

## Chapter 10

# **Affect, decision-making, and value: neural and psychological mechanisms**

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### **Interactions between affect and decision-making**

To examine the intersection of affect, value, and decision-making, we begin with the question “What is the role of affect in decision-making?” Though appealing in its simplicity, this question is rooted in the classic dual-process models of “emotion” and “cognition” (e.g., Cohen 2005), implicitly assuming that “affect” is a singular construct with a singular role in altering “decision-making.” There are three primary reasons that this question is ultimately unsatisfying.

First, the word “affect” describes a broad category that covers many phenomena different in their origins, time scale, and consequences (Scherer 2005). In fact, the definition of emotion, and emotion theory in general, is an active area of research. Some theories consider emotion to be a collection of component processes, each of which captures an objectively distinct piece of the emotional experience (e.g., bodily physiological reactions, facial expressions, subjective feelings, etc.; Scherer 2005), while others propose definitions centering on concepts of core affective responses interacting with appraisals and contexts (Barrett 2006) or take a more functionalist view (Farb et al. 2013). Regardless of the specific definition, we can certainly conclude that emotion does not live on a single axis, and is not a unitary construct. To consider emotion, we must therefore consider the *parts* or *components* of emotion.

Second, our original question, as phrased, ignores the growing neuroscience of emotion and cognition. This literature highlights the emerging understanding of both emotions and cognitive function as distributed across different brain regions. Evidence for this comes not only from neuroimaging studies (Lindquist et al. 2012), but also from lesion (Feinstein 2013) and single-neuron recording studies (Salzman and Fusi 2010). These find that cells or regions of the brain involved in “emotion” are not separate from cells or regions related to “cognitive” functions. In other words, neuroscientific data suggest that “emotion” and “cognition” are not separate systems in the brain. Rather, their shared substrates suggest that we should think in terms of interrelated networks and their functions instead of the classic, but ultimately less truthful, dichotomous labels of “emotion” and “cognition.”

Third, decision-making is also multi-faceted and complex. Though this may seem a basic point, its consequence is that we should expect not a single shift in decision-making

(i.e., toward the “irrational”), but rather changes in specific processes that contribute to decision-making. This logically follows from the observation that option values are not all computed in exactly the same way. Sometimes an option will entail risk; other times, weighing losses against gains; or balancing fairness in an interpersonal interaction. Especially in recent years, studies have begun to dissociate these and other processes that underlie the computation of value, and thus the ways in which different option attributes shape the choices made about those options. This means that the ways in which affect and decision-making interact will be characterized not only by the affective dimension at play, but by the computations being used in the context at hand to make a choice.

Taking these three points into account, we can re-define our question. Attempting to address the many dimensions of affect, the neuroscience suggesting that emotion and cognition are not truly separable, and an appreciation for the complexity of decision-making, we propose a revised question: “How do different components of affect and emotion represent or modulate specific decision-making processes and their neural mechanisms?” Note that this asks not how emotion changes decisions, but how components of emotion might represent and/or modulate decision processes. This is the difference between asking how drugs change a cough, and how a particular antibiotic chemically interferes with infectious bacterial growth. By being more specific in our question, we only improve our ability to answer it.

This chapter will be organized around two main approaches taken in the literature to studying the interactions between emotion and decision-making. The first, correlational approach, is to measure affect and relate it to the variables at hand and the decisions made; the second is to introduce stimuli or contexts that evoke emotional responses, and examine how choices change as a result of that intervention.

The studies we include in this chapter generally meet three criteria. First, as we are examining the neuroscience of interactions between affect, value, and decision-making, the studies must be part of a literature contributing to our understanding of the neural mechanisms underlying these interactions. Second, they include measurement or manipulation of affect. In particular, when we use the word “emotion” here, we will be doing so mostly in the sense captured in Scherer (2005)—as a collection of discrete, short-lived, coordinated responses to an event of significance. These responses could include bodily physiological responses (e.g., measurements of arousal), reported subjective feelings (like anger or disgust), emotional expressions (e.g., a fearful face), or cognitive appraisals (the interpretation of an event), among others. We will also examine moods and stress responses, which while sometimes not considered discrete “emotions” due to their longer timescales and diffuse focus (Scherer 2005), still fall under the umbrella term of affect. Third, the studies must include observations of some kind of decision over options that differ in their subjective value, or utility to the decision-maker.

In the studies we consider, we will endeavor to identify some of the roles of affect in decision-making in terms of the processes and neural mechanisms modulated by affect, and when possible, the specific ways affect contributes to the assessment of value. In domains other than decision-making, as the interactions between emotions and more classically

“cognitive” processes have been investigated, a consistent pattern has emerged in which the role of emotion is one of modulation—that is, changes in emotions are linked to changes in specific processes that define those domains. For example, emotions can act in perception to sharpen or broaden attention (Phelps et al. 2006), or in memory they can enhance the subjective confidence associated with a memory (Poldrack et al. 2008) or the consolidation of the memory itself (LaBar and Cabeza 2006). As we will see, such a modulatory perspective makes sense in the context of decision-making as well (Phelps et al. 2014).

We begin by discussing “assessed emotion,” a category of research largely characterized by the measurement of components of discrete emotional responses during otherwise un-manipulated decision-making tasks.

## Assessed emotion

Three main types of paradigms have dominated the literature examining the links between discrete emotional responses and value-based decision-making. The first set of paradigms has focused on gambling, in the casino sense, by simulating slot machines, also known as electronic gambling machines (EGMs). Understandably, studies in this category have largely been concerned with the clinical implications of emotion’s role in gambling by examining the factors that drive continued gambling despite the relative rareness of reinforcing wins. The second dominant paradigm has examined emotions in the context of what might be termed “risky decision-making.” These tasks, many of which borrow from behavioral economics, generally present participants with multiple options characterized by potential gains or losses and their associated probabilities of occurrence. In contrast to the focus of EGM studies, studies of risky decision-making instead examine processes or variables related to the choice at hand (for example, loss aversion, risk, volatility, etc.), with the aim of understanding the basic motivations that drive choices under risk. Finally, the third paradigm type considers decisions in social contexts. In these studies, participants generally play simplified, highly stylized monetary games that are designed to isolate various aspects of interpersonal interactions, such as punishment, social loss, or trust. We will consider each of these dominant approaches in turn.

In neuroscience, a large and growing literature has highlighted the roles of the insula and the ventromedial prefrontal or orbitofrontal cortex in representing value, and the striatum as integrating value with action (see Bartra et al. 2013 for a review). As we will see later in this chapter, activity in these regions has been found to scale with components of emotions as well, including self-reported subjective feelings (like the desire to play a game), as well as discrete arousal responses like the skin conductance response (an increase in the electrical conductivity of the skin over several seconds driven by activity in the “fight or flight” sympathetic nervous system).

## Gambling

The paradigms researching gambling behavior have used real slot machines or EGMs (Wilkes et al. 2009; Wilkes et al. 2010) or have aimed to replicate the experience of EGMs

in a simpler structure (e.g., Clark et al. 2009). In a typical simulated version of these games, participants are presented with two “wheels,” each with six distinct objects. Participants select one object on the left wheel, after which the right wheel spins. If the two wheels line up, participants win some amount of money (a “win”). If the wheels are one object away from lining up (a “near-miss”) or more (a “full-miss”), participants do not win anything. The decision to persevere in this kind of game is of strong clinical relevance, as problem gambling is associated with clinically significant disorders that incur very real societal costs (Potenza 2006).

Studies combining EGM tasks with the measurement of emotions have found a pattern of results consistent with a role for emotional responses in reinforcing game play. There are two sources of evidence for this—discrete arousal responses, and the self-reported desire to continue playing. One of the most common measurements of arousal is the transient increase in the conductivity of the skin as the sympathetic (“fight or flight”) nervous system increases sweat gland output. This brief increase in conductance is called the skin conductance response, or SCR. In EGM-like tasks, arousal responses appear focused on the positive aspects of gameplay: participants experience elevated SCRs at the time of outcome when they win, but not when they lose or miss (Lole et al. 2011; Wilkes et al. 2009; Wilkes et al. 2010) (though see Studer and Clark 2011). There may also be changes in measures like heart rate (Wilkes et al. 2009), but the evidence on this point is more mixed (Wilkes et al. 2010), and may reflect a combination of anticipation and outcomes (Lole et al. 2011). These findings suggest that when the structure of the task makes non-wins or losses less salient, responses to wins may instead dominate behavior, and could thus drive choices to continue to play.

Though objectively there are only wins and misses in EGM games, a number of studies have made a convincing case that “near-misses” also play a critical role in encouraging gambling by altering participants’ reported subjective feelings. Studies that separated near-misses from full-misses and wins found that relative to wins (which increased desire to play and were rated as pleasurable), full-misses decreased desire to play and were unpleasant. However, while near-misses felt even more unpleasant than full-misses, they paradoxically increased the desire to play the game (Clark et al. 2009; Clark et al. 2012; Clark et al. 2014). Near-misses have also been found to elicit SCRs, which, while less than those to wins, are greater than those to full-misses, which result in no response at all (Clark et al. 2012). Importantly, these physiological responses to, and desire to, continue playing after near-misses appear to arise only in contexts in which participants are able to exert control—that is, when they physically participate in play (Clark et al. 2009; Clark et al. 2012; Clark et al. 2014), and may be related to an increased perceived chance of winning resulting from active choice (Clark et al. 2009; Clark et al. 2012; Clark et al. 2014; see also Langer 1975).

In probing the underlying neural mechanisms that drive EGM play and the near-miss effects, studies using functional magnetic resonance imaging (fMRI; Clark et al. 2009) and patients with focal brain lesions performing these tasks (Clark et al. 2014) have converged to suggest that the underlying neural mechanisms may include the

striatum and the insula in mediating the effect of near-misses on EGM behavior. The insula's role, in particular, accords with previous research tying insula activity to cravings in addition (Naqvi and Bechara 2010), physiological arousal responses (Critchley et al. 2000), and the sensation of internal bodily states, or "interoception" (Craig 2009; Critchley et al. 2004; Khalsa et al. 2009). The insula exhibits a salience-like signal in response to value, increasing for both greater gains and losses (Bartra et al. 2013), which may have the effect in gambling behavior of increasing the salience of positive or near-positive events, as these dominate behavior generally. However, as only a couple of studies have examined the neural correlates of EGM behavior, the precise functional roles of the insula and the striatum in mediating the responses to near-miss outcomes are as yet unclear. Future studies will hopefully deconstruct some of the processes that drive the desire to play and begin to ascribe those processes to specific underlying neural mechanisms.

Finally, there is some empirical evidence that gambling behavior in such experimental contexts is related to real-world pathology. First, measurements of insula activity during near-miss outcomes in the simulated EGM were found to correlate with a measure of participants' errant cognitions surrounding gambles (e.g., whether they felt that their active participation in a game of chance increased the probability of winning) (Clark et al. 2009; though unilateral lesions to the insula did not significantly reduce such explicit cognitions: Clark et al. 2014), suggesting that the insula may contribute to the irrational cognitions surrounding gambling behavior through altered subjective perception of probabilities and outcomes. Second, and more generally, it's possible that long-term emotional adaptation may dampen the power of emotions in problem gamblers. In a study with both recreational and problem gamblers, problem gamblers were found to exhibit blunted stress responses (as measured by the hormone cortisol) to arousing videos (one of which featured gambling, and the other of which featured rollercoasters), implying a general reduction in intensity of responses to arousing events (Paris et al. 2009). If emotional responses to discrete events encourage gambling by signaling positive outcomes (or proximity to them), blunted responses to those events may have an additive effect, encouraging more gambling in an effort to attain similar levels of physiological responses. However, the extant research on this topic is correlational in nature, making it impossible to disentangle at this time whether such decreased responses result from, or cause, pathological levels of gambling.

The role of emotion in casino-like gambling scenarios seems best characterized by a focus on positive events, mediated by insula (and maybe striatal) activity. Critically, this focus extends to objectively negative "near-miss" events that are subjectively perceived as "close" to positive events. These near-miss events may have a particularly central role in gambling behavior, as their occurrence is related to an increased desire to continue playing, relative to full-misses. Any theory of gambling behavior will benefit from incorporating this focus of emotional arousal on positive and near-positive events in explaining why people gamble with the intensity they do, and how to change it.

## Risky decision-making

Despite a similar underlying mathematical structure and focus on monetary outcomes, a category of paradigms that we will call “risky decision-making” has found very different roles for emotion in contributing to value and shaping choices. The experimental paradigms in this category generally involve selections amongst multiple options with clearly defined gains and/or losses that occur with known or learned probabilities. This emphasis on value and probability is paired with meaningful choices between options with different objective attributes, and differs from EGM studies’ emphasis on subjective framing effects (like near-misses), and lack of true multiple options to evaluate and decide between (e.g., different objects on a slot machine wheel do not have objectively different probabilities of success if selected). Having established that the influence of emotion in EGM tasks tends to be on positive events and continued play, we now examine how that pattern changes in “risky choice” scenarios.

One of the earliest studies to measure emotional responses during decision-making measured skin conductance responses during the classic Iowa Gambling Task (IGT; Bechara et al. 1997). Researchers found that anticipatory skin conductance responses predicted subsequent avoidance of decision options that would ultimately yield a net loss if repeatedly selected, suggesting that emotional responses served as warnings of possible negative consequences in the game. Patients with amygdala and ventromedial prefrontal cortex (VMPFC) damage failed to generate anticipatory SCRs and subsequently anticipate and avoid net negative decision options (Bechara et al. 1999), suggesting that both brain regions were necessary to integrate avoidance signals with action. More recently, other studies have used similar games and generally confirmed that differentially greater arousal to “bad” options predicts the subsequent avoidance of those options (Dunn et al. 2010). Though numerous critiques have exposed issues with the IGT (Fellows and Farah 2005; Maia and McClelland 2004) and the related somatic marker hypothesis (LeDoux and Gorman 2001), Bechara et al. (1997) remain one of the first to have objectively measured a component of emotions, the arousal response, and related it to decision-making. Unfortunately, the IGT does not allow the quantitative decomposition of decision behavior into separate processes, with the consequence that any inferences about arousal’s role are limited by the multiple confounded valuation and decision processes at work. If the measure of decision behavior is only the number of risky options selected (as has been the case in many decision-making studies), then it naturally follows that anything that changes the number of risky selections (including risk, ambiguity, learning, gain–loss weighting, probability weighting, or consistency across choices, depending on the task) is unavoidably confounded, as in the IGT. The solution to this problem is a quantitative, mathematical model of the processes-driving choices, combined with a decision task that allows the separation of the model’s components.

Such quantitative approaches to decision-making have recently enabled precise analysis of the relationship between emotional responses and value. One set of studies using such quantitative analysis has focused on the phenomenon of loss aversion (Sokol-Hessner

et al. 2009; Sokol-Hessner et al. 2013a; Sokol-Hessner et al. 2014), defined as an overweighting of potential losses relative to gains of equivalent size. In these experiments, participants choose between risky gambles and guaranteed alternatives. For example, in a choice between a gamble with an equal chance of receiving +\$9 or -\$6, and an alternative of \$0 (neither winning nor losing), consistently rejecting the gamble in favor of \$0 would suggest that loss dollars were weighted at least 1.5 times as much as gain dollars. That relative weighting is captured in the multiplicative parameter  $\lambda$ , the loss aversion coefficient (e.g., in this example,  $\lambda$  would be  $\geq 1.5$  so that  $-\$6 \times \lambda$  would be greater in absolute magnitude than +\$9). By examining choices made over many similar options with slightly different amounts in the gamble and guaranteed alternative, it's possible to estimate each individual's unique  $\lambda$ . By additionally including choices between options that only contained gains (e.g., a large, risky gain versus a smaller certain gain), risk attitudes (a dislike of chance relative to certainty) can be separated from loss aversion, as risk is involved in both the former and latter kinds of choices, but loss aversion only affects the former. Finally, risk and loss aversion could be separated from noisiness in the decision process (how consistent participants are across choices) by asking participants to make many similar choices. Using this carefully constructed choice set and a model of the decision process, these studies were able to separate these easily and commonly confounded processes.

The first study to use the above task and model measured the arousal component of emotions by recording SCRs as participants won or lost money in the task (Sokol-Hessner et al. 2009). Examining SCRs to wins and losses, the authors found that the skin conductance response per dollar lost was greater than that per dollar won, and that this relative overarousal to losses correlated with each individuals' weighting of potential losses relative to gains in their choices, as quantified by  $\lambda$ . Importantly, this correlation was selective—SCRs to gains and losses did not correlate with risk attitudes or choice consistency.

Neuroimaging studies of this task and a slightly different, but similar task, have found that activity in the striatum reliably reflects the subjective expected value of the gamble under consideration (Sokol-Hessner et al. 2013a; Tom et al. 2007), consistent with a role of the striatum in integrating value with action. However, fMRI of the outcome period found that amygdala activity to losses relative to gains correlated with individuals' behavioral loss aversion (Sokol-Hessner et al. 2013a), just as SCRs to losses relative to gains correlated with loss aversion (Sokol-Hessner et al. 2009). A case study in which patients with lesions to the amygdala performed a similar gambling task also found less loss aversion in those patients, suggesting the necessity of the amygdala to loss aversion (De Martino et al. 2010). Since the amygdala is known to mediate arousal responses in other domains (Garavan et al. 2001; Glascher and Adolphs 2003; Williams et al. 2001), and contribute to the computation of value in other regions (Rudebeck et al. 2013), these findings thus suggest the working hypothesis that amygdala-mediated arousal responses at outcome may drive striatally mediated decisions to avoid losses. This hypothesized amygdala–striatal avoidance circuit directly parallels that observed elsewhere, in which the amygdala has been found to mediate avoidance actions via its projections to the striatum (LeDoux and Gorman 2001), and modulate memory by altering activity in the striatum and hippocampus (McGaugh

2004). In the latter case, the amygdala's modulatory effects were found to rely critically on noradrenaline, such that blocking noradrenergic receptors had the effect of preventing the modulation of downstream memory systems like the striatum. To test whether a noradrenergic system also supported the relationship between the amygdala and loss aversion, Sokol-Hessner et al. (2013b) administered the noradrenergic receptor antagonist propranolol in a double-blind, within-subjects design and found that it selectively reduced loss aversion without affecting risk aversion or choice consistency. This suggests that a domain-general modulatory system exists in which amygdala-mediated arousal responses drive avoidance actions via noradrenergic projections to the striatum.

Note that this relationship between arousal and decision-making in mediating avoidance-related behavior in risky decision-making contrasts with the relationship between arousal and decision-making identified in studies using EGMs. In those studies, arousal-related responses are related to *increased* engagement, and so we should expect some divergence in their underlying neural basis (e.g., the effects of emotion may be mediated by interactions between the insula and the striatum).

To the extent to which laboratory studies benefit from being tightly controlled and designed, they are also distanced from the ecological validity associated with “real life” choices. Field studies attempt to bridge this gap. One excellent example was a study in which various physiological measurements were recorded from professional securities traders during live trading sessions (Lo and Repin 2002). The authors recorded skin conductance, cardiovascular variables, respiration, and body temperature during trader's decisions in the course of real, unplanned market fluctuations. The authors found greater cardiovascular responses and more SCRs both in response to discrete market events and during periods of heightened market volatility. While the complexity of market events leaves it unclear what precise decision-related information these physiological variables represented, this study strongly argues that emotion doesn't just play a role in naive participants' decision-making in laboratory tasks, but in the real world, with experienced decision-makers in complex contexts.

### Social interactions

The emphasis of emotional responses on negative events within the context of risky decisions (and hence avoidance-related behaviors like loss aversion) appears to extend to the social domain, in which studies have found that emotional responses generally guide actions like rejection or punishment.

An early neuroimaging study scanned people using fMRI to identify regions of the brain involved in the “Ultimatum Game” (U.G.). In the U.G., “proposers” are endowed with a sum of money. They can then split that money between themselves and a “responder” who is given veto power over the split. If the responder dislikes the split and chooses to exercise their veto, neither the proposer nor the responder receives any money. Otherwise, the money is apportioned as proposed. The authors scanned responders, and found differentially greater activity in the insula, among other regions, to unfair versus fair offers—but only when that offer was made by a human proposer. This unique pattern suggests that



insula activity indexes the subjective unfairness of the offer, and not just its monetary value. In line with this interpretation, greater activity in the anterior insula also correlated with the probability of offer rejection. This general pattern of insula activity has since been replicated in multiple studies (e.g., Grecucci et al. 2012; Kirk et al. 2011), and may be related to the insula's aforementioned putative role in interoception (Craig 2009; Critchley, et al. 2004; Khalsa et al. 2009) and value salience (Bartra et al. 2013).

One of the limitations of neuroimaging in the study of affect is that a change in brain activity cannot be taken as evidence of affect due to the problem of reverse inference (Poldrack 2011). In order to identify whether affect is present, affect must be measured. One of the earliest studies to do so in social interactive games used the "Ultimatum Game" (van 'T Wout et al. 2006). The authors found that SCRs were greater to unfair versus fair offers, but only if the opponent was human—just as in previous imaging findings (Sanfey et al. 2003). Responses to offers from a computer were not affected by the fairness of the offer. Critically, these arousal responses were also related to behavior: the magnitude of the differential SCR to unfair vs. fair offers was positively correlated with rejection behavior, a pattern reminiscent of avoidance behaviors in the risky choice domain (Bechara et al. 1997; Dunn et al. 2010; Sokol-Hessner et al. 2009). That there was no differential arousal when the U.G. proposer was a computer suggests that some aspects of value, and the emotional responses related to it, can be selectively and powerfully motivated by social contexts.

Social interactions are complex, not only in the structure of the interaction, but in the people interacting. While Sanfey et al. (2003) and van 'T Wout et al. (2006) examined how emotional responses to unfair offers shaped decisions, other research has focused on how our perception of others can shape the decisions we make about them (Stanley et al. 2011). In this study, individuals played a "trust game." In the classic trust game (T.G.), Player A is endowed with money and must decide how much of that money to send to Player B. Whatever money is sent to B is quadrupled in value. Player B then decides how much of that increased amount to send back to A, after which the game ends. Because the money sent from A to B increases so much in value, A has an incentive to send that money to B, so long as she trusts B to share it back. Participants in Stanley et al. (2011) played a series of one-shot games as Player A. On each trial they were matched with a different Player B, of whom they were shown a facial photo. Crucially, on the trials of interest, Player Bs were either black or white. After the T.G., participants then completed a test measuring their implicit associations with black and white races called the Implicit Association Test (IAT). In this IAT, participants faced a stream of words and faces, and had to categorize words as pleasant or unpleasant, and faces as white or black—but participants had only two buttons to do so. In one portion of the IAT, one button was used to indicate pleasant words and white faces, while the other button was used for unpleasant words and black faces; in the other portion of the IAT, one button was used for pleasant/black and one button for unpleasant/white. Empirically, people tend to sort words and faces faster and with fewer errors in the first mapping (white/pleasant and black/unpleasant) compared to the second (black/pleasant and white/unpleasant). The extent of this difference quantifies the bias in the implicit associations individuals make with these racial groups. In

Stanley et al. (2011), the authors asked whether this affective variable measuring implicit attitudes was related to how much participants chose to trust their partners in the T.G., and found a strong correlation—the more participants had an anti-black/pro-white bias, the less money they shared with black partners compared to white partners. Crucially, the authors also assessed participants' explicit beliefs and associations with both black and white racial groups (i.e., those they explicitly reported), and even when taking those beliefs into account, the relationship between the IAT and trusting behavior held. When this task was performed during fMRI, amygdala activity was found to scale with the amount of money offered, more strongly for black partners than white partners, while activity in the striatum reflected the racial difference in decisions to trust the partner (Stanley et al. 2012). This suggested a model in which the amygdala coded the racial identity of the partner while the striatum represented and integrated action with overall value, in a direct parallel to the amygdala–striatal modulatory circuit discussed above (LeDoux and Gorman, 2001; McGaugh 2004; Sokol-Hessner et al. 2013a). Clearly, when understanding value and emotion in social contexts, we must take into account not only what is happening (e.g., fairness), but who is interacting, and how they perceive one another both explicitly and implicitly. The valenced associations we hold with those individuals and with their social groups (racial group, but also age, gender, etc.) can dramatically shape how we perceive value, and how we behave toward those individuals.

## Conclusion

The studies in this section have all attempted to measure some aspect of our affective experience and then connect those measures to a decision-making process or phenomenon. While studies of casino-like gambling find that emotional responses to positive events dominate, and that those responses may drive more gambling, studies of risky decision-making and interpersonal interactions both find a clear role for discrete emotions in signaling negative events and driving behaviors broadly associated with avoidance or rejection. The contrast of the findings in these areas highlights the need for more study, and the importance of contextual factors in shaping when and how emotions contribute to decision-making.

Differences aside, one recurrent theme has been the emotional response as a signal used by the decision-maker. This conceptualization suggests that the ability to clearly and accurately perceive the signal may also be a variable of interest. Perceiving one's own internal bodily state is referred to as "interoception." A number of studies have recently examined interoception and related it to decision-making. Although they do not measure affective variables *during* the decision process, studies that show correlations between interoception and decision behavior provide indirect evidence for a role for emotion. Evidence for such a relationship has emerged relating interoception to decision performance in tasks similar to the Iowa Gambling Task (Dunn et al. 2010; Werner et al. 2009), to loss aversion in risky monetary decision-making (Sokol-Hessner et al. 2014), and to rejection behavior in the ultimatum game (Dunn et al. 2012). In some cases, better interoception has been found to mediate the relationship between arousal responses and behavior such that the

relationship only exists for good interoceptors (Dunn et al. 2010; Dunn et al. 2012), while in other cases, interoception is a simple linear predictor of behavior (Sokol-Hessner et al. 2014; Werner et al. 2009). Understanding the extent to which affective variables are not only generated but perceived is clearly going to be important in future studies of the roles of emotion in decision-making.

## Introducing and changing affect

Though measuring emotional responses during unperturbed decision-making is an effective way of identifying correlations between affect and estimates of value, an alternative option is to introduce or alter affective states, stimuli, or responses, and examine how choices change. Studies taking this approach fall into three main categories. In the first, manipulations are used to create incidental affective states with long temporal timescales, on the order of minutes to tens of minutes—like sad or angry moods or stress responses. These studies often feature between-subjects designs using an induction of some kind followed by a decision task. The second category of manipulation introduces emotional primes, like angry or happy faces, that then affect other, nominally unrelated value- and decision-related processes driving the choices at hand. Both of these first two categories involve experimenter-introduced incidental affective variables. In contrast, the third and final type of manipulation leverages the central role cognitive appraisals play in affect (Ochsner and Gross 2008; Scherer 2005) to change existing affective responses, asking participants to use cognitive strategies to endogenously alter their emotional responses, and thus change their choices.

## Mood

Moods are defined as diffuse affective states that typically occur on a scale of tens of minutes, have no precise focus (e.g., aren't necessarily in response to an event), and are relatively low in intensity despite their long duration (Scherer 2005). One of the most straightforward ways to induce such a state in the laboratory is to view film clips featuring emotional content. In one of the first studies to demonstrate the power of mood, participants watched film clips that led to self-reported feelings of sadness or of disgust, or a neutral clip (Lerner et al. 2004). Afterwards, participants were either given a set of highlighters and asked how much money they would require to sell them (their selling price), or asked to choose between highlighters and money (their “choosing” price). When these objectively identical questions are posed this way, the classic finding, replicated in the neutral condition, is that the selling price is higher than the choosing price (Kahneman et al. 1991). The induced moods, however, led to different price patterns. When sad, the endowment effect was reversed, leading to higher choosing prices than selling prices. The authors interpreted this as a consequence of a mood-related desire (called an “action tendency”) to change participants' circumstances that selectively lowered the value of endowed goods, thereby promoting the acquisition of new things. Disgust, on the other hand, reduced both choosing and selling prices to equally low levels, a finding attributed to a global desire to

expel or get rid of things that reduced the value of all objects, whether owned or not. This study was an early, but powerful example of how moods could dramatically change how participants valued everyday objects, and how much that valuation depended on the framing of the question itself.

A similar induction technique was used in a study of the Ultimatum Game (described earlier) to examine how such moods (and their attendant subjective feelings and action tendencies) related to interpersonal interactions (Harlé and Sanfey 2007). In this study, participants viewed clips that were neutral or that induced feelings of sadness or of amusement, after which they played the U.G. as the responder, deciding whether to accept the proposer's monetary split, or veto the offer and prevent anyone from receiving any money. While the amusement film clip did not change choice behavior compared to the neutral clip, participants accepted fewer unfair offers the sadder they felt in response to the sad clip. This increased rejection was interpreted as a negative attentional focus brought on by the sad mood: rather than focusing on the money they would receive if they accepted even an unfair offer, the majority of their attention was commanded by the offer's unfairness. A follow-up neuroimaging study found that the relationship between induced sadness and increased rejection behavior was statistically mediated by increases in anterior insula activity (Harlé et al. 2012), consistent with earlier work placing the insula at the center of the subjective perception of unfairness in interpersonal interactions (Sanfey et al. 2003). Notably, a separate, more recent study also examined U.G. rejection behavior in the contexts of moods, though in this case, neutral, sad, and disgust moods were induced with sequences of images. The authors found that the induced sad mood had no effect on rejection behavior, but disgust led to significantly more rejections (Moretti and di Pellegrino 2010), raising the possibility that even within a given type of mood, the exact induction approach may be a critical variable. In the context of Lerner et al. (2004), these studies generally highlight the importance of specifying the kind of decision at hand and the exact affective manipulation used when considering how something like a mood can change the actions or decisions participants make. While simple action tendencies to "change" or "expel" dominated behavior during straightforward valuation, the ability of a mood to shift attentional focus became more important in a complex, multi-attribute interaction like the U.G..

Finally, the negative affective states of fear and anger have been the focus of several studies examining risk-taking. One of the reasons for this focus is that while fear and anger share a negative valence, they differ in their consequences for action: the former emphasizes avoidance and withdrawal, and the latter, approach and engagement. Thus, if the effect of these mood states on behaviors like decision-making is due to changes in appraisals and not simple valence-contamination, then fear and anger should have different consequences for choices. In an early study, this kind of difference was indeed found (Lerner and Keltner 2001). Examining individuals' natural dispositions toward fear and anger showed that while high-fear individuals were risk averse, high-anger individuals were risk seeking. Cementing the centrality of appraisals in risk behavior, the pattern of responses for individuals disposed to anger held for those disposed to

happiness (which results in similar approach and engagement appraisals). Beyond dispositions, experimental inductions using writing prompts to encourage individuals to re-experience previous fear- or anger-inducing events led to identical patterns in risk perception. Finally, statistical mediation confirmed that the differential effects of anger and fear on the perception of decision options was due to the cognitive appraisals those affective states generated. Clearly, mood has subtle effects—the valence of subjective feelings was not predictive of behavior, but one of the components of the mood state, appraisals, was closely related to the processing of risky options. More recent work has followed up on the finding linking anger to risk-taking by examining how the context of the task might make appraisals versus subjective feelings more salient (Baumann and DeSteno 2012). The study found that manipulations that emphasized appraisals over feelings confirmed the prior findings of anger leading to more risk-taking, but when the task context was shifted to emphasize feelings over appraisals, risk-taking under anger actually decreased.

The above studies provide strong evidence that when considering moods, we must understand the components of that mood (e.g., how it changes our appraisals vs. how it makes us feel), the decision at hand, and the current context, in order to predict how the mood will affect the decisions we make. Much more work remains to be done in understanding the components of moods and their relationship to decision processes, but it is already clear just how important it is to consider these dimensions.

## Stress

In contrast to moods, much more is known about stress as a biological process involving different neural and hormonal systems at varying time scales. Stress can be defined as the body's response to real or implied threats induced by novel, unpredictable, or uncontrollable situations (Lupien et al. 2007). The activity of two different systems together comprises the stress response. One system consists of sympathetic nervous system responses that occur on a scale of seconds to minutes and result in increased bodily arousal and hormones like adrenaline surging through the bloodstream. The other system consists of a hormonal cascade in which each hormone triggers the release of the next, leading to a physiological response on a scale of minutes to tens of minutes. Though there is evidence that both systems are required for stress to alter behavior (Roosendaal et al. 2006; Schwabe et al. 2010), the slower-moving HPA axis hormone cascade most strongly differentiates the stress response from shorter-term arousal responses. In that it involves the hypothalamus, pituitary, and adrenal glands, the system underlying the hormonal cascade is thus termed the hypothalamic–pituitary–adrenal (HPA) axis of the stress response. In practice, studies quantifying the effect of stress generally assay one of the final hormones produced by the HPA axis, cortisol. Cortisol is a glucocorticoid that can be easily and non-invasively measured using a cotton swab to collect saliva, and because of its position near the end of the hormone cascade, only peaks about 20–30 minutes after an acute stressor. Because of this delay, studies examining the effect of the HPA axis response on behavior generally administer their task during this period of peak cortisol response.

The consequences of stress in the brain are two-fold: stress impairs prefrontal cortical (PFC) regions that support executive control and top-down processing, while simultaneously potentiating reactivity in subcortical regions like the amygdala, driving bottom-up associations and attentional saliency (Arnsten 2009). In decision-making, it is thus unsurprising that the single most consistent effect of stress is a reduced reliance on structured, often intentional, cognitively complex decision mechanisms (“goal-directed” processes), and increased influence of simple action-outcome behaviors (habits or heuristics). One seminal study in rats showed that chronic stress led rats to become insensitive to changes in value (Dias-Ferreira et al. 2009). The rats were initially trained to press levers for food, and when fed to satiety on one of the food items, unstressed rats subsequently stopped pressing the specific lever for that food. In contrast, chronically stressed rats continued to press equally on all levers, showing no specific reduction in pressing related to their satiety for one of the foods. This suggests that while unstressed rats could use decision systems that linked actions with objects and objects with value, the stressed rats were disproportionately relying on simple habit systems that connected actions directly to value—and so couldn’t update the value of an action when an outcome changed (e.g., when the food that action produced was no longer valuable). In other words, the effect of chronic stress on decision-making was not directly on value, in this case, but on which mechanisms were being used to act in the service of value. The authors found that stress also led to changes in the striatum (both hypertrophy and hypotrophy), a region known to link actions with values (Rangel et al. 2008) and to process surprising outcomes (Maia and McClelland 2004), suggesting that the effect of chronic stress on which system was being used to guide action might be mediated by morphological changes in the striatum.

Though using acute stress manipulations instead of chronic stress, a similar study done in humans found much the same pattern: acute stress led to insensitivity to changes in action-associated value (Schwabe et al. 2011). Additionally, this study found that propranolol, a beta-adrenergic receptor antagonist that blunts noradrenergic function, restored normal, goal-directed behavior (that is, people who took propranolol prior to stress were normally sensitive to devaluation). Propranolol’s protective effect is consistent with evidence that interactions between glucocorticoid and noradrenergic systems produce the effects of stress, perhaps through glucocorticoids enhancing noradrenergic function (e.g., Roozendaal et al. 2006; Schwabe et al. 2010). More research, however, is necessary to fully understand how these two branches of the stress response interact in humans during decision-making, and to what extent the effects of stress rely on one or the other branch.

One of the limitations of Schwabe et al. (2011) was that while the dominance of habit systems under stress is the most likely explanation for the behavior, the influence of habits on behavior were not computationally dissociated or quantified relative to more goal-directed influence. To address this gap, a recent study asked participants to perform a complex task involving two stages of choices (Otto et al. 2013), designed to separately identify the contributions of two different learning mechanisms to behavior. The first mechanism, called “model-based” learning, entails building a model of the two-stage structure of the task linking actions to objects to value and relies upon the PFC (Balleine

and O'Doherty 2010). The second simply involves reinforcing actions that ultimately lead to reward (linking action directly to value, such “model-free” learning is conceptually similar to habits), and is known to rely upon the striatum (Montague et al. 1996). While both mechanisms contribute to behavior under normal circumstances, the authors found that acute stress impaired the PFC-dependent model-based mechanism and did not affect the model-free mechanism. In other words, stress didn't alter habit-like model-free learning, but instead attenuated other, competing mechanisms, allowing model-free learning to dominate how participants learned about value, and thus the choices they made. Finally, the authors found that HPA axis activity (as quantified by cortisol) predicted the decrease in model-based learning, subject to the constraint that working memory capacity had a protective effect—acute stress attenuated model-based learning less for participants with high working memory capacity relative to those with lower capacity. The effect of stress was very selective, though not uniform across people.

Beyond habits and learning, the effect of stress on value and decision-making is less clear, though it may play a role in a variety of contexts. Acute stress has been shown to eliminate the success of PFC-reliant, appraisal-based emotion regulation techniques (Raio et al. 2013); it may make people less sensitive to rewards (Berghorst et al. 2013; Bogdan and Pizzagalli 2006) or punishments (Petzold et al. 2010); and stress may lead to greater impulsivity in intertemporal choices (Kimura et al. 2013), depending on contextual factors like trait perceived stress or future/present orientation (Lempert et al. 2012). However, the effects of stress in other realms of decision-making are as yet unclear. In social contexts, acute stress has been found to increase generosity while not affecting punishment behavior (von Dawans et al. 2012), while others have found stress reduces both generosity and punishment (Vinkers et al. 2013). Studies of risky decision-making have generally focused on risk aversion but their findings have been similarly inconclusive, showing that acute stress increases (Cingl and Cahlikova 2013; Porcelli and Delgado 2009), decreases (Pabst et al. 2013; Preston et al. 2007; Starcke et al. 2008), or does not affect (Delaney et al. 2014; von Dawans et al. 2012) risk aversion. Of note is that the above-mentioned research on risk attitudes has relied on coarse behavioral measures of decision-making (e.g., probability of gambling) that do not separate the processes that contribute to decisions under risk, including risk attitudes, loss aversion, and choice consistency. One recent study that did use modeling to estimate risk attitudes directly administered cortisol and found no effect of an acute administration (Kandasamy et al. 2014). This same study also administered cortisol over multiple days to a separate group of participants, and found that this “tonic” administration of cortisol led to increased risk aversion. Of course, cortisol is only one piece of the complex, multi-system neurohormonal responses that occur during stress. This may be why, for example, another recent study examining endogenous cortisol levels on a scale of months found that increased cortisol did not have any relationship to risk aversion, but instead was correlated with reduced loss aversion (Chumbley et al. 2014). These studies' different timescales (a week versus two months) and assessments or manipulations of stress (exogenously administered bursts of cortisol; quantification of endogenous stress responses via basal cortisol) may ultimately be the key to reconciling their findings.

The single clearest effect of stress discussed above is its reduction of the contribution of prefrontal cortex-dependent intentional, goal-directed, and working-memory-based computations to our estimates of value and our behavior. Though our relatively deep understanding of the biological effects of stress is a tremendous foundation from which to start in examining how it shapes decision-making, we clearly have more work to do to understand the timescales and components of stress and its effects. Stress can be acute, with responses occurring on a scale of tens of minutes, but as some of the studies we discussed have found, stress on a scale of days, weeks, or months (let alone years) may have important and divergent effects on decision-making. Timescale aside, stress is also a complex phenomenon, comprising multiple systems each with multiple components. For example, while cortisol is used to quantify endogenous stress responses as a marker of HPA axis activity, pharmacologically administering cortisol in isolation from the rest of the stress response may lead to different effects. In addition to appreciating the subtleties of stress, unraveling the effects of stress on risky monetary decision-making is going to require a high level of specificity and sophistication in analyzing the processes that compute value and use it to make decisions. Future studies using models of these processes will likely have the greatest success in identifying when and how stress changes value.

### Emotional primes

Turning to a different component of the affective experience, expression, yields studies on how the perception of facial expressions can change the choices made in a variety of domains. For example, one early study presented participants with photographs of faces with different expressions just before decisions about drinks (Winkielman et al. 2005). Importantly, the faces were on the computer screen so briefly that participants did not report any awareness of their presence. Despite being perceived only at a subliminal level, the faces, which were angry, happy, or neutral, changed participants' pouring, consumption, rating, and pricing of a drink. Angry faces preceding the task resulted in less drink poured, less consumed, lower ratings, and lower dollar value given to the drink. Happy faces had the opposite effect. Because the faces were both irrelevant to the task at hand and subliminally presented, the authors concluded that participants' subtle responses to those faces contaminated affective processes contributing to their subsequent actions and judgments in the drink task.

In a study with important differences and similarities, Luo et al. (2014) asked participants to hold a fearful, happy, or neutral face in memory during an intertemporal choice task involving tradeoffs between small rewards in the present and larger rewards in the future. Each trial began with an expressive face that participants were asked to remember. Next, they chose between a smaller, sooner reward and a larger, later reward (while holding the face in memory), after which they were shown a second expressive face from the same individual and were asked if the intensity of the expression was the same as the first face. Once again, the emotional faces were irrelevant to the task at hand, but the authors found that holding happy faces in memory led to more impulsive choices relative to fearful faces, which led to more patience (Luo et al. 2014). Thus while the use of faces as an



irrelevant contaminant was similar, despite differences in awareness, face emotionality, and decision task, the perception of facial emotion was able to change choice, in this case apparently contaminating the processes supporting the valuation of reward and its discounting with time. In an important caveat, other studies using either pictures or words in a similar fashion have found that the consequence of preceding an intertemporal decision with an affective stimulus can depend not only on the stimulus, but on the current affective state and the personality traits of the individual making the choices (Augustine and Larsen 2011). As with some of the research discussed earlier, while the stimulus is obviously important, these findings highlight the importance of stimulus context, including the attributes of the decision-maker themselves (Dunn et al. 2010; Sokol-Hessner et al. 2014; Stanley et al. 2011).

One remarkably consistent factor in the studies discussed above (and others) using emotional primes is the frequent choice of social stimuli (faces) as the manipulation (Aïte et al. 2013; Luo et al. 2014; Winkielman et al. 2005). While other stimuli can certainly be used (e.g., pictures or words; Augustine and Larsen 2011), this predominance demonstrates the emotional power often found in social stimuli and serves as a reminder of the significant overlap between the social and emotional domains (Phelps and Sokol-Hessner 2012).

### **Cognitive regulation and strategy use**

Cognitive appraisal as a component of emotion has a central role in modulating the influence of other affective components on decision-making. Recent research has shown that internally generated reinterpretive appraisals can dramatically change behavioral, physiological, and neural responses to stimuli that normally cause emotional reactions (Delgado et al. 2008; Eippert et al. 2007; Ochsner et al. 2002). In these studies, the dorsolateral prefrontal cortex (DLPFC) is generally found to increase in activity during regulation, while other regions, like the amygdala, decrease (Ochsner and Gross 2008). Because DLPFC does not have strong direct connections to regions like the amygdala, it's possible that its effects are mediated by the ventromedial (Delgado et al. 2008) or ventrolateral prefrontal cortex (Buhle et al. 2014), which do have direct subcortical projections. As noted earlier, this prefrontal dependence is one of the reasons cognitive regulation is vulnerable to stress (Raio et al. 2013). In the domain of decision-making, cognitive strategies that emphasize reinterpretation, like in classic emotion regulation paradigms, have also been shown to be effective in changing how we assess value.

One early study, portions of which we discussed earlier, examined whether such intentional cognitive strategies could change risky monetary decision-making (Sokol-Hessner et al. 2009). Participants were asked to make choices over the same set of gambles twice, allowing a within-subjects comparison of any changes in the processes underlying their decisions, including loss aversion, risk attitudes, and choice consistency. One set of choices was completed using a baseline strategy that emphasized considering each choice on its own merits, in isolation from any context. For the other set, participants were asked to consider their choices as one of many, in their greater context. When participants used this second strategy to re-appraise or contextualize their choice, they were less loss-averse. Not

everything changed about their choices, though—their sensitivity to risk and their consistency across choices remained the same. This strategy also reduced participants' arousal (Sokol-Hessner et al. 2009) and amygdala hemodynamic responses (Sokol-Hessner et al. 2013a) to losses, suggesting that they did, in fact, feel the weight of losses less. When using the strategy, regions of the brain, including the DLPFC and VMPFC, increased their activity, exhibiting a similar pattern as in more classic emotion-regulation studies (Ochsner and Gross 2008). Other subsequent studies using different kinds of gambles and different strategies have confirmed the power of reinterpetive strategies to alter risky monetary decision-making (Martin Braunstein et al. 2013; Martin and Delgado 2011), and even shown that habitual, every day use of cognitive strategies to regulate emotions may function as a “baseline trait” of sorts, shaping risk-taking behavior in the lab in the absence of explicit strategy instruction (Panno et al. 2013). Appraisals can alter the context within which possible gains and losses are considered and weighed. By changing the context, the resulting estimate of value is also shifted, and thus different decisions are made.

Not all decisions are exclusively about money, of course—and cognitive strategies are equally capable of changing how these other factors are interpreted; for example, altering decisions in social contexts, like the Ultimatum Game. In a follow-up to a study described earlier (van ‘T Wout et al. 2006), responders were asked to reappraise the offers they received from proposers—take a more detached view of them, or imagine reasons why that offer may have been made (e.g., that the proposer was not well off and could use the money). When participants did so, rejection rates dropped, consistent with a reduction in the negative value assigned to unfair offers. Fewer rejections also had an interesting consequence down the line in a second phase of the study: after responding to offers, participants took on the role of the proposer and made their own offers. Those participants who reduced their own rejection behavior using reappraisal made more generous offers when the tables turned (van ‘T Wout et al. 2010).

A subsequent fMRI study, briefly mentioned above, confirmed the basic behavioral finding of van ‘T Wout et al. (2010): positive reinterpretations increased acceptance of unfair offers, while additionally showing that negative reappraisals (e.g., that the proposer was selfish and wanted all the money) could increase rejection rates (Grecucci et al. 2012). The authors also found that frontal regions increased in activity during reinterpretation, consistent with studies of the reappraisal of emotional images (Ochsner et al. 2004) and risky monetary decision-making (Sokol-Hessner et al. 2013a). A similar pattern was observed in another neuroimaging study examining individual differences in U.G. rejection behavior (Kirk et al. 2011), in which individuals who accepted most unfair offers had greater DLPFC activity during those decisions, suggesting that they were spontaneously regulating their responses. These findings highlight that changing choices through changing appraisals operates very similarly to changing emotions in other, non-decision contexts: PFC regions implement regulation strategies, which can alter emotional and neural responses in other regions, and thereby change the assessment of value and the decision. Importantly, the effects of reappraisal can extend beyond the choice at hand. Especially as we consider choices in social contexts, these studies convincingly show that such reappraisals

have the power to change the tone of an entire extended interaction, making appraisal a very important tool in shaping decision-making.

Because (re)appraisal is one of the most powerful and flexible ways to alter emotions, it is unsurprising that differences in appraisal habits and techniques have been related to experience and performance in real-world decision-making. Real traders' self-reports of emotional responses in the course of doing their job indicate that while all traders experience such responses, the more experienced and well-paid traders additionally report strategies for managing and using their emotions to perform their job better—less-experienced traders tend to discuss emotions only as a distraction to be minimized if at all possible (Fenton-O'Creevy et al. 2011). However, in the course of aiming to minimize the relationship between their emotions and their choices, low-performing traders ironically appear to maximize it: they have a tighter, stronger relationship between their subjective emotional experience and the day's trading events than do high-performing traders (Lo et al. 2005). While the two studies above both examine participants' self-report of their subjective emotional experience, the connection between emotions and trading extends to the physiological domain: traders with less experience have stronger autonomic responses to discrete market events and market volatility compared to more experienced traders (Lo and Repin 2002). Though these studies find that greater experience and performance is related to reduced emotional reactivity, note that emotions are reported by, and objectively measured in, *all* traders—the question is not who experiences emotions, but what they do with their emotions when they experience them. More generally, these studies make it clear that emotions have a role in value and decision-making not only in the lab, but in the real world as well.

### **The many ways affect and decision-making interact**

As we have seen above, affect and decision-making are clearly related in their shared behavioral, physiological, and neural correlates. As we observe measures or manipulations of affect changing neural mechanisms in ways that correlate with changes in choices, the parsimonious explanation is that affect is intertwined with the computation of value across a wide variety of decision-making domains (Phelps et al. 2014). Regions like the amygdala, insula, striatum, DLPFC, and VMPFC appear repeatedly at the center of these studies. Roles may be emerging for the amygdala in mediating the effects of arousal on decision-making, the insula in mediating the subjective perception of probability, fairness, and interoception, the striatum in integrating value with action, the DLPFC in implementing intentional strategies or regulation, and the VMPFC in combining different sources of information to compute an overall value estimate. There are other portions of the affective experience whose roles don't appear as tightly linked to single regions in the brain, including stress, mood, and emotional primes, though more research will be necessary to understand their neural correlates. Critically, all of these regions are not only identified in studies manipulating or measuring affect, but are commonly found in studies examining value and decision-making generally (Bartra et al. 2013; Phelps et al. 2014; see also Levy and

Glimcher, this volume). It is likely that the construction of value consistently involves the integration of affect—the precise component of which, and the way it influences decision-making, depend on the context and the choice being made.

One important caveat is that the exact function of many of these regions is still under debate. We know neurons calculate quantities that they then pass on to other neurons, which integrate those computations with their own, ultimately culminating in the muscle movements of making a choice—the question for us is what is that computation? Unfortunately, even in commonly studied regions like the amygdala, numerous divergent theories of its computational role have been put forth. These include representing the relative stability of stochastic events (termed “associability”; Li et al. 2011), ambiguity (Hsu et al. 2005), simple Pavlovian conditioned attentional value (Seymour and Dolan 2008), or the integrated value of contexts, motivational states, stimuli, and learning (termed “state value”; Morrison and Salzman 2010). Clearly, much work remains to be done to understand the linkages between regions of the brain, the neural computations they implement, and the mapping of those computations to the component processes underlying affective phenomena—work which will require an increasing focus on computational specificity in analyzing both behavior and the brain (Behrens et al. 2009).

In the introduction, we stated our main question: “How do different components of affect and emotion represent or modulate specific decision-making processes and their neural mechanisms?” As this chapter can clearly attest, there is no single, simple answer. Affect has a very real effect on our choices, but it depends on the context of the choice, the choice target, our appraisals (instructed or induced), and who we are, among other factors. To the extent that there is a theme, it is this: affect changes the ongoing computation of value, effectively weighting different aspects of the situation in a given choice—the hallmark of a modulatory role (Phelps et al. 2014). However, as our perspective on affect and decision-making increases in complexity, so too will our challenge in neuroscience. We will likely find that the classic module-based approach to studying the brain will break down as we begin to focus more on computations and distributed representations than on discrete regions and discrete categorical factors (Salzman and Fusi 2010).

The more we understand about how aspects of what we call “affect” interact with what we call “cognition,” the clearer it becomes that they are in fact not fundamentally separable. “Affective” processes are a natural part of “cognition,” and vice versa—and nowhere is this more apparent than in the study of the myriad processes and factors that interact when computing value and using it to make decisions.

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