valuation (see Figure 2.1B). We propose that this typically happens across levels of valuation, as a higher-level PVA places a good or bad valuation on a lower-level PVA (although it can also happen between PVAs at a single level). It also can happen if there is a high level of conflict between active PVAs, such as whether the impulse to flee a potentially dangerous situation conflicts with the impulse to freeze, and a clear set of goals (e.g., to escape or run). We propose that when this happens, the level of conflict constitutes an input to the next PVA cycle, and evaluation of that conflict triggers an appropriate course of regulatory action.

One key feature of our framework is the idea that some of the prefrontal systems that support emotion regulation are involved in the control of nonaffective forms of action, such as maintaining goal-directed behavior even when the initial motivational state is no longer relevant. For example, the anterior cingulate cortex, which is involved in monitoring conflicts in goal-directed behavior, is also activated by the need for controlled behavior. Medial regions that support mental state attribution, and ventromedial prefrontal regions that place contextual constraints on the expression of core-level PVAs (Miller, 2000; Ochsner & Gross, 2005; Ochsner et al., 2008; Wager, Jonides, & Reading, 2004; Wager & Smith, 2003). As detailed below, the regulatory actions supported by these systems comprise different types of “Al’s” in PVA sequences that place a value on one’s current affective state.

**Distinguishing among Emotion Regulation Processes**

We have previously argued that emotion regulation processes can be differentiated into five families according to which stage of the emotion generation sequence they target. In the context of the present framework, this idea is expressed by suggesting that emotion regulatory processes differ in their inputs to the PVA sequence at which they have their primary impact (see Figure 2.3). Some strategies influence the situation-dependent stimulus inputs (situation selection, situation modification, and attention deployment). Others influence the valuation step itself (cognitive change). Still others influence the response output associated with activated action sequences (response modulation). By impacting different states of the PVA cycle, different strategies impact emotional responding in different ways, as detailed below.

**Situation selection** refers to altering the inputs to the PVA sequence through decision making to either expose oneself to a given situation/stimulus based on its projected affective impact. For example, calling to mind the image of the subway might lead to a negative evaluation, and a feeling of fear. This feeling might motivate a higher-level PVA and would trigger a decision to take an alternative means of transportation in order to decrease the probability of the negative experiences that one associates with taking the subway. More generally, situation selection can take many forms, for example, when a feared stimulus or an anxious individual avoids a social event. To date, the neural bases of this affective sequence have been studied only with the use of conditioning tasks in which an animal learns to select an action (e.g., running in a wheel when a light is illuminated predicts an upcoming shock) that enables it to avoid experiencing a noxious stimulus (that prevents shock administration). Rodent studies have shown this involves modulation of two core valuation systems, the striatum and amygdala (Everitt et al., 1999; LeDoux & Gorman, 2001), and one human imaging study (Delgado et al., 2009) indicates that it also engages vmPFC and dorsolateral prefrontal cortex (dLPFC) regions involved in cognitive control that presumably modulate the core valuation systems.

**Situation modification** refers to altering the situation one is in, thereby modifying inputs to the PVA sequence, and changing the emotion (e.g., sitting further away from the teens or exiting the subway). We would expect that prefrontal systems should be involved in the selection of escape behaviors—especially in the kind of emotionally arousing situations humans face in everyday life. Although this hypothesis has not been tested, the involvement of prefrontal regions is suggested by behavioral studies in humans showing that emotion can be regulated by deliberately changing one’s environment (e.g., using a dependent stimulus inputs in the service of explicit regulatory goals. For example, either physically or mentally, using visual imagery, one can move closer to or further away from an emotion eliciting stimulus (e.g., making oneself feel more positive by approaching a pleasant stimulus or less negative by withdrawing from an unpleasant one; Davis, Gross, & Ochsner, 2011; Muhleber, Neumann, Wieser, & Paul, 2008; Williams & Bargh, 2008).

**Attentional deployment** refers to altering the inputs to the PVA sequence by increasing or decreasing attention to them (e.g., looking away from the teen and at the man or woman). While this can gate specific stimuli wholly into or out of the PVA stream, thereby promoting or preventing response selection to them, we propose that more graded changes in attention to stimuli may result in correspondingly graded levels of activation of their associated PVA sequences. This strategy involves interactions between cognitive control systems and valuation systems, with particular involvement of dorsal PFC and inferior parietal regions associated with selective attention ( Pessoa et al., 2008; Menon, 2009) and in some cases vmPFC regions implicated in attending to and explicitly judging the value of stimuli (Bishop, 2007; Egner, Gaier, Galé, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Lane et al., 1998; Ochsner, Hughes, Robertson, Cooper, & Gabrieli, 2009). A growing but somewhat inconsistent literature shows that, by and large, when a task manipulation diminishes attention to an affectively arousing stimulus, activation increases in PFC regions implicated in cognitive control (sug- gesting that cognitive control systems are involved in manipulating attention), and activity decreases in regions implicated in emotion (e.g., amygdala, PAG, contextual area, insula or conceptual area, in mPFC valuation (e.g., Ochsner & Gross, 2005; Pessoa, 2009). While it is clear that the specific valuation systems modulated by attentional deploy-
### FIGURE 2.3. Neural systems for valuation and control posited by the valuation framework presented in the chapter (left-hand columns), as well as the roles these neural systems play in three kinds of emotion regulation strategies (center columns, see text) and three kinds of related phenomena (right-hand columns, see text). Up arrows indicate increased activation, down arrows indicate decreased activation, and "?" indicates involvement in some (but not the majority) of the studies. The final row diagrams, in PVA terms, how each emotion regulation strategy or related phenomenon might operate (see text for details). The three center columns show, for each emotion regulation strategy, how control actions impact either attention to particular stimuli at the perception stage (attentional deployment), how one values those stimuli (reappraisal), or what actions one takes as a consequence of this valuation (response modulation). The three right-hand columns show for related phenomena how initial valuations (e.g., threat) may be overridden if one learns new valuations (e.g., safe) for a stimulus (extinction) one may select among choice options as a function of their relative valuations, with control actions coming into play when the choice is being made (interference choice), or a placebo may influence the valuation of a painful stimulus via the action of control processes (placebo effects).

### TABLE 2.1. Neural systems for emotion regulation and related phenomena

<table>
<thead>
<tr>
<th>Neural Systems</th>
<th>Type of System</th>
<th>Process</th>
<th>Attentional Deployment</th>
<th>Cognitive Change</th>
<th>Response Modulation</th>
<th>Affective Learning</th>
<th>Affective Decisions</th>
<th>Related Phenomena</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsolateral PFC</td>
<td>Frontal control</td>
<td>Valuation (assess value and decide)</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Ventromedial PFC</td>
<td>Control</td>
<td>Valuation (assess overall emotional value and value extinction)</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Insula</td>
<td>Valuation</td>
<td>Representation and awareness of bodily states for all types of stimuli</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

### Valuation and Emotion Regulation

Valuation depends on the sensory qualities of the stimuli, emotional decision from pain modulates nociceptive regions of insula and cingulate cortex (Frankenstein, Richter, McIntyre, & Romy, 2004; Tracey et al., 2002), whereas distraction from an aversive image modulates the amygdala (McRae et al., 2010; Pessoa, 2009), for example, cross-study variability in attentional deployment strategies and the lack of a common metric for determining how much any given strategy diminishes attention to a stimulus in one study compared to others (see Ochsner & Gross, 2005, for a detailed review) have limited the conclusions that can be drawn about when and how specific cognitive control systems are involved.

Cognitive change refers to altering the subjective meaning and/or perceived relevance of the present situation (e.g., thinking of the knife as a stage prop or that knife-tossing is an innocent way of passing time). The framework suggests that this strategy should involve interactions between cognitive control systems that can be used deliberately to change one's interpretation of a stimulus and valuation systems that trigger an affective response. Of note here is the fact that the framework predicts that conceptual valuation systems can play a role on either side of this regulatory equation: on the one hand, altering the target of cognitive control systems that seek to change one's high-level conceptual valuation of a stimulus, and on the other, altering those cognitive control systems in reformulating the attributions one makes about the nature of one's own beliefs, desires, and feelings (e.g., "I'm feeling less afraid now")—or those expressed by others (e.g., "The subway passengers are anxious about the crowding, not the teens")—as one deliberately changes his or her interpretation of an emotion-evoking stimulus. Research on cognitive change—referred to in the literature as "reappraisal"—consistently supports the predictions of the framework: When engaging in a cognitive change strategy, activation is observed in IFPC and cingulate PFC regions associated with cognitive control, as well as mPFC regions associated with conceptual valuation (albeit primarily when up-regulating emotional responses) and at the same time increasing or decreasing activity in core (e.g., amygdala, striatum) and contextual (e.g., insula) valuation systems (e.g., Kober et al., 2010; Ochsner et al., 2004; Urry et al., 2006; Wagner, Davidson, Hughes, Lindquist, & Ochsner, 2008; reviewed in Kalisch, 2009; Ochsner & Gross, 2005, 2008) in accordance with one's regulatory goals.

Finally, response modulation refers to targeting behavioral manifestations of emotion (e.g., playing it cool by not showing fear of the knife-wielding teen). Human research primarily has focused on one exemplar of this strategy, expressive suppression, which involves hiding behavioral manifestations of emotion (Gross, 1998). Behaviorally, expressive suppression effectively reduces facial expressions of emotion, but the effort and attention required to do so trigger autonomic responses, impair memory for visual cues, and can negatively impact social interactions (Bussier et al., 2003; Gross, 1999; Urry & Gross, 1998). In keeping with these findings, an initial imaging study showed that suppressing the expression of disgust activated two key PFC regions associated with cognitive control (dIPFC associated with maintaining goals, and vIPFC associated with response selection and inhibition more generally; Aron et al., 2004; Badre & Wagner, 2007; Thompson-Schill et al., 2003), and increased activation in core (amygdala) and contextual (insula) valuation regions associated with detection of threats and awareness of body states (Goldin, McRae, Ramel, & Gross, 2008). This supports the idea that expressive suppression, like other strategies, depends on interactions between cognitive control and valuation regions, and may have neural bases similar to those supporting response inhibition more generally (Aron et al., 2004).

### Applications of the Valuation Perspective

The neural systems implicated in emotion and emotion regulation play key roles in other phenomena that involve valuation and cognitive control (Hartley & Phelps, 2010; Murray et al., 2007; Pessoa, 2009; Phillips et al., 2008; Rangel et al., 2008). We believe it is important that any account of emotion and emotion regulation use terminology and concepts that are broadly applicable to allied phenomena as well.
With this in mind, we illustrate in this section the broad applicability of our valuation perspective on emotion and emotion regulation by showing how it can provide a framework for describing the mechanisms underlying three types of related phenomena that traditionally are considered in relatively distinct traditions. This has the dual advantage of broadening the framework to account for aspects of related phenomena it was not initially formulated to address, and in so doing, making the framework more robust and generally applicable.

Affective or Emotional Learning

As noted in the earlier section on the PVA processing dynamics, our valuation perspective allows learning to occur by updating predictions of the stimulation placed on the stimulus and the iteration of the PVA sequence. To account more broadly for various forms of affective or emotional learning, we can elaborate the way in which this updating process occurs.

When encountering a stimulus, one’s current valuation of it sets an expectation for the outcome states of the world that should follow from execution of the associated action. If the outcome state becomes better, it has either enhanced the next PVA, which evaluates discrepancies between the expected and actual outcomes. If this valuation is negative (i.e., when the discrepancy is large and/or important in light of currently active goals), this valuation triggers learning and updating processes that change links between a stimulus and its valuation (F-VA) or between a valuation and an action (VA)—or between separate PVA sequences—so that future valuations are more accurate (Delgado, Onson, & Phelps, 2005; Schlüter, Dayan, & Montague, 1997). Each change is small, so that one’s value expectations for a stimulus at a given moment in time are a function of one’s prior experiences with it, biased more heavily toward recent experiences. While this value updating process typically is studied in the context of conditioning, reward, and affective learning, it fits nearly within our current framework as the way that changes in the contingency between actions and outcomes can adaptively alter the valuations that drive the actions.

To illustrate this, we can use our subway example to consider one of the most studied examples of value updating, namely, extinction of a fear response. We discussed extinction earlier as an example of contextual valuation in which an organism learns that previously signaled danger is no longer to be feared in the current temporal context. In that section, however, we did not explain how contextual learning operates at the level of the organism. Here we propose that value updating is the learning mechanism.

The subway example can help make this concrete. Recall that the knife-wielding teen initially elicits a threat valuation and fear response involving amygdala-mediated core level PVAs. If the expected outcome does not transpire (i.e., the teen takes no harmful actions), however, then over time a new contextual-level PVA is acquired by ventromedial/orbitofrontal PFC systems indicating that no fear or threat is present. Eventually, the teen takes no harmful action, the stronger this PVA becomes. Ultimately, even though the teen still connotes threat at the core level, the contextual PVA wins out for expression in behavior (see the section on PVA processing dynamics). Recall that the core-level PVA itself remains unchanged, a fear response can be quickly reinstated in the future should the teen become truly threatening (Bouton, 2004; LeDoux, 1993). The framework can be similarly applied to other cases where conflict arises, such as a case where a dominant emotional impulse is inappropriate or unnecessary in the current context, as when an adolescent child refuses to cooperate, or its aggressive actions (Bouton, 2004; Coccaro & Quirk, 2007; Schonbaum et al., 2007).

As this example makes clear, affective learning and the types of regulatory strategies reviewed earlier are not mutually exclusive or mutually antagonistic as some have claimed. For example, the act of reappraising can be seen as a way of cognitively creating a discrepancy between an expected internal outcome (e.g., a fear response) associated with a given percept (e.g., the knife-wielding teen) and the response that actually occurs (e.g., calmness). This discrepancy could activate learning processes that weaken core-level PVAs and strengthen new contextual-level PVAs of the teen as an actor. In this way reappraisal—and by extension other regulatory strategies—can be seen as providing bottom-up "teaching" inputs to output-driven regulatory processes that typically are triggered by external cues (e.g., Delgado, Gollin, & Phelps, 2003; Delgado, Nearing, LeDoux, & Phelps, 2008).

Valuation and Emotion Regulation

Our valuation perspective also may be applied to affect-laden decision making. Affective decisions require a choice between options that are associated with different expected rewards or punishments. In our framework, these expectations are reflected in the values compared for choice options at various levels of the valuation hierarchy. To the extent that the play of activation and inhibition across PVA sequences associated with choice options results in a core-level, contextual, or conceptual-level valuation determining the behavioral output, then the choice option associated with that valuation will be selected. However, in some cases, this play of activation fails to determine clearly a most biologically valued selection, and cognitive control processes may be engaged in order to construct, hold in mind, and implement top-down processes that influence PVA associated with choice options. This commonly happens when choice options are similarly valued, in conflict with one another, but also may happen when the valuation process itself becomes a target of valuation (e.g., when there is a negative valuation of an attractive response option).

In summary (see Figure 2.3), consider how the framework accounts for a complexly studied choice dilemma in behavioral economics and neuroeconomics known as "moral licensing choice" (or as delay of gratification in the developmental literature; Mischel, Shoda, & Rodriguez, 1989). This dilemma involves choosing between two moral actions, one of which is a smaller reward available now or a larger reward available at some point in the future. If one’s decision were based on the immediate reward, then the temptation would be promoted by core-level (i.e., affective) or contextual-level (medial orbitofrontal frontopolar) PVAs that reflect the reward value of the currently available stimulus. By contrast, picking the delayed reward would require the use of lateral prefrontal cognitive control systems in order to maintain a representation of the delayed reward in working memory and inhibit activation of PVAs for the immediately available choice option (Figner et al., 2011). In keeping with this account, functional imaging studies have shown greater whole brain (VS) and/or vmPFC versus greater dIPFC activity when participants select immediate versus delayed rewards (Knoch, Pascual-Leone, Meyer, Loewenstein, & Cohen, 2007; McClure, Loewenstein, & Cohen, 2004), and a recent transcranial magnetic stimulation study showed that disruption of VS—but not right—dIPFC led participants to "impulsively" select immediate rewards when they had a prior preference for the delayed reward (Figner et al., 2011). Strikingly, this result dovetails with the finding that a pathway from left dIPFC to the VS supports the use of reappraisal to diminish craving for desired substances (e.g., drugs, overeating, or fattening foods) when participants think about the negative long term (e.g., diabetes) as opposed to the immediate (e.g., delicious/taste) consequences of consuming them (Kober et al., 2010).

As these findings make clear, affective decision making and the regulatory strategies reviewed earlier may depend upon very similar neural systems and mechanisms, but that the link between them is not always clear. Indeed, intertemporal choices—and other choices that require selecting between two options that are consistent with long-versus short-term goals—can be viewed as self-control tasks (Figner et al., 2011; Hare, Camerer, & Rangel, 2008; Wunderlich, Rangel, & O’Doherty, 2009) in which the decision to select an option consistent with a long-term goal is influenced by attention deployment and cognitive change strategies (Michel & Wüstenhagen, 2008) in which case the decision to select an option consistent with a long-term goal is influenced by attention deployment and cognitive change strategies (Michel & Wüstenhagen, 2008). Valuation and decision making can also be applied to other types of choices dilemmas in which control and valuation processes interact to determine choice, including risky decision making (Gianotti et al., 2009), in which the choice is to be fair toward or to punish others (Knoch et al., 2008; Knoch, Pascual-Leone, Meyer, Treyer, & Fehr, 2006), and when the act of choice itself changes our valuations of stimuli via the value-updating mechanism (Zelzer et al., 2008).
Expectancies, Beliefs, and Placebo Effects

Our valuation framework also helps make sense of the growing imaging literatures on the ways in which expectancies and beliefs of various sorts—including placebo effects—influence responses to various kinds of affective stimuli (Wager, 2005). In these tasks, participants are given one of two kinds of explicit expectations. In studies of expectancies or anticipation, participants are told that an upcoming stimulus—whether a painful sensation, an image, or something else—will be of a particular intensity or kind. In placebo experiments, participants are told that a drug (e.g., a cream or a pill) will increase or decrease their subsequent responses to a stimulus. In either case, these expectations lead participants to experience the stimuli, whether real or imagined, as functionally more similar to what they expected than would have been the case had they held no expectations or beliefs about its nature or the protective properties of a drug.

From the perspective of our framework, these phenomena all involve the top-down influence of cognitive control systems on valuation systems or the influence of higher level valuation systems on lower level valuation systems. Our interpretation of these effects is consistent with results of imaging studies of expectancies and placebo effects on pain responses. Such studies indicate that expectancies and placebo beliefs about pain are maintained in a combination of lateral prefrontal/parietal working memory systems and medial prefrontal systems (Atlas, Bolger, Lindquist, & Wager, 2010; Lieberman, Jachso, Berman, et al., 2004; Wager, 2005; Wager, Atlas, Leotti, & Rilling, 2011) that in the framework could be described as representing either conceptual-level beliefs (e.g., "The cream on my forehead suppresses the pain") or contextual expectations about the stimulus or placebo.

According to our framework, these systems influence attention to and appraisal of the contextual and core-level valuations of stimuli (see Figure 2.3), modifying their levels of activation to bias participants toward or away from top-down beliefs (e.g., the lessening activation of pain-sensitive valuations systems, including context-level interpretations of the stimulus, and core-level regions) and core-level regions (e.g., amygdala and PACG (Ploghaus, Eccert, Borries, & Borsook, 2003; Wager, 2005).

Thus, from the viewpoint of the framework, expectancies and beliefs operate much like the two of the emotional control systems described earlier—attention deployment and cognitive change—in that they alter lower-level inputs to the PVA systems and the valuation process.

Summary

One of the fundamental challenges faced by any animal is computing and expressing the value of stimuli in an accurate and timely manner. This is difficult, because the animal's internal state and external environment change over time, and its information acquisition, processing, and response resources and capabilities are limited. To address these challenges, humans (and other animals) have developed a complex set of interacting valuation systems, each of which can be described in terms of a simplified PVA sequence, in which a particular perceptual input is valued negatively (or positively) to a given degree, leading to an impulse to alter ongoing behavioral or cognitive responses. These PVA sequences run in parallel at various levels in the brain and compete for expression.

This process-oriented valuation framework suggests a number of directions for future research. One direction concerns the valuation systems of Figures 2.2 and 2.3 feature three kinds of valuation systems (core, contextual, and conceptual); future work should clarify the number and kind of valuation systems, as well as the rules that govern their engagement in particular contexts. A second direction has to do with how the often-competitive actions impulses associated with different PVA sequences are coordinated. We emphasize the role of competitive activation and inhibition, but how this and other processes lead to coordinated and sustained adaptive behavior rather than erratic and conflicting behavior is not yet clear. A third direction concerns the inputs and outputs of valuation systems. We have suggested that the class of top PVA sequences whose inputs are other PVA sequences, and outputs that include the engagement of cognitive control processes are fundamental to emotion regulation and self-control more generally. That is, the range of relevant inputs and outputs, and the malleability of input-output relations requires further study. A fourth direction involves the forms of value regulation and how they are intermixed in everyday life. Which "pure" or "mixed" form of regulation is most effective? A fifth direction concerns translation of what we learn to illuminate individual differences. In our framework, a given emotional response and regulation profile could involve individual differences in (1) the initial valuations placed on specific classes of stimuli by systems at the core, contextual, and/or conceptual levels; (2) the speed with which these valuations are made; (3) how quickly and easily one resolves conflicts between them to express emotional responses; and (4) how quickly and effectively learning processes update these valuations given that some emotional responses may be more difficult to change than others; (5) the knowledge of how and when to deploy emotion regulatory strategies; and (6) the capacity and ability to deploy down-top control systems to implement these strategies. One important direction for future research is exploring each of these differences—and others—may interact to produce various forms of psychopathology.

Our goal in presenting this valuation framework is to provide a common platform for analyzing the neural systems that are important for many different types of valuation. The impetus for this framework came from the observation that neural systems implicated in emotion generation and emotion regulation overlapped in important ways with neural systems implicated in other literatures that typically are not considered side by side (see Figure 2.3). Across all these research domains an organism's adaptive capacity crucially hinges on the coordination and valuation systems of real placebos.

According to our framework, these systems influence attention and appraisal of the contextual and core-level valuations of stimuli (see Figure 2.3), modifying their levels of activation to bias participants toward or away from top-down beliefs (e.g., the lessening activation of pain-sensitive valuations systems, including context-level interpretations of the stimulus, and core-level regions) and core-level regions (e.g., amygdala and PACG (Ploghaus, Eccert, Borries, & Borsook, 2003; Wager, 2005).

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