

RUNNING HEAD: MOTUS MODERARI

Motus moderari: A neuroscience-informed model for self-regulation of emotion and motivation

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Main text word count: 9374

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**To appear in: G. H. E. Gendolla, M. Tops, M., & S. Koole (Eds.), *Biobehavioral foundations of self-regulation: A handbook*. New York: Springer.**

## 1 Introduction

The Latin word *motus* refers to movement. It is the root of common English words including motion, momentum, and commotion. It is also the root of the words emotion and motivation, and provides a compelling explanation of the link between the two: both are for action. Emotion and motivation, to borrow a phrase from William James, are for the sake of doing (James, 1890). Contemporary thinkers largely agree with this view, and have placed emotion and motivation immediately before action in some of the most powerful theories of behavior including reinforcement sensitivity theory (Gray, 1970) and feedback control theory (Carver & Scheier, 1980), not to mention a range of functionalist accounts of emotion and motivation (Cosmides & Tooby, 2000; Fredrickson, 1998; Frijda, 1986; Izard & Ackerman, 2000). Each of these theories is backed by robust evidence of a role for emotion and motivation in regulating, moderating, guiding, or anticipating action if not directly causing it (Baumeister, Vohs, DeWall, & Zhang, 2007). Research aside, the subjective experience of each demonstrates a strong link to the other. What is fear without the accompanying urge to run or hide? And what is the longing to be with a loved one without the feelings of affection and desire?

Despite the clear connections between emotion and motivation in both science and everyday experience, the research on the self-regulation of each of these topics is an island unto itself. Early studies of emotion regulation (e.g., Gross, 1998) focused narrowly on the modification of basic emotions such as fear and disgust, and research on the self-regulation of motivation typically examines a specific motive (e.g., food craving; Ward & Mann, 2000) to the exclusion of other types of motivation. There is little cross-talk between the two lines of research, even when there are clear parallels such as between reward motivation and positive emotion. (The domain of self-regulation of behavior takes an even more extreme position,

studying “behavior” in terms of button presses using purely cognitive models of executive control that have no place for emotion or motivation (e.g., Aron, 2008; Miyake & Friedman, 2012), but that is beyond the scope of our argument here.)

The present disconnect between these bodies of research on self-regulation in different domains is not intentional but rather reflects a natural trajectory in the development of the field. Early studies were isolated because they were pioneering new territory, and many of their design choices (e.g., to use standardized stimuli known to reliably elicit specific emotions) reflected this. Building upon these studies, researchers have begun to assemble an argument that self-regulation of emotion, motivation, and behavior are related even perhaps to the point of being interchangeable (Cohen, Berkman, & Lieberman, 2013; Heatherton & Wagner, 2011; Volkow, Wang, Fowler, & Telang, 2008). Emotions, motivations, and actions may be qualitatively distinct from one another, but the top-down processes that regulate them are likely shared across domains (Heatherton & Wagner, 2011). The central aim of this chapter is to review evidence for and against this position.

### **1.1 A role for neuroscience in developing self-regulation theory**

The psychological science community has been engaged in a conversation about the usefulness of neuroscience methods (Diener, 2010; Poldrack, 2010, Shimamura, 2010). The central questions are whether neuroscience data can advance psychology theory, and if so, under what conditions. We and others have argued that indeed they can (Berkman, Cunningham, & Lieberman, in press; Cunningham, 2010; Mitchell, 2009). Specifically, neuroscience methods can distinctly answer four types of questions about mental processes: “brain-mapping” questions about which structures in the brain support a given process; “prediction” questions seeking to foretell specific behaviors based on a pattern of neuroscience data; “divergence” questions about

whether two or more processes rely upon different neural systems even though those processes may feel qualitatively alike (e.g., different forms of learning); and “convergence” questions about whether two or more processes rely upon the same neural systems even though the processes seem distinct (Berkman et al., in press). Our working hypothesis here about various domains of self-regulation sharing a common neural pathway is a “convergence” question in that it asks whether processes that have been traditionally studied separately by different theoretical camps actually draw upon the same neurobiological machinery. However, in the present review we also entertain the idea that unexpected divergences may emerge that could have value for informing theory about self-regulation.

The advantages of uncovering a possible neural convergence and divergences across several aspects of self-regulation are numerous. From a theoretical perspective, it would provide additional information about which types of self-regulation are related to which other forms and how. It would also begin to suggest the possible mental processes that underlie those relationships. For example, suppose that there is a neural distinction not between “emotion regulation” and “motivation regulation” but rather between the regulation of positive/appetitive stimuli and negative/aversive ones. This would suggest that regulation varies as a function of the eliciting stimulus more so than the nature of the mental process being regulated. Identifying convergences allows scholars to import theoretical constructs from one domain into another. For example, the theories on emotion regulation are highly developed relative to those on motivation regulation (Gross & Thompson, 2009), but if it turns out that both kinds of self-regulation rely on the same neural systems, then it would be reasonable to apply the more elaborated emotion regulation theory to models of motivation regulation. From a practical perspective, convergences

would enable researchers to share experimental paradigms across the (perhaps) artificial boundaries between these fields and leverage existing knowledge into new territory.

## **1.2 Organizing principles: Domain, direction, process, and agency**

As implied above, the field of self-regulation is currently fractionated around distinctions between “emotion”, “motivation” and “action”. We have referred to these as “domains” of self-regulation and made the case that there might be “cross-domain” similarity in the neural systems of self-regulation (Cohen et al., 2013). Beyond domain, several other distinctions have been investigated to some extent and will be reviewed here: direction, process, and agency.

The first organizing principle—and the one used to structure the main sections in this chapter—is *direction*. For our purposes here, direction encompasses both the automatic action tendency with respect to the stimulus (toward vs. away) and the valence of the stimulus (appetitive vs. aversive). Thus, in the following review, studies of “approach” include those investigating regulation of positive basic emotions (e.g., happiness) and of approach motivational impulses (e.g., cravings for food). Similarly, studies of “avoidance” include those investigating negative basic emotions (e.g., sadness) and of avoidance motivational impulses (e.g., loss aversion). We note that positive/negative valence and approach/avoidance motivation are not interchangeable and indeed that some have studied cases under which people approach negative stimuli and avoid positive stimuli (e.g., Berkman & Lieberman, 2010). However, for the purposes of simplicity, we have focused our review on self-regulation of approach-to-positive stimuli (e.g., delicious foods, happy faces) and of avoidance-to-negative stimuli (e.g., aversive foods, fear faces). For a review of the neural systems of the approach and avoidance motives per se, as opposed to the systems involved in regulating them, see Harmon-Jones (2014) in this volume.

A second organizing principle that has been noted informally by researchers but proposed systematically only recently (McRae, Ciesielski, & Gross, 2012) is *process*, or the specific cognitive process targeted by a regulation strategy. The idea that different cognitive processes can support the same ultimate goal of self-regulation goes back at least to Gross's (1998) process model, but has been somewhat lost in practice. For example, reframing, distancing, and distraction have each been described as "antecedent-focused" types of cognitive reappraisal, even though the mental calculations involved in each may be entirely different (in a process analysis sense; see Bilder, Sabb, Parker, Kalar, Chu, Fox, et al., 2009): reframing involves making new meaning from the same concrete information; distancing involves altering the visual representation of the scene or shifting visual perspectives; and distraction involves shifting attention in a controlled way to different properties of the stimulus or to a different internal or external stimulus altogether. It is particularly important to consider mental process when using functional neuroimaging, as that class of tools is presumably optimized to detect neural activity at the level of the mental process (e.g., attention) rather than at the level of the broader psychological construct which may involve a collection of more basic processes (e.g., reappraisal; see Davis & Poldrack, 2013 for a more detailed discussion of this issue). In the present review, we note differences and similarities in the processes likely deployed in various self-regulation strategies where appropriate.

The final distinction we consider throughout the chapter is *agency*, which encompasses two distinct yet closely related ideas. First, as the name implies, agency refers to choice during the regulation process, either of regulation strategy or of the target being regulated. Our general hypothesis here is that regulation strategies that are self-chosen will be more effective than those that are experimenter-assigned because of previous practice, comfort, or mere cognitive

dissonance. Second, we also use agency to refer to whether or not the self-regulation effort results in a self-relevant behavior. In other words, is there an implied behavior or decision that will have real consequences for the person engaging in regulation (see also Beer & Flagan, 2014, in this volume for further discussion of self-processes in self-regulation). Considerable evidence suggests that self-processing is distinct from other forms of processing (Heatherton, 2011), perhaps because it requires a unique convergence of processes including memory, valuation, emotion, decision-making, and action selection (Legrand & Ruby, 2009). The experimental paradigms employed in studies of emotion and motivation regulation vary in how self-relevant or self-referential they are. In some cases, participants regulate generic emotional stimuli that are self-relevant only because they tend to evoke certain emotions in most people; in other cases, participants regulate personalized stimuli with actual behavior at stake (e.g., a purchase or consumption of a food). We hypothesize that the degree of agency as such would generate quantitative and possibly qualitative differences in the patterns of neural activity during regulation, and will use this chapter as a vehicle to explore that hypothesis.

### **1.3 The present review**

In the following two sections, we review neuroimaging studies on the regulation of “approach” and “avoidance” emotions, motivations, and impulses. For each, we describe the methods with particular attention to how the paradigm relates to the distinctions described above of domain, direction, process, and agency. We then describe the results, using neuroanatomical labels as consistently as possible to allow for comparisons across studies. We also note research gaps and open questions where appropriate. Finally, we conclude by synthesizing the general results with respect to each distinction and providing several recommendations for future studies on self-regulation of emotion and motivation.

## 2. Approach

In this section, we focus specifically on the overlap between regulation of approach motives and positive affect. For example, it would be logical if similar brain regions were involved in both craving for a stimulus (a motivational state) and the enjoyment of consuming it (an emotional state). To the end of uncovering possible connections between them, this section reviews and synthesizes the functional neuroimaging literatures on the regulation of these two types of experiences.

A ubiquitous daily experience is to approach stimuli in the environment such as food, money, or other potential rewards. This experience is sometimes goal-directed (e.g., striving toward a desired professional outcome) but often more stimulus-driven (e.g., impulsively reaching for a high calorie snack that one otherwise doesn't want to eat). Thus, regulating the motivation to approach these types of stimuli has been the focus of a large body of research. For a little over a decade, research has investigated the neural systems underlying the regulation of cigarettes, food, monetary reward anticipation, risky behavior, and sexual arousal.

In addition, some high-arousal emotions such as excitement or anger elicit approach motivation, and these emotions may likewise be the target of regulation. Although positive emotions (like happiness or excitement) are usually not the target of regulation, there are some situations where positive emotion can be inappropriate, either due to social contexts (e.g. laughing at an inappropriate time) or in the case of bipolar disorder, where excessive positive emotion can be maladaptive (Gruber, Eidelman, & Harvey, 2008). (However, emotion regulation in clinical populations is outside the scope of the present review.) Though some recent work has begun to examine the behavioral mechanism supporting regulation of positive emotion in these contexts (Giuliani, McRae, & Gross, 2008), very few studies have investigated the neural



mechanisms supporting regulation of positive emotion (Kim & Hamann, 2007). In contrast, the utility of regulating negative approach emotions is perhaps more obvious. Expressing anger in an inappropriate context (e.g., at your coworker in a meeting) may lead to negative consequences. Only a few studies have begun to investigate the neural underpinnings of anger regulation (e.g., Pietrini et al., 2000), making this a fruitful area for future research. Understanding the mechanisms underlying regulation of approach emotions, when combined with knowledge about the regulation of avoidance emotions, may help us understand whether the same neural systems underlie both types of regulation.

In this section, we review existing studies that investigate how the brain supports regulation of motivation toward appetitive stimuli and positive emotion. We will review the brain regions that are commonly involved in approach regulation which significantly increase or decrease during the attempt to regulate. We also discuss whether the cognitive regulation strategy deployed and the nature of the stimulus being regulated (e.g. food vs. cigarettes) influence the specific neural systems recruited during approach/positive affect regulation.

### **2.1 Brain regions that increase during the regulation of approach motivation and positive affect**

A variety of regions have been found to be more active during attempts to regulate versus naturally view appetitive stimuli such as cigarettes, food, and monetary rewards. Though active regions vary between different paradigms, perhaps due to a difference in strategies deployed to effectively regulate (see below), there are some regions that commonly appear during this kind of regulation. Several studies have found activity in dorsal anterior cingulate (Brody et al., 2007; Martin & Delgado, 2011), which has often been associated with conflict monitoring and cognitive control more generally (Botvinick, Cohen, & Carter, 2004). Another region frequently

observed during regulation is the ventrolateral prefrontal cortex (vlPFC; Kober et al., 2010; Hutcherson et al., 2012; Delgado et al., 2008; Hollmann et al., 2011), which has often been implicated in response inhibition (for a review, see Aron et al., 2004). A range of other regions have been observed as well, though less consistently than the dACC and vlPFC, including dorsomedial prefrontal cortex (dmPFC; Kober et al., 2010; Hollmann et al., 2011), inferior parietal lobe (Delgado et al., 2008), posterior parietal cortex (Hutcherson et al., 2012; Hollmann et al., 2011; Staudinger et al., 2011), posterior cingulate cortex (Brody et al., 2007), dorsal striatum (Hollmann et al., 2011), lateral orbitofrontal cortex (lateral OFC; Hollmann et al., 2011; Siep et al., 2012), and anterior prefrontal cortex (Siep et al., 2012). Many of these regions are recruited across a variety of types of approach regulation, suggesting that approach regulation may employ a system that is at least partially domain-general. However, a formal test of this hypothesis – eliciting multiple forms of approach regulation and assessing the similarity among the neural correlates – has yet to be conducted. The only study that directly examined regulation of positive affect (Kim & Hamann, 2007) supports a domain-general account of emotion/motivation regulation in finding similar regions (e.g., dmPFC, vlPFC, and lateral OFC) to those reviewed above. See Table 1 for a summary of these regions.

One puzzling result is that activity in some regions has been found to increase with regulation in some studies but to decrease in others. For example, activity in the dorsolateral prefrontal cortex (including parts of the middle frontal gyrus) increased in some studies (Kober et al., 2010; Delgado et al., 2008; Staudinger et al., 2011; Hollmann et al., 2011; Siep et al., 2012; Beauregard, Levesque, & Bourgouin, 2001; for regulation of positive affect, see Kim & Hamann, 2007) but decreased in others (Hutcherson et al., 2012). Similarly, one study found increases in subgenual ACC activation during regulation (Delgado et al., 2008), but another

found decreases (Westbrook et al., in press). Next, we will discuss several possible explanations for these discrepancies through the theoretical lens of heterogeneity among the cognitive strategies deployed for regulation and in the targeted stimuli.

## **2.2 Are the neural systems of regulation consistent across cognitive strategies?**

Although the tasks in the studies described in this section all can be classified as “regulation,” the cognitive strategy deployed by participants varies greatly. In some studies, participants are given very narrow instructions (e.g. “imagine a calming ocean”) and other times, they are told to regulate their motivation toward the stimuli without being given specific tactics to accomplish this. Examples of non-specific instructions include the instruction to resist feelings of cravings (Brody et al., 2007), to distance or disengage from their emotions (Staudinger et al., 2011), to inhibit emotional reactions (Beauregard et al., 2001), or to use whatever strategy allows them to regulate their motivation (Hutcherson et al., 2012; Kim & Hamann, 2007).

The specific instructions used in different studies vary, but several general categories of strategies emerge among the studies that provide them. First, in some paradigms, participants are asked to focus on the consequences of engaging in regulation (Kober et al., 2010; Hollmann et al., 2011; Siep et al., 2012). However, even among paradigms where participants are asked to focus on consequences, there are many variants that may or may not be qualitatively different. For example, several paradigms use negative long-term consequences of eating food as a strategy to down-regulate cravings (Siep et al., 2012; Hollmann et al., 2011). One study compares thinking about (presumably negative) long-term versus (presumably positive) short-term consequences of smoking (Kober et al., 2010). An open question about consequences-focused regulation is whether regulation that is motivated by the drawbacks of failure relies on different neural regions than regulation motivated by the gains of success. Though both strategies are

cognitive and future-oriented, they are different in terms of their direction (i.e., approach-avoidance focus).

Another set of strategies uses mental imagery to regulate approach motivation. In a study by Delgado and colleagues (2008), participants were asked to think of a calming scene as a method of down-regulating their desire for the upcoming monetary reward, rather than thinking of the potential reward itself. A similar strategy was used in a decision-making task in which participants were instructed to imagine either a calming scene or an exciting scene before making a choice between a risky and safe financial option (Martin & Delgado, 2011). One interesting aspect of these two studies is that, besides just causing participants to employ mental imagery, these strategies may also manipulate physiological arousal. Imagining a calming scene may literally change physiological arousal, and accordingly, skin conductance responses reflected this manipulation (Delgado et al., 2008). Given its central role in affect and motivation, regulation strategies that alter peripheral physiology may be qualitatively different from those that don't.

It is difficult to draw firm conclusions about how brain activity varies from strategy to strategy because of the relatively small number of studies on the neural correlates of regulating approach motivation. However, we note there are similarities between these strategies that may ultimately lead to similar results. At a high level, most of these strategies involve some sort of attention manipulation, by way of intentionally directing attention either to calming mental imagery or to long-term consequences. This may explain why most of these studies report increased activation in attention and executive control networks during regulation. However, it remains unclear if those regions are involved in regulation per se, or if some kinds of regulation require attentional focus, which in turn recruits those regions. One unique study used mindfulness practice – attention to thoughts, feelings, and sensations in a nonjudgmental fashion

– as a manipulation of cigarette craving regulation (Westbrook et al., in press). Revealingly, this is one of the few studies in this body of literature that did not report increased prefrontal cortical activation during the regulation of approach motivation. In our view, a plausible explanation for this discrepancy is that this type of regulation reduces reactivity to the cigarette cues in a bottom-up fashion by reducing cue reactivity, thus not requiring top-down control from prefrontal cortex. This supports the theoretical prediction that attention modulation is but one of many forms of emotion regulation (Gross & Thompson, 2009).

An important future target for research is the differences between various strategies. Not only may some strategies recruit different brain networks, but also some strategies may simply be more effective than others. One study investigated this hypothesis by directly comparing suppression and reappraisal (Siep et al., 2012). Interestingly, suppression was more effective at regulating reactivity in classical reward regions, despite the fact that suppression is generally found to be less effective than reappraisal (Gross, 2002). This result highlights the need to link laboratory findings to real-life outcomes by increasing the ecological validity of neuroimaging studies.

### **2.3 Brain regions that decrease in activation with regulation of approach motivation and positive affect**

Along with identifying the brain regions that are engaged during regulation, it is also interesting to consider the brain regions whose activation decreases during regulation, presumably as the level of appetitive motivation or positive affect they support decrease. These regions are revealed using the opposite contrast from the one described above, namely the contrast of natural viewing > regulation. This contrast provides a tight control for regulation, since natural viewing involves the same visual processing and motor responses as regulation.

Importantly, if the regions in the viewing > regulation contrast also come online during viewing of appetitive stimuli compared to rest, it suggests that these regulated regions were initially involved in reactivity, and that regulation results in a decrease of activation in those regions that would otherwise be active.

Most studies of approach regulation report which brain regions show less activity during regulation versus passive viewing, and they find a variety of regions including those involved in sensory processing, reward, and value computation. In a study of cigarette craving regulation, Brody and colleagues (2007) found that activation in somatosensory and occipital regions decreases as a function of regulation, suggesting that the sensory and visual salience of the rewards decreases with regulation. By contrast, other studies find that activation in reward-related regions such as ventral striatum (Kober et al., 2010; Martin & Delgado, 2011; Delgado et al., 2008; Siep et al., 2012), the closely connected ventral tegmental area (Kober et al., 2010; Siep et al., 2012), and the amygdala (Kober et al., 2010) decrease during regulation. Two studies have also found decreased activity in subgenual anterior cingulate cortex (sgACC) as a result of regulation (Kober et al., 2010; Westbrook et al., in press). Interestingly, during regulation using mindful attention, sgACC activity decreased its coupling with activity in several regions including caudate, insula, dlPFC, IPL, and precuneus (Westbrook et al., in press). These studies suggest that regulatory processes in the brain indeed act to decrease activity supporting affective reactivity.

A second and more precise way of investigating decreases in activation during regulation is by using a method called “parametric modulation,” in which regions whose activity scales with a particular metric (in this case, stimulus value) can be detected. In other words, the activity in these regions should correspond to the subjective value the participant places on that stimulus.

Regions responding parametrically to stimulus value include ventromedial prefrontal cortex (vmPFC) and dorsolateral prefrontal cortex (dlPFC) (Hutcherson et al., 2012; Westbrook et al., in press; Siep et al., 2012). Interestingly, within the same study those regions also show regulation-related decreases (Hutcherson et al., 2012; Westbrook et al., in press; Siep et al., 2012). Furthermore, these two prefrontal regions demonstrated functional connectivity with other regulatory regions, further supporting the claim that these decreases are systematically linked with regulation and not just coincidental (Hutcherson et al., 2012). Future research will be strengthened by more network-based analyses in order to make stronger claims about how different regions may be associated with one another during regulation.

In summary, regions that show less activity during regulation than during passive viewing have been linked to a variety of psychological functions, including sensory perception, reward (Knutson, Adams, Fong, & Hommer, 2001), motivational salience (McClure, Daw, & Montague, 2003), and value computation (Chib, Rangel, Shimoho, & O'Doherty, 2009). However, the common link between all these processes is that they provide salience or vividness to the appetitive stimulus being regulated. By this logic, a compelling interpretation of these results is that regulation causes change in affect and motivation through a salience or value modulation mechanism, which in turn drives behavior. In other words, regulation alters the salience or value of a stimulus, and the decision that follows results from the ultimate level of salience, which is a product of a competitive interaction between some initial evaluation of the salience and a regulatory process.

An open question is whether the target of regulation (e.g. cigarettes, food, money) changes which “reactive” regions must be decreased in order for regulation to occur (Heatherton & Wagner, 2011). It is possible that the particular regions observed to decrease in any given

paradigm may be a function of the particular target of regulation. In the studies reviewed above, however, no clear pattern emerges. For example, ventral striatum, which is commonly associated with reward processing, decreases during regulation of motivation toward cigarettes (Kober et al., 2010), food (Siep et al., 2012), and potential financial rewards (Martin & Delgado, 2011; Delgado et al., 2008). However, other regions (e.g., visual cortex) decrease in some paradigms (Brody et al., 2007) but not others, perhaps due to the nature of the particular stimuli. An alternative technique to interrogate the data such as multivoxel pattern analysis, which reveals what kind of information a brain region is representing at the pattern level rather than detecting general heightened activation across a broad region, may lead to a better understand of how the brain regulates motivation towards different types of appetitive stimuli.

#### **2.4 Down-regulation versus up-regulation**

In all of the studies discussed in this section, the term “regulation” has referred to the process of reducing approach motivation. However, one might ostensibly want to increase approach motivation as well. These two types of regulation have been referred to as down- and up-regulation, respectively. There are far fewer studies investigating the neural mechanisms of up-regulation, perhaps because practically, we are generally interested in how to counteract reactive processes, not how to heighten them. However, understanding the mechanisms of up-regulation is important because there are many situations in which up-regulating emotions is encouraged (e.g., artful expression) and because knowledge about the differences between up- and down-regulation at a neural level may reconcile previous questions regarding the involvement of certain brain regions in regulation in general. For example, vmPFC has been commonly found as a region with parametric representations of value (Chib et al., 2009; Hutcherson et al., 2012). Hutcherson and colleagues (2012) observed increased value signals in



vmPFC during up-regulation, and these signals had more influence over behavior during up-regulation as well. However, during down-regulation, this pattern was observed in dlPFC instead: decreased value signal due in dlPFC to regulation, and increased influence of the dlPFC value signal on behavior. These results suggest that multiple value signals (vmPFC, dlPFC) compete for control, and that part of effective regulation (up or down) is linking behavior with appropriate value signal. Without examining up-regulation separately from down-regulation, an important neural dissociation between those two processes would have gone unnoticed.

## **2.5 Future directions for regulation of approach motivation and positive affect**

Above we have described how the brain supports regulation of approach motivation towards appetitive stimuli like cigarettes, food, money, sexual arousal, and risky behavior. One relevant and interesting extension to this work is into the area of social reward regulation. For example, social psychologists have regarded the motives to belong and to be accepted as fundamental to healthy functioning (Baumeister & Leary, 1995). To what extent do people regulate these motives, and how? Another relatively unexplored area is the regulation of approach emotions like excitement and anger. Some work on these topics has come from the clinical literature in terms of anger regulation among individuals with aggression disorders (Coccaro et al., 2011). Some neuropsychological evidence suggests that mOFC lesions cause aggressive behavior, perhaps due to a lack of regulation (Grafman et al., 1996). Furthermore, simply imagining restraining aggressive behavior seems to engage mOFC (Pietrini et al., 2000). Unfortunately, almost no research has further investigated this possibility. Fully understanding regulation of negative approach emotions like anger would not only help us understand those with problems regulating such emotions, but also might enlighten us of the differences between regulating negative and positive approach emotions.

The growing body of work investigating regulatory processes on approach emotion and motivation has thus far yielded only a preliminary view of how the brain supports the regulatory processes described above. As the field moves forward, we hope that this view is refined with a careful consideration and comparison of what is being regulated, and with what strategies the regulation is being implemented. As such, we now turn our attention to review what is known about how people regulate avoidance motivation and negative emotion, which are different constructs from approach motivation and positive emotion, but nonetheless may be regulated with similar neural machinery.

### **3 Avoidance**

As noted previously, the literatures on the regulation of approach- and avoidance-type reactions evolved in parallel and without much interchange. We juxtapose our reviews of them here, acknowledging that there may be a vast gulf between the two, with the hope that merely connecting them theoretically through their neural systems and some shared constructs (e.g., process, agency) might encourage others to do the same.

Our working definition of regulation of avoidance emotions and motivations encompasses the processes of overcoming or controlling the reaction to a negative or aversive stimulus that can be either emotional or motivational in nature. For example, one may desire to overcome one's fear of the barking dog next door (regulation of negative emotion) or to overcome one's dislike of broccoli (regulation of avoidance motivation). To date, the large majority of studies investigating the neural systems responsible for regulating avoidance reactions have focused on the regulation of negative emotions rather than motivations. For this reason, this section emphasizes the regulation of emotions over the regulation of motivation, but does note important and recent developments in the regulation of avoidance motivation.

### 3.1 Regulation of negative emotion

Emotion regulation has traditionally been defined as “the processes by which individuals influence which emotion they have, when they have them, and how they experience and express these emotions” (Gross, 1998), and a number of comprehensive reviews detailing the neural systems responsible for regulating negative affect, in particular, have emerged in recent years (e.g., Buhle et al., in press). Interestingly, these reviews have generally focused on comparing and contrasting the various cognitive strategies used when regulating negative affect (e.g., reappraisal). Thus, we begin with a review of these various strategies with a particular eye toward the cognitive processes engaged by each, but we conclude by considering other potentially important constructs that have emerged from the literature on avoidance regulation and its neural substrates, with a particular eye toward the role of agency.

By far, the most studied regulation strategy to date has been cognitive reappraisal, in which participants “reinterpret [...] the meaning of a stimulus, including one’s personal connection to it, to change one’s emotion response” (Ochsner, Silvers, & Buhle, 2012). One reason for the popularity of this strategy is that it generalizes to other types of regulation (Ochsner et al., 2012). Undoubtedly, such an emphasis on reappraisal has been fruitful: one recent meta-analysis of cognitive reappraisal, alone, included 48 separate neuroimaging studies (Buhle et al., in press).

From such a large wealth of data, a number of consistencies in terms of the neural regions recruited by this strategy have emerged (Table 1). At the broadest level, most studies have found that cognitive reappraisal utilizes regions typically implicated in cognitive control (e.g., lateral PFC) in order to down-regulate emotional responding in the amygdala (Ochsner & Gross, 2008). More specifically, dorsolateral PFC (typically involved in selective attention and working

memory), ventrolateral PFC (typically involved in goal selection and inhibition), and dorsomedial PFC (typically involved in attributing mental states and self-reflection) seem to be consistently recruited during studies of cognitive reappraisal (Ochsner et al., 2012; Buhle et al., in press). Additionally, reductions in amygdala activation are nearly always found, suggesting a strong relationship between PFC and amygdala. In studies where connectivity between PFC and amygdala is measured (e.g., Banks et al., 2007), PFC activation is inversely related to amygdala activation.

However, the magnitude and location of PFC activations and amygdala deactivations vary to some extent across different forms of reappraisal. For example, whereas reinterpretation of a stimulus recruits a more dorsal, left-lateralized region of the prefrontal cortex, mentally distancing oneself from a scene recruits a more medial, right-lateralized region of the prefrontal cortex (Ochsner & Gross, 2008). Such distinctions likely result from the different cognitive processes involved in each strategy (e.g., left-lateralization required for using language during reinterpretation; right-lateralization required for using imagery-based attentional control), and perhaps due to overarching differences in attentional focus as noted in the review of approach/positive emotion above.

Similarities and differences between cognitive reappraisal per se and other strategies such as distraction and suppression have also emerged. Distraction involves “the use of selective attention to limit the extent to which the emotionally evocative aspects of an event are attended and appraised” (McRae, 2010), and two studies have now directly compared the brain systems involved in distraction with those involved in cognitive reappraisal. Both studies found that distraction and reappraisal led to deactivation in the amygdala as well as recruitment of inferior parietal cortex, medial PFC, and lateral PFC for regulation, but that distraction led to greater

increases in parietal regions and greater decreases in the amygdala than did cognitive reappraisal (McRae, 2010; Kanske, 2011). One interpretation of these divergences is that the distraction requires more allocation of attention away from negative emotions, and therefore less emotional processing than reappraisal.

Reappraisal can also be compared and contrasted with suppression, a strategy “directed towards inhibiting behaviors associated with emotion responding” (Goldin et al., 2008). Previous behavioral studies have shown that suppression effectively reduces emotionally expressive behavior but have also noted that suppression does not result in meaningful change in subjective reports of emotion (Goldin et al., 2008). Recent studies have suggested that suppression engages prefrontal activation, particularly in lateral PFC (Vrticka, 2013; Shimamura, 2013). In a study directly comparing suppression with cognitive reappraisal, researchers found that although both reappraisal and suppression activated similar regions in prefrontal cortex (e.g., lateral PFC), the activation of these regions was early during reappraisal but late during suppression (Goldin et al., 2008). Additionally, whereas reappraisal was associated with decreased amygdala responses, suppression was associated with increased amygdala responses, highlighting that the two strategies draw upon similar regions but in different ways.

A recent review of the emotion regulation literature expanded upon these direct comparisons to note that right ventrolateral PFC is recruited for distraction, suppression, and reappraisal, but that the time courses for the strategies differ such that distraction and reappraisal recruit relatively early activation, whereas suppression recruits relatively late activation (Cohen et al., 2013). Thus, a comparison of all three strategies reveals that there may be some commonalities across various forms of negative emotion regulation, at least in their location if

not their timing. However, a broad conclusion is not yet comprehensive because other emotion regulation strategies that are also effective at reducing negative emotion need to be included.

Specifically, mindfulness meditation has been an emotion regulation strategy on the rise that has yet to be integrated into the frameworks described above. Mindfulness meditation can be described as “paying attention in a particular way: on purpose, in the present moment, and non-judgmentally” (Kabat-Zinn, 1994). Because affective neuroscience is only beginning to study mindfulness, direct comparisons of mindfulness with other, more commonly studied forms of emotion regulation are limited. Although no quantitative meta-analyses have yet been able to synthesize the growing number of studies comparing the neural correlates of mindfulness and other forms of emotion regulation, the field is moving in that direction, allowing for a more thorough understanding of the similarities and differences between these two types of strategies.

Recent studies have revealed a number of convergences in the neural systems involved in mindfulness and other, more cognitively based forms of emotion regulation. One recent study (Lutz et al., in press) found increased prefrontal activation in both dorsolateral and dorsomedial PFC during anticipation of negative images during a mindfulness task, mirroring the activity found during studies of cognitive reappraisal. Furthermore, participants who used a mindfulness strategy for regulation demonstrated reduced amygdala activation during perception of the negative emotional images (Lutz et al., in press). This finding is consistent with our earlier discussion of mindfulness for craving regulation, where (approach motivation) regulation effects seemed largely to be due to reduced reactivity. Other similarities between mindfulness and traditional emotion regulation have also emerged within the context of pain regulation, particularly within the anterior cingulate cortex (Zeidan et al., 2012). See Van Dillen and Papiés

(this volume) for more discussion of the self-regulatory effects of mindfulness and their neural underpinnings.

Even after considering the various forms of cognitive reappraisal, distraction, suppression, and mindfulness meditation, a complete comparison among emotion regulation strategies is nowhere near complete. For example, Gross and Thompson's (2009) description of emotion regulation includes a variety of strategies such as situation selection and directed attention that have received little to no empirical attention. In the meantime, it is important to consider that emotion regulation also varies across a variety of other characteristics such as direction (e.g., up- versus down-regulation) and agency (e.g., self-relevant versus generic) that are likely relevant to any attempt to understand and organize the neural signatures of emotion regulation (Ochsner et al., 2012; McRae et al., 2012). A careful theoretical taxonomy of such factors might prove informative in our understanding of the neural processes involved in emotion regulation.

The discussion about the role of the ventromedial PFC (vmPFC) in emotion regulation illustrates the need for such additional considerations. Recently, it has been proposed that vmPFC may act as a mediator between prefrontal and subcortical regions (Ochsner et al., 2012; Etkin et al., 2011). In fact, in a meta-analysis of studies investigating placebo effects, fear extinction, and emotion regulation, Diekhoff et al. (2011) suggests that the *only* common region involved in modulating negative affect is vmPFC. In turn, Buhle and colleagues (in press) performed a meta-analysis of emotion regulation studies investigating whether vmPFC mediates the relationship between cognitive control regions and the amygdala. Results yielded no support for this claim, leading the authors to suggest that perhaps the vmPFC, commonly found in a number of studies on “fear extinction, reversal learning, and regulation of social behavior,” is

also involved in cognitive reappraisal of emotion but does not emerge in such studies because the vmPFC is recruited during both emotion regulation tasks and the comparison conditions. Here, we consider a variety of mental processes with established neural correlates, such as vmPFC, that are likely involved in emotion regulation to illustrate how such a process analysis of emotion regulation can inform this specific debate and emotion regulation theory more broadly.

Based on our reading of recent work in the field, we argue that the degree to which a target or a strategy is valued by or relevant to the self is a critical factor in emotion regulation studies that is rarely considered. Though the precise function of the vmPFC is a hotly debated topic, studies have shown it to be involved in valuation (Rangel & Hare, 2010; Schoenbaum et al., 2011) and self-reflection (Kelley et al., 2002; Northoff & Bermpohl, 2004), both of which are processes that might be involved in emotion regulation when the target of regulation or strategy deployed is valued by or highly relevant to the self.

One way “value to the self” can be construed is with regards to the value of the target being regulated. Though few emotion regulation studies have made distinctions among the specific negative emotions being regulated, the regulation of fear has been an exception. Researchers investigating the regulation of fear (as separate from other negative emotions such as disgust or anger) have consistently found that vmPFC plays a role in dorsolateral PFC’s regulation of the amygdala regardless of the specific strategy that is deployed (Delgado et al., 2008; Schiller & Delgado, 2010; Hartley & Phelps, 2010), a finding which has generally not been true for the regulation of other emotions. Bringing the construct of value to the self into the discussion might explain why vmPFC is active for regulation of fear but not necessarily other emotions: fear is a basic emotion perhaps most central to human survival, and thus might be personally valued more than other emotions. In fact, certain negative emotions such as fear and



anger have proven desirable if they help people attain their goals (Tamir, 2009). In other words, fear may be more “affectively meaningful” because of its relatively higher value to the self across an entire sample, leading to a greater involvement of vmPFC in the regulation of this emotion over others (Roy, Shohamy, & Wager, 2012).

Agency in some part of the emotion regulation process is another way in which value to self may help in understanding and organizing the neural correlates of emotion regulation. Kuhn, Haggard, and Brass (in press) recently found that regulation (versus passively experiencing) recruits dorsomedial PFC for endogenous (i.e., self-chosen) cues but lateralized regions for exogenous (i.e., experimenter-provided) cues. One reason dorsomedial PFC may be involved in the endogenous condition is because of the self-reflective, volitional nature of this condition. This fits well with the differences between self-chosen and experimenter-provided regulation strategies discussed above. Though studies investigating the role of choice in regulation are just emerging, the topic provides a promising way in which to directly test the extent to which self-relevance and self-value plays a role in emotion regulation.

However, choice need not be involved in order to invoke self-value. Rather, value may be instantiated by the success or failure of the regulatory act. A number of studies have suggested that vmPFC (and/or the overlapping Brodmann’s Area 10) is only recruited during *successful* regulation (Urry et al., 2006; Johnstone et al., 2007; Denny et al., in press) and, complementarily, that *unsuccessful* regulation is reflected in a disruption of the otherwise-inverse relationship between the vmPFC and the amygdala (Wagner & Heatherton, 2013). In this view, successful regulation relies on motivation derived in part from self-value (Baumeister, 1986; Wicklund & Gollwitzer, 1982), and the involvement of vmPFC speculatively implies that success or the anticipation of success might play an important role.

Together, this evidence suggests that factors beyond the specific cognitive strategy or target emotion may be worth considering when investigating the neural patterns of emotion regulation. This is particularly true in resolving the debate over the role of vmPFC in emotion regulation, but presumably applies to many other regions involved in emotion regulation. We have considered how the regulation target, temporal duration, choice to regulate, and success or failure of regulation may all contribute to varying patterns of activation in vmPFC and related regions. Importantly, we speculate that differing patterns across emotion regulation, particularly but not only in vmPFC, may result from different ways in which various components of the emotion regulation experience are valuable to the self.

### **3.2 Motivation**

Though the majority of studies investigating regulation of avoidance emotions or motives have centered on the regulation of negative affect, the field will need to extend beyond this narrow framework to provide a more comprehensive picture of avoidance regulation. To date, the literature extending beyond emotion regulation and into regulation of avoidance motivation is sparse, but there is some work on the regulation of the motive to avoid losses. A number of studies have now demonstrated that cognitive emotion regulation strategies can decrease loss aversive behavior (Grecucci et al., 2012; Heilman, 2010; Sokol-Hessner, Camerer & Phelps, 2012), providing support for the theoretical notion that the neurocognitive systems involved in regulating emotion and motivation may be quite similar.

Neuroimaging provides one way of establishing whether different processes such as regulation of motivation versus emotion share similar neurocognitive substrates. For example, Sokol-Hessner, Camerer, and Phelps (2012) showed that when emotion regulation decreased loss aversion during financial decision-making, both dlPFC and vmPFC were engaged, and amygdala

activity to losses decreased. Similarly, Hare et al. (2009) showed that regulation of aversion for healthy foods during food-related decision-making involved the modulation of vmPFC by dlPFC. In both studies, the same regions that consistently emerge during emotion regulation (e.g., dlPFC) also appear in the regulation of motivations. Intriguingly, both studies also suggest that vmPFC may only be involved in regulation to the extent that the goal is valuable to the self. Because these studies again provide evidence that value to the self may play an important role in the neurocognitive differences amongst regulation strategies, studies investigating regulation of motivation may be particularly suited to inform the debate over the role of vmPFC in emotion regulation. However, because of the sparse literature within this domain, these conclusions remain speculative.

#### **4 Conclusion**

Our goal in this chapter was to compare and contrast the neural systems engaged during the regulation of emotions and motivation. We argued that comparing these two domains of regulation could have the potential to broaden existing knowledge about the neural correlates of self-regulation, which in turn would inform theoretical accounts of both. In general, a number of similarities seem to exist between these two forms of regulation (e.g., recruitment of prefrontal regions; down regulation of amygdala), suggesting that more commonalities than differences may exist within the broader domain of self-regulation (Heatherton & Wagner, 2011). A second goal was to review factors that are relevant in driving the observed patterns of neural activity during self-regulation. In addition to the distinction between the regulation of emotion and motivation (which did not account for much variance across studies), we noted differences in the mental processes associated with various strategies, the direction of the emotion or motivation being regulated, and the extent to which self-value was involved in a given experimental

paradigm. Below, we synthesize our findings regarding each of these distinctions, then provide some future directions for research in this area.

#### **4.1 Emotion vs. motivation**

We deliberately juxtaposed results from lines of research that have evolved separately: regulation of emotion and regulation of motives. We are struck by the similarities between the two, particularly in terms of recruitment of lateral prefrontal regions. The overall similarity was consistent with domain-general models of self-regulation (Cohen et al., 2013; Heatherton & Wagner, 2011), but still raises some important questions. For example, if all regulation recruits the same regions, why did we observe differences in terms of strategy? Or in terms of the target of regulation? More research will be needed to conclusively answer these kinds of questions. This review highlighted some factors that might be important, which we discuss in turn below. In the interim, we see no need to make fine distinctions between “emotional” and “motivational” targets when it comes to regulation. These two constructs are highly overlapping and may be identical in terms of top-down control. Indeed, other factors such as the cognitive strategy used to target them or their value to the self may be more influential on the neural systems of regulation than the mere distinction between basic emotions and motivational states per se.

#### **4.2 Approach vs. avoidance**

Early neuropsychological investigations using electroencephalography focused on a lateral distinction between approach and avoidance motivation, with approach being associated with increased relative left prefrontal activation and avoidance with increased relative right activation (Coan & Allen, 2004; Sutton & Davidson, 1997). However, with few exceptions (Berkman & Lieberman, 2010; Herrington et al., 2005), studies using fMRI have failed to find such a distinction, perhaps because they typically do not directly compare activity based on

laterality. The studies we reviewed are no exception; none of them compared activation in, say left to right dorsolateral prefrontal cortex. Nonetheless, comparing the results of approach versus avoidance in a qualitative way, we note that regulating approach is much more likely to elicit activation in traditional reward regions including dorsal striatum, OFC, and, at times, subgenual ACC. Contrasts tapping approach regulation also tended to reveal more stimulus-driven attention systems such as posterior parietal and cingulate cortices more often than contrasts targeting avoidance regulation. On one hand, this trend may not be surprising given the much greater appetitive value of the stimuli typically used in studies of approach (e.g., delicious looking food) versus avoidance (e.g., contamination) regulation. On the other, the presence of reward system activation in conditions wherein participants are effortfully trying to regulate reward motivation seems to belie the general claim that “bad is stronger than good” (Baumeister et al., 2001); perhaps a more accurate description is that “bad motivates disengagement more than good”. This description explains this finding, and also suggests that regulating approach/positive emotion might be inherently more difficult than regulating avoidance/negative emotion because there is more at stake in a failure to regulate the latter compared to the former.

#### **4.3 Process distinctions**

As noted throughout, the precise cognitive strategy or tactic (McRae et al., 2012) deployed has a strong impact on the neural systems recruited during regulation. From a cognitive neuroscience perspective, this is entirely unsurprising; emotion regulation is a psychological construct that can be instantiated in a number of ways through varying neurocognitive processes. The results here support an emerging trend within the field of emotion regulation to focus more on the nature and quality of those processes rather than on emotion regulation per se, which can be conceived of as the goal or outcome of the processes. Indeed, one of the principal strengths of

neuroimaging is its ability to inform upon the neurocognitive processes that underlie mental phenomena such as emotion regulation.

Along those lines, one theme that emerged from our review is the importance of attention (and attention regulation) for emotion regulation. It remains an open question in our minds whether most forms of emotion regulation studied thus far reduce to simple attention manipulations. Is the “active ingredient” in emotion regulation just effortful regulation of attention toward one stimulus (internal or external) and away from another? The only possible exception to this question is mindfulness, which can produce emotion regulation-like effects but in the absence of activation in frontoparietal regions typically engaged in attention regulation (e.g., Westbrook et al., in press). The possibility that mindfulness represents a distinct class of emotion regulation strategies—more “bottom-up” than “top-down” like nearly all other forms—is an intriguing possibility that is beginning to receive extensive empirical attention. When we next review this literature, we hope to have more data to directly speak to that issue.

Another process-level distinction that emerged from our review is the role of value modulation in self-control (Hare et al., 2009). Given that vmPFC appeared across a range of emotion/motivation regulation studies—usually when the regulation was successful—and the well established role of that region in global value computation (Hare et al., 2011), it seems plausible that altering the value attached to a particular stimulus (positive or negative) is the proximal effect of emotion regulation that drives its downstream affective/motivational and behavioral consequences. For example, perhaps successful regulation of food craving is caused by a decrease in the subjective value of consuming the food relative to not consuming it. This proposition seems simple enough, but it is a radically different way of viewing emotion regulation than the traditional dual process (e.g., top-down control versus bottom-up impulse)

view. In the value modulation account, there is only one process—value computation—and the outcome of a controlled or impulsive action is determined not through a competition between two types of processes (e.g., controlled versus automatic or cognitive versus emotional) but rather through integration of various inputs to the value computation (e.g., short-term and long-term value). As is the case with mindfulness, this is presently a robust area of research and we anticipate having extensive relevant data in the near future.

#### **4.4 Agency and choice**

A final theme that cut across several types of regulation and emerged throughout as important is the role of agency and choice. Emotions and motivations can be intensely personal, and so, it turns out, are the strategies that we use to regulate them. An ongoing challenge in social and affective neuroscience is to blend the tradition of ecological validity from social psychology and affective science with the rigor and experimental control of cognitive neuroscience. In this case, that means using stimuli with personal relevance and meaning, and regulation strategies over which participants feel ownership and control, even when homogenizing the stimuli and strategies might be more convenient. Studies are beginning to emerge that directly compare the effects of constructs such as personal relevance, agency, and choice on neural systems related to self-regulation (e.g., Giuliani, Mann, Tomiyama, & Berkman, in press). Studies like this will provide better knowledge than we currently have about how our brains actually engage in emotion/motivation regulation in our daily lives.

Another way that agency is important in emotion regulation is through the behavioral implications of the regulation or lack thereof. Most of the paradigms used to study emotion/motivation regulation rely upon participants to remain engaged in a task that ultimately has no meaning for them; participants typically have nothing at stake. For example, in a standard

reappraisal of negative emotion task, participants know that the aversive image will be removed within a matter of seconds regardless of how well or poorly they are able to regulate their emotion. Even in a study of food craving reduction, dieting participants presumably are aware that, unlike in real life, they will not actually eat the appetitive foods shown in the images if they fail to regulate their craving for it. We argued here that one reason for the presence or absence of activation in the vmPFC, a region likely involved in the computation of value for the ultimate purpose of making a decision, is the relevance of choice on a given task. As noted in the introduction, William James's (1890) position was that "thinking is for the sake of doing", and we tend to agree. An important consideration for future studies of emotion and motivation regulation is the degree of "doing" involved in the task; the less there is, the lower the quality of the "thinking" is likely to be.

#### **4.5 Future directions**

We have reviewed studies on the regulation of emotions and motivations, intentionally juxtaposing the two as a way of highlighting the extensive similarities between the cognitive and neural processes involved in regulating each. Interestingly, most of the research on motivation is related to approach states (e.g., craving), and most of the research on emotions is related to negative affect (e.g., sadness), with large research gaps in regulation of avoidance motives and positive emotions. Those gaps are logical given the relative infrequency of those kinds of regulation, but still are substantively interesting (e.g., regulation of loss aversion or joy) and theoretically meaningful. Other high priority research topics include the role of value modulation in emotion/motivation regulation, the component neurocognitive processes of regulation (particularly control processes versus mindfulness), and the ecological validity of the neural



systems of regulation in terms of the strategies people actually choose and the degree to which they are predictive of actual choices and behaviors in vivo.

We began this chapter by noting the etymological relationship between emotion and motivation. Now we will close by noting that the root of the word “regulate”, *moderari*, relates to the English words restrain, control, moderate, govern, and guide, among others. The breadth of the connotations of these words underscores the diversity of possibilities when it comes to guiding affective and motivational responses. We have many options for guiding these responses, and just as many ways of studying them. We’ve learned a lot in a short time, but are still only at the beginning.

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*Neuroscience Letters*, 520, 165-173.

*Table 1.* Involvement of brain regions in self-regulation of approach and avoidance motives and emotions

Target of Regulation	Lateral cortex				Medial cortex				Subcortex
	Prefrontal cortex		Parietal	IPL	Prefrontal cortex		Cingulate		Striatum
	Dorsal	Ventral	Anterior		Dorsal	Ventral	Dorsal anterior	Posterior	Dorsal
Approach	-	xx	x	x	x	-	xx	x	x
Avoidance	xx	xx	x	x	xx	x	x	-	-

*Note.* xx = frequent involvement; x = some involvement; - = no involvement; IPL = Inferior parietal lobule