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Authors

Saragosa-Harris, Natalie

Silvers, Jennifer

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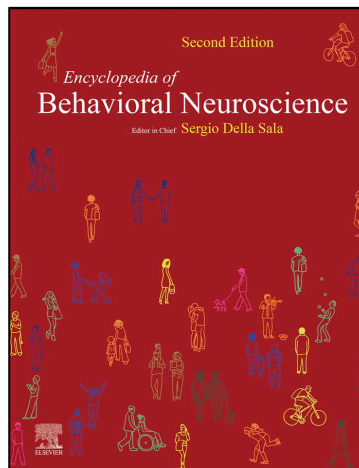
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## The Neural Bases of Emotion Regulation Within a Process Model Framework

Natalie M Saragosa-Harris and Jennifer A Silvers, University of California, Los Angeles, CA, United States

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<b>Introduction</b>	<b>439</b>
<b>The Process Model of Emotion Regulation</b>	<b>439</b>
<b>Neural Bases of Emotion Regulation Within the Process Model Framework</b>	<b>440</b>
Situation Selection and Situation Modification	440
Attention Deployment	441
Cognitive Change	441
Response Modulation	442
<b>Conclusions</b>	<b>443</b>
<b>References</b>	<b>444</b>

### Glossary

dACC dorsal anterior cingulate  
 DLPFC dorsolateral prefrontal cortex  
 DMPFC dorsomedial prefrontal cortex  
 IPC inferior parietal cortex  
 LPFC lateral prefrontal cortex  
 MPFC medial prefrontal cortex  
 NAcc nucleus accumbens  
 OFC orbitofrontal cortex  
 VLPFC ventrolateral prefrontal cortex  
 VS ventral striatum

### Introduction

The ability to adaptively respond to emotional events is an important human skill. The implementation of processes that allow an individual to consciously or non-consciously monitor, inhibit, or modulate the trajectory of an emotion or emotional response is referred to as emotion regulation (Etkin et al., 2015; Klemanski et al., 2017). Over 20 years ago, Gross (1998b) introduced the process model as a framework for conceptualizing the processes involved in emotion regulation. The process model has since guided a multitude of neuroimaging studies that aim to outline the neural instantiations of effective regulatory strategies (Ochsner and Gross, 2005; Buhle et al., 2014; Kohn et al., 2014). Early work investigating the neural bases of emotion regulation demonstrated that different strategies identified in the process model rely on distinct neural mechanisms. In recent years, a considerable body of research has built upon these preliminary findings and furthered our understanding of the neural architecture of emotion regulation (Ochsner et al., 2012; Silvers et al., 2013, 2014; Gross, 2015; Etkin et al., 2015; Guassi Moreira and Silvers, 2018; Hartley and Phelps, 2010). In this article, we provide an overview of the literature on neural mechanisms underlying emotion regulation by synthesizing recent research. We will first introduce the process model of emotion regulation (Gross, 1998b). Next, we will synthesize what is known about the neural bases of emotion regulation within the framework of the process model. We will conclude by outlining empirical questions that remain unanswered and merit further examination.

### The Process Model of Emotion Regulation

Gross's (1998b) process model provides one useful way of conceptualizing emotion regulation, though many other models have been suggested (e.g., Ochsner and Gross, 2007; Etkin et al., 2015; Braunstein et al., 2017; see Gross and Barrett, 2011 for review). This model is rooted in appraisal theory (Lazarus, 2001; Roseman and Smith, 2001) and organizes emotion regulation into distinct stages of emotion and response generation, each of which presents opportunities for the implementation of regulatory strategies. Different strategies offer the opportunity to regulate emotions by targeting different levels of the emotional event, including the situation itself (situation level), smaller details of the situation (aspect level), the meaning generated from the event (meaning level), or the individual's response to the emotion (response level). In particular, the process model identifies five processes by

which individuals can regulate their emotions during emotion generation: (1) selection of the situation, (2) modification of the situation, (3) deployment of attention, (4) change of cognitions, and (5) modulation of responses (Gross, 1998b). Each of the five processes are conceptualized as either antecedent-focused, regulation that occurs before the emotion is generated, or response-focused, regulation that occurs after the emotion is generated (Gross 1998a,b).

## Neural Bases of Emotion Regulation Within the Process Model Framework

### Situation Selection and Situation Modification

The two earliest antecedent-focused processes in the model are situation selection, which occurs before exposure to the emotional stimulus, and situation modification, which occurs before the emotion is generated (Gross, 1998b). In situation selection, an individual approaches or avoids certain settings, people, or objects that are likely to elicit an emotional response. For instance, one might preemptively choose to work remotely from a favorite coffee shop instead of a stressful workplace. In contrast, during situation modification, an individual actively modifies a situation in order to alter its emotional repercussions—for example, by leaving the office for a coffee shop *after* realizing how hectic the workplace is that day. In both processes, the individual copes by altering her engagement with a potentially emotion-eliciting situation. Notably, both strategies require a degree of emotional self-awareness, the ability to predict the likely emotional consequences of a given situation, and the autonomy to change one's situation (Gross, 1998b). Given the conceptual similarities between the two strategies and the lack of neuroimaging studies that specifically probe situation modification, the focus of this section will be on the neural bases of situation selection.

Recent work has suggested that situation selection may encompass two mechanisms that jointly regulate emotion. Thuillard and Dan-Glauser (2017) argue that one mechanism (referred to here as mechanism (1)) involves modification of the situation itself. Through mechanism (1), individuals selectively engage with situations that are more likely to make them feel more positive or less negative. The resulting regulatory effects are straightforward: Removing oneself from negative situation is a means of reducing negative affect and choosing an alternative, preferable situation is a means of promoting positive affect (Webb et al., 2018). A less obvious regulatory feature of situation selection concerns the presence of agency afforded by having the option to choose between alternative situations, irrespective of the situation at hand (Thuillard and Dan-Glauser, 2017). Indeed, the mere act of making a choice appears to be rewarding in nature (Leotti et al., 2010; Leotti and Delgado, 2011; Bobadilla-Suarez et al., 2017) and can buffer against negative emotional responses (Hartley et al., 2014). Due to the intrinsically rewarding effects of agency, the act of selecting the situation may itself be a regulatory mechanism (referred to here as mechanism (2)). Together, these mechanisms may promote positive affect or buffer negative experiences by permitting an individual to modify or avoid an undesirable situation.

Individuals are capable of preemptively avoiding situations that are likely to lead to unwanted temptation or negative emotional states (Fujita, 2011; Crockett et al., 2013). For instance, someone on a diet might remove all unhealthy snacks from his kitchen in order to avoid indulging and experiencing shame for diverging from his diet. Crockett et al. (2013) designed an experiment in which individuals could restrict their access to temptation while undergoing functional neuroimaging. Mirroring the theorized mechanism (1) of situation selection, individuals separated themselves from a tempting but less desirable situation in pursuit of a more desirable one. The researchers observed recruitment of the lateral frontopolar cortex when participants restricted their own access to temptation. Additionally, they found that the lateral frontopolar cortex demonstrated increased functional connectivity with the dorsolateral prefrontal cortex (DLPFC) and posterior parietal cortex during the decision to restrict access to temptation. In line with other work on goal-directed decision-making (Rangel and Hare, 2010) and willpower (Figner et al., 2010; Kober et al., 2010), these findings suggest that a network of brain regions including the lateral frontopolar cortex, DLPFC, and posterior parietal cortex are recruited when individuals disengage from a situation in order to hinder future negative emotions (Crockett et al., 2013). Moreover, in requiring participants to decline immediate rewards for the sake of fulfilling longer-term goals, this paradigm involved a process referred to as temporal discounting (also referred to as intertemporal choice or delay discounting; Myerson and Green, 1995; Peters and Büchel, 2011; van den Bos and McClure, 2013). The network of neural regions recruited in Crockett et al. (2013) study align with those reported in studies of temporal discounting (e.g., van den Bos et al., 2014; Anandakumar et al., 2018), suggesting that certain forms of situation selection involve simulating future outcomes and weighing competing rewards.

In addition to avoiding momentarily rewarding situations in pursuit of a higher goal—e.g., abstaining from one's favorite junk food while on a diet—mechanism (1) of situation selection can also involve avoiding aversive experiences. An extensive literature on active avoidance has characterized the ability to evade adverse experiences as a means of avoiding undesirable emotional consequences (Krypotos et al., 2015). For instance, individuals can learn to actively avoid receiving an electrical shock by pressing a "safe" button (Delgado et al., 2009; Hartley et al., 2014; Boeke et al., 2017). Across species, active avoidance of threat has been associated with interactions between the amygdala, ventral striatum, hippocampus, and MPFC (Delgado et al., 2009; Boeke et al., 2017; Ramirez et al., 2015; Moscarello and Maren, 2018; Qi et al., 2018; Diehl et al., 2018; Martínez-Rivera et al., 2019). This same circuitry is involved in fear learning and extinction (Hartley and Phelps, 2013), suggesting that active avoidance is a fundamental and relatively automatic form of emotion regulation. While preemptive decisions to avoid affective stimuli appear to rely on dorsal and lateral prefrontal and parietal circuitry implicated in cognitive control (Crockett et al., 2013), decisions to escape aversive situations are mediated by mPFC-subcortical interactions commonly involved in more automatic fear learning processes (Hartley and Phelps, 2013; Moscarello and Maren, 2018; Qi et al., 2018). Together, these findings suggest that mechanism (1) of situation selection—avoiding situations that are likely to lead to negative emotional states—relies on cortical regions as well as evolutionarily conserved subcortical circuitry.

The second mechanism in situation selection is contingent on an individual's agency in deciding future outcomes. Having control over one's environment has been shown to be intrinsically rewarding (Leotti et al., 2010; Leotti and Delgado, 2011; Bobadilla-Suarez et al., 2017) and can confer resilience to future stressors (Hartley et al., 2014). Fascinatingly, choice can be rewarding even if the outcome is negative (Thuillard and Dan-Glauser, 2017). For instance, Thuillard and Dan-Glauser (2017) demonstrated that having the choice to view negative images decreased self-reported negative affect, skin conductance, and respiratory activity when compared to responses during forced viewing. This suggests that although participants were exposed to exactly the same negative stimuli, the act of choosing the outcome regulated their emotional response. Similarly, individuals given the ability to prevent the delivery of a shock demonstrate attenuated skin conductance responses to subsequent shock-paired stimuli, indicating that previous agency confers emotional resilience to future negative encounters with the same stressor (Delgado et al., 2009; Hartley et al., 2014; Boeke et al., 2017). Importantly, these designs control for exposure to the stressor or situation itself—thereby controlling for mechanism (1)—and indicate that the mere presence of choice can regulate emotional responses (Thuillard and Dan-Glauser, 2017). Neuroimaging work has provided further evidence that the anticipation of choice recruits corticostriatal networks and midbrain regions involved in reward processing (Leotti et al., 2010). This work suggests that when an individual has control over her environment, reward circuitry involved in anticipation of and valuation of rewards is recruited and may contribute to successful emotion regulation (Leotti et al., 2010).

### Attention Deployment

Another antecedent-focused process in the process model is attention deployment, which occurs during exposure to an emotional stimulus (Gross, 1998b). Examples of attention deployment include distraction, wherein an individual directs her attention away from the aversive stimulus or situation altogether, and selective attention, wherein an individual focuses on positive or nonemotional details of the situation (Gross, 1998b; Todd et al., 2012). While other experimental paradigms have examined the inverse of attentional deployment—that is, how the presence of affective stimuli can distract and disrupt cognitive control (e.g., emotional go/nogo or emotional Stroop tasks; Epp et al., 2012; Cohen et al., 2016)—these do not model intentional efforts to regulate emotion and thus are not discussed further here. Because selective attention may be a subcomponent of distraction (Kalisch et al., 2006), the delineation between distraction and selective attention is not always clear. Given this conceptual overlap and the availability of neuroimaging studies on distraction, the focus of this section will be the neural bases of distraction.

Several neuroimaging studies have utilized a “self-distraction” paradigm that instructs participants to distract themselves from a negative stimulus in order to attenuate their emotional reactions (Kalisch et al., 2006). Kalisch et al. (2006) reported recruitment of the left lateral prefrontal cortex (LPFC) while participants engaged in self-distraction from a forthcoming shock. McRae et al. (2010) further examined the neural substrates of distraction outside of the realm of physical pain. In their experiment, participants were instructed to keep a six-letter string in mind while attending to aversive pictures, a manipulation that uses working memory load in order to deploy attentional resources. In line with Kalisch et al. (2006), they demonstrate that distraction from aversive events recruits the left LPFC. The authors further identify the dorsal anterior cingulate (dACC), left inferior parietal cortex (IPC), and the lateral frontopolar cortex as potential mechanisms through which distraction regulates emotions. In comparison to other emotion regulation strategies, distraction appears to selectively engage right prefrontal and parietal regions implicated in the control of attention (McRae et al., 2010), evidencing the role of selective attention in distraction strategies. Other neuroimaging studies have demonstrated that down-regulation of amygdala activity may occur during distraction. In particular, functional connectivity patterns during distraction link reduced amygdala activity to the previously identified DLPFC, IPC, and dACC (Kanske et al., 2011). These patterns suggest that attentional control networks activated during distraction attenuate emotional responsivity by modulating amygdala activity.

### Cognitive Change

The aforementioned emotion regulation strategies involve avoiding or directing one's attention away from an emotional situation or stimulus. Cognitive change, on the other hand, offers the opportunity to transform one's perception or evaluation of an emotional stimulus (Gross, 1998b). The most widely studied form of cognitive change is cognitive reappraisal, a process in which individuals change the way they think about a situation in order to alter its emotional effect (Gross, 1998b; McRae, 2016). To this end, reappraisal involves attempts to reframe or reconsider the situation from a new perspective (Giuliani and Gross, 2009), which can involve considering that the situation will get better, that it is not as bad as it first seemed, that it is not personally relevant, or that going through the negative experience will be beneficial in the future (McRae et al., 2012b; McRae, 2016).

Over a decade of neuroimaging work has aimed to characterize the neural architecture of reappraisal. Recent meta-analyses and synthetic reviews have highlighted the neural circuits most consistently recruited during cognitive reappraisal across studies. In a meta-analysis of 48 neuroimaging studies of cognitive reappraisal, Buhle et al. (2014) identified the lateral temporal cortex and cognitive control regions including the dorsomedial prefrontal cortex (DMPFC), DLPFC, ventrolateral prefrontal cortex (VLPFC), and posterior parietal lobe as regions consistently activated during reappraisal tasks (Buhle et al., 2014). Across numerous studies, reappraisal has been shown to modulate activity in the bilateral amygdala (Ochsner et al., 2012). Recent evidence suggests that among reappraisal techniques, distancing—reframing the event as not personally relevant—is more effective at regulating amygdala activity than reinterpretation—reframing the event as positive or less negative—thus indicating that modulation of amygdala responses may differ in accordance with reappraisal sub-strategy (Picó-Pérez et al., 2019). Together, converging conclusions

from the literature suggest that reappraisal is supported by the lateral prefrontal cortex which acts either directly or indirectly to attenuate amygdala activity by modifying representations of emotional stimuli (Buhle et al., 2014; Ochsner and Gross, 2008; Picó-Pérez et al., 2019; Kohn et al., 2014; Kanske et al., 2011).

Although there are many consistencies in reported neural instantiations of reappraisal, there is evidence that reappraisal may involve multiple pathways that vary in accordance with individual differences and contextual demands (Wager et al., 2008; McRae et al., 2010; Silvers et al., 2015). For instance, research has demonstrated that the prefrontal-subcortical pathways underlying reappraisal can vary in accordance with individual differences in the ability to successfully regulate emotions via reappraisal techniques. Activation in the VLPFC has been shown to relate to reappraisal success, often operationalized as reduced negative reactions to aversive images (Wager et al., 2008; Kohn et al., 2014). Pathways connecting the VLPFC to subcortical regions appear to mediate the relationship between VLPFC activation and reappraisal success. During reappraisal, activation of the left amygdala has been shown to negatively mediate the positive relationship between VLPFC activity and reappraisal success and thereby predict reduced reappraisal success. This suggests that negative affective responses to aversive stimuli may be generated through a VLPFC-amygdala pathway. Conversely, activity in the nucleus accumbens/ventral striatum (NAcc/VS) appears to positively mediate the relationship between VLPFC activity and reappraisal success—that is, activity in both the VLPFC and NAcc/VS predicts more effective reappraisal—suggesting a positive appraisal pathway that dampens the negative emotional response (Wager et al., 2008). Given these two VLPFC-subcortical pathways, the VLPFC may be instrumental in both (1) generating negative affective responses to emotional stimuli via the ventral amygdala and (2) effectively regulating that response via NAcc/VS. As such, it is possible that effective appraisal requires dampened activity in the PFC-amygdala pathway and enhanced recruitment of the PFC-NAcc/VS pathway (Wager et al., 2008).

Another individual-level factor shown to predict differences in neural instantiations of reappraisal is gender (McRae et al., 2008). One study demonstrated that, despite similar behavioral responses to reappraisal (e.g., similar reduction in negative affect following reappraisal), men and women exhibited differential patterns of neural activity during reappraisal (McRae et al., 2008). In particular, compared to men, women demonstrated increased engagement of prefrontal and cingulate cortices and less down-regulation of amygdala activity, suggesting gender differences in the implementation of cognitive control in response to emotional stimuli. Moreover, women demonstrated greater recruitment of reward-related ventral striatal regions, which led the authors to hypothesize that, to a greater extent than men, women may down-regulate negative responses by generating positive affect (McRae et al., 2008). The authors further hypothesize that the observed neural gender differences may in part shed light on gender differences in affective disorders including depression and anxiety (McRae et al., 2008).

Reappraisal may also elicit differential neural circuitry depending on the context and intensity of the emotional situation (Silvers et al., 2015). Given that reappraisal relies on the ability to inhibit initial reactions and maintain the steps of the strategy in mind, activation of systems involved in cognitive control and inhibition may be differentially recruited depending on the difficulty of the reappraisal task at hand (McRae et al., 2010; Silvers et al., 2015). Silvers et al. (2015) identified the DMPFC, DLPFC, and VLPFC as regions recruited during reappraisal of both high intensity and low intensity emotional responses. However, the left DLPFC appears sensitive to the intensity of the emotions, exhibiting greater activation in response to higher intensity emotions. Moreover, unlike low intensity appraisal, appraisal of high intensity emotions selectively activated right lateral and dorsomedial PFC regions. The observed differential recruitment of prefrontal regions during higher intensity reappraisal is in line with prior work suggesting that reappraisal, especially in more affectively intense contexts, is a cognitively demanding task (McRae et al., 2010; Sheppes and Meiran, 2008).

## Response Modulation

The response-focused process identified by the process model is response modulation, wherein an individual directly modifies a physiological, experiential, or behavioral response to an emotional stimulus (Gross 1998b). Unlike the other strategies detailed in the process model, response modulation occurs after an emotion has been generated. Although there are many ways in which an individual may modulate the experience or expression of an emotional response (e.g., mitigating negative emotions by enjoying comfort food or practicing muscle relaxation), the most commonly studied form of response modulation is suppression of emotion-expressive behavior.

Early studies of the neural bases of suppression identified recruitment of the right VLPFC and dorsomedial and dorsolateral PFC, neural pathways involved in inhibitory control and cognitive regulation, respectively (Goldin et al., 2008). Neuroimaging work has also demonstrated increased amygdala and insula responses to emotional stimuli during expressive suppression. Given the joint role of the amygdala and anterior insula in affective response generation and arousal (Kober et al., 2008; Lindquist et al., 2016), this suggests that suppression may up-regulate rather than down-regulate emotional responses and lead to affective arousal. The anterior insula's role in emotional and bodily awareness (Coen et al., 2009; Craig, 2009) further underscores its importance in suppressing expressions of emotions. Intriguingly, additional research has demonstrated that self-reported usage of expressive suppression positively correlates with anterior insula volume (Giuliani et al., 2011). In addition to the VLPFC and dorsomedial and dorsolateral PFC, studies have identified the orbitofrontal cortex (OFC) as a key region involved in suppression. A positron emission tomography (PET) study linked the OFC to physiological response regulation by demonstrating a correlation between skin conductance response and OFC activation during suppression (Ohira et al., 2006). That OFC activation is particularly relevant for the outward expression of emotion dovetails with lesion studies suggesting that OFC is crucial for regulating appropriate social behavior (Beer et al., 2006).



Recent work has identified ways in which suppression affects memory encoding of negative events while altering immediate emotional expressions (Hayes et al., 2010; Katsumi and Dolcos, 2018). In one neuroimaging study, participants were instructed to suppress the expression of emotional responses to negative images while in the scanner (Katsumi and Dolcos, 2018). During suppression, participants were asked to rate their subjective emotional reaction to the images on a scale from neutral to extremely negative. One week later, participants completed a surprise memory test for the images. Intriguingly, behavioral suppression led to lower subjective ratings of negative affect and a reduction in memory for the viewed images. While functional connectivity between the amygdala and hippocampus predicted successful recognition memory in baseline (non-suppression) trials, expressive suppression diminished this relationship. The authors suggest that suppression interferes with amygdala-hippocampal interactions required for emotional memory formation, thereby affecting subsequent recognition memory. The observed interference of amygdala-hippocampal interactions during suppression suggests a neural mechanism through which suppression not only alters immediate responses to emotional stimuli but also weakens memory for negative stimuli via encoding interference.

## Conclusions

In this article, we have reviewed several emotion regulation strategies within the framework of the process model. While existing work has outlined a broad picture of the neural architecture of regulatory strategies, further examination is required in order to assess how emotion regulation unfolds naturally within individuals. In particular, we will discuss two ways in which future research can provide deeper insight into the processes involved in emotion regulation. Namely, we suggest that in order to effectively compare regulatory strategies, future work would benefit from examining strategy-based differences in neural activation within individuals. We also posit that an important goal of future research will be to examine how agency, or having control over when and how to regulate, affects subsequent emotional responses.

Although the strategies reviewed here all rely upon prefrontal-subcortical interactions, the exact nature of these patterns differ. While little work has directly contrasted different regulatory strategies within the same individuals, initial studies suggest that distinct cognitive strategies rely on a mixture of common and distinct neural mechanisms (Dörfel et al., 2014; Morawetz et al., 2017). For example, the dACC, left IPC, regions of the left LPFC, and regions of the right inferior prefrontal cortex appear to be commonly recruited during both reappraisal and distraction (McRae et al., 2010; Kanske et al., 2011; Kohn et al., 2014). The overlapping prefrontal networks recruited by both strategies may reflect their common reliance on cognitive control and working memory, given that both strategies require individuals to inhibit prepotent responses such as negative appraisals and to maintain their goals in working memory (McRae et al., 2010). Heightened engagement of regions of the MPFC during reappraisal underscores that reappraisal requires self-monitoring (McRae et al., 2010; Ochsner and Gross, 2008). Additional work suggests that, while reappraisal and distraction both attenuate amygdala activity, suppression heightens amygdala activity (Goldin et al., 2008; Kanske et al., 2011). An important future direction will be to conduct more work comparing the neural bases of regulatory strategies within individuals so as to move beyond interindividual analyses. Intraindividual work will allow for direct comparisons between regulatory strategies and provide integral insight into their shared and distinct neural mechanisms.

A second important future direction for emotion regulation research will be to examine the role of choice in selecting regulatory strategies. Effective emotion regulation can promote flexible interactions with emotionally salient events in our environments. Accordingly, the ability to elicit regulatory strategies in response to emotionally salient cues may confer resilience to mental health disorders and promote wellbeing (Aldao et al., 2010; Berking and Wupperman, 2012; Hu et al., 2014; Zilverstand et al., 2017). Although the literature on emotion regulation has largely focused on cognitive reappraisal, individuals vary in the extent to which they employ regulatory strategies and in which strategies they choose to implement (Gross and John, 2003; Blalock et al., 2016; Schäfer et al., 2017; Silvers and Guassi Moreira, 2019). Moreover, individual differences in the tendency to employ certain emotion regulation strategies may have important implications for mental health. For instance, techniques such as suppression have been identified as maladaptive strategies associated with risk for psychopathology (Aldao and Nolen-Hoeksema, 2010), whereas adaptive strategies such as reappraisal may predict resilience to psychopathology (Schutte et al., 2009; Hopp et al., 2011; McRae et al., 2012a). Although recent work has examined the neural processes involved in the decision to reappraise or not (Doré et al., 2017; Cosme et al., 2018; Milyavsky et al., 2019), very little is known about how individuals choose which regulatory strategy to employ. Given prevalent individual differences in emotion regulation tendencies and their relevance to emotional wellbeing, the decision-making processes that compel an individual to utilize particular regulation strategies merit further examination.

Most experimental paradigms probing emotion regulation explicitly instruct participants when and how to regulate their emotions. This poses an obstacle for researchers interested in delineating the decision-making processes that motivate individuals to regulate their emotions. Evidence has suggested that people may flexibly employ different emotion regulation strategies based on situational factors, including the intensity of the situation (Sheppes et al., 2011, 2014; Van Bockstaele et al., 2019). In particular, people appear more likely to utilize situation modification and distraction during high-intensity situations and reappraisal during low-intensity situations (Sheppes et al., 2011; Van Bockstaele et al., 2019). Implementation of strategies such as situation selection may also depend on perceived control over the situation at hand (Thuillard and Dan-Glauser, 2017) and how difficult the strategy is to implement (Milyavsky et al., 2019). In order to understand the factors that contribute to decisions of when and how to regulate emotions, future experiments should give participants agency in deciding which—if any—regulatory strategy to employ. In consideration of the role of individual differences and situational demands in emotion regulation, recent work has called for research that addresses the interplay of both situational and personality factors that contribute to emotion regulation success

(Kobylińska and Kusev, 2019). Moreover, introducing choice in emotion regulation paradigms would permit researchers to further investigate how the rewarding nature of choice contributes to emotion regulation (Thuillard and Dan-Glauser, 2017), or if in some cases choice can be detrimental to regulation success (Bigman et al., 2017; Cosme et al., 2018). By including choice in emotion regulation paradigms, experiments might better reflect the self-regulation processes that occur outside of the lab. Allowing participants to choose which regulatory strategy to employ would also present the opportunity to examine hybrid or alternating strategy use (e.g., using distraction during an aversive event followed by reappraisal at a later point when reflecting on it). This may more accurately represent how individuals use regulatory strategies flexibly and over time. Perhaps most importantly, allowing individuals to employ different strategies would allow for examinations into how differences in the implementation of emotion regulation strategies confer risk or resilience for mental health disorders.

The process model identifies five processes by which one can regulate their emotions during emotion generation and response generation. Neuroimaging studies have demonstrated the neural pathways involved during the implementation of these antecedent-focused and response-focused strategies. In particular, empirical work within the past decade has identified recruitment of distinct and overlapping neural circuits during situation selection and modification, attention deployment, cognitive change, and response modulation. More work on the decision-making processes involved during non-instructed implementation of these strategies within individuals is merited. Future research on the neural instantiations of emotion regulation may offer important insights into the fundamental human ability to adaptively respond to our environment and fine-tune our behaviors in accordance with situational demands.

## References

- Aldao, A., Nolen-Hoeksema, S., 2010. Specificity of cognitive emotion regulation strategies: a transdiagnostic examination. *Behav. Res. Ther.* 48 (10), 974–983.
- Aldao, A., Nolen-Hoeksema, S., Schweizer, S., 2010. Emotion-regulation strategies across psychopathology: a meta-analytic review. *Clin. Psychol. Rev.* 30 (2), 217–237.
- Anandakumar, J., Mills, K.L., Earl, E.A., Irwin, L., Miranda-Dominguez, O., Demeter, D.V., Walton-Weston, A., Karalunas, S., Nigg, J., Fair, D.A., 2018. Individual differences in functional brain connectivity predict temporal discounting preference in the transition to adolescence. *Dev. Cogn. Neurosci.* 34, 101–113.
- Beer, J.S., John, O.P., Scabini, D., Knight, R.T., 2006. Orbitofrontal cortex and social behavior: integrating self-monitoring and emotion-cognition interactions. *J. Cogn. Neurosci.* 18 (6), 871–879.
- Berking, M., Wupperman, P., 2012. Emotion regulation and mental health: recent findings, current challenges, and future directions. *Curr. Opin. Psychiatr.* 25 (2), 128–134.
- Bigman, Y.E., Sheppes, G., Tamir, M., 2017. When less is more: effects of the availability of strategic options on regulating negative emotions. *Emotion* 17 (6), 993.
- Blalock, D.V., Kashdan, T.B., Farmer, A.S., 2016. Trait and daily emotion regulation in social anxiety disorder. *Cogn. Ther. Res.* 416–425. <https://doi.org/10.1007/s10608-015-9739-8>.
- Bobadilla-Suarez, S., Sunstein, C.R., Sharot, T., 2017. The intrinsic value of choice: the propensity to under-delegate in the face of potential gains and losses. *J. Risk Uncertain.* 187–202. <https://doi.org/10.1007/s11166-017-9259-x>.
- Boeke, E.A., Moscarello, J.M., LeDoux, J.E., Phelps, E.A., Hartley, C.A., 2017. Active avoidance: neural mechanisms and attenuation of Pavlovian conditioned responding. *J. Neurosci.* 4808–4818. <https://doi.org/10.1523/jneurosci.3261-16.2017>.
- Braunstein, L.M., Gross, J.J., Ochsner, K.N., 2017. Explicit and implicit emotion regulation: a multi-level framework. *Soc. Cogn. Affect Neurosci.* 12 (10), 1545–1557.
- Buhle, J.T., Silvers, J.A., Wager, T.D., Lopez, R., Onyemekwu, C., Kober, H., Weber, J., Ochsner, K.N., 2014. Cognitive reappraisal of emotion: a meta-analysis of human neuroimaging studies. *Cereb. Cortex* 24 (11), 2981–2990.
- Coen, S.J., Yágüez, L., Aziz, Q., Mitterschiffthaler, M.T., Brammer, M., Williams, S.C., Gregory, L.J., 2009. Negative mood affects brain processing of visceral sensation. *Gastroenterology* 137 (1), 253–261, 261.e1–2.
- Cohen, A.O., Dellarco, D.V., Breiner, K., Helion, C., Heller, A.S., Rahdar, A., Pedersen, G., Chein, J., Dyke, J.P., Galvan, A., Casey, B.J., 2016. The impact of emotional states on cognitive control circuitry and function. *J. Cogn. Neurosci.* 28 (3), 446–459.
- Cosme, D., Mobasser, A., Zeithamova, D., Berkman, E.T., Pfeifer, J.H., 2018. Choosing to regulate: does choice enhance craving regulation? *Soc. Cogn. Affect Neurosci.* 13 (3), 300–309.
- Craig, A.D., 2009. How do you feel — now? The anterior insula and human awareness. *Nat. Rev. Neurosci.* 59–70. <https://doi.org/10.1038/nrn2555>.
- Crockett, M.J., Braams, B.R., Clark, L., Tobler, P.N., Robbins, T.W., Kalenscher, T., 2013. Restricting temptations: neural mechanisms of precommitment. *Neuron* 79 (2), 391–401.
- Delgado, M.R., Joo, R.L., LeDoux, J., Phelps, L., 2009. Avoiding negative outcomes: tracking the mechanisms of avoidance learning in humans during fear conditioning. *Front. Behav. Neurosci.* 3, 33.
- Diehl, M.M., Bravo-Rivera, C., Rodríguez-Romaguera, J., Pagan-Rivera, P.A., Burgos-Robles, A., Roman-Ortiz, C., Quirk, G.J., 2018. Active avoidance requires inhibitory signaling in the rodent prelimbic prefrontal cortex. *eLife*. <https://doi.org/10.7554/elife.34657>.
- Doré, B.P., Weber, J., Ochsner, K.N., 2017. Neural predictors of decisions to cognitively control emotion. *J. Neurosci.* 37 (10), 2580–2588.
- Dörfel, D., Lamke, J.P., Hummel, F., Wagner, U., Erk, S., Walter, H., 2014. Common and differential neural networks of emotion regulation by Detachment, Reinterpretation, Distraction, and Expressive Suppression: a comparative fMRI investigation. *NeuroImage* 298–309. <https://doi.org/10.1016/j.neuroimage.2014.06.051>.
- Epp, A.M., Dobson, K.S., Dozois, D.J., Frewen, P.A., 2012. A systematic meta-analysis of the Stroop task in depression. *Clin. Psychol. Rev.* 32 (4), 316–328.
- Etkin, A., Büchel, C., Gross, J.J., 2015. The neural bases of emotion regulation. *Nat. Rev. Neurosci.* 693–700. <https://doi.org/10.1038/nrn4044>.
- Figner, B., Knoch, D., Johnson, E.J., Krosch, A.R., Lisanby, S.H., Fehr, E., Weber, E.U., 2010. Lateral prefrontal cortex and self-control in intertemporal choice. *Nat. Neurosci.* 13 (5), 538–539.
- Fujita, K., 2011. On conceptualizing self-control as more than the effortful inhibition of impulses. *Pers. Soc. Psychol. Rev.* 15 (4), 352–366.
- Giuliani, N.R., Gross, J.J., 2009. Reappraisal. In: *Oxford Companion to the Affective Sciences*.
- Giuliani, N.R., Drabant, E.M., Bhatnagar, R., Gross, J.J., 2011. Emotion regulation and brain plasticity: expressive suppression use predicts anterior insula volume. *NeuroImage* 58 (1), 10–15.
- Goldin, P.R., McRae, K., Ramel, W., Gross, J.J., 2008. The neural bases of emotion regulation: reappraisal and suppression of negative emotion. *Biol. Psychiatr.* 63 (6), 577–586.
- Gross, J.J., Barrett, L.F., 2011. Emotion generation and emotion regulation: one or two depends on your point of view. *Emot. rev.* 3 (1), 8–16.
- Gross, J.J., John, O.P., 2003. Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. *J. Pers. Soc. Psychol.* 85 (2), 348–362.
- Gross, J.J., 1998a. Antecedent- and response-focused emotion regulation: divergent consequences for experience, expression, and physiology. *J. Pers. Soc. Psychol.* 74 (1), 224–237.
- Gross, J.J., 1998b. The emerging field of emotion regulation: an integrative review. *Rev. Gen. Psychol.* 271–299. <https://doi.org/10.1037/1089-2680.2.3.271>.



- Gross, J.J., 2015. Emotion regulation: current status and future prospects. *Psychol. Inq.* 1–26. <https://doi.org/10.1080/1047840x.2014.940781>.
- Guassi Moreira, J.F., Silvers, J.A., 2018. In due time: neurodevelopmental considerations in the study of emotion regulation. In: *Emotion Regulation*. Routledge, pp. 111–134.
- Hartley, C.A., Phelps, E.A., 2010. Changing fear: the neurocircuitry of emotion regulation. *Neuropsychopharmacology* 35 (1), 136–146.
- Hartley, C.A., Phelps, E.A., 2013. Fear models in animals and humans. In: Vasa, R.A., Roy, A.K. (Eds.), *Pediatric Anxiety Disorders: A Clinical Guide*. Springer, New York, pp. 3–21.
- Hartley, C.A., Gorun, A., Reddan, M.C., Ramirez, F., Phelps, E.A., 2014. Stressor controllability modulates fear extinction in humans. *Neurobiol. Learn. Mem.* 113, 149–156.
- Hayes, J.P., Morey, R.A., Petty, C.M., Seth, S., Smoski, M.J., McCarthy, G., LaBar, K.S., 2010. Staying cool when things get hot: emotion regulation modulates neural mechanisms of memory encoding. *Front. Hum. Neurosci.* 4, 230.
- Hopp, H., Troy, A.S., Mauss, I.B., 2011. The unconscious pursuit of emotion regulation: implications for psychological health. *Cogn. Emot.* 25 (3), 532–545.
- Hu, T., Zhang, D., Wang, J., Mistry, R., Ran, G., Wang, X., 2014. Relation between emotion regulation and mental health: a meta-analysis review. *Psychol. Rep.* 114 (2), 341–362.
- Kalisch, R., Wiech, K., Herrmann, K., Dolan, R.J., 2006. Neural correlates of self-distraction from anxiety and a process model of cognitive emotion regulation. *J. Cogn. Neurosci.* 18 (8), 1266–1276. MIT Press.
- Kanske, P., Heissler, J., Schönfelder, S., Bongers, A., Wessa, M., 2011. How to regulate emotion? Neural networks for reappraisal and distraction. *Cereb. Cortex* 1379–1388. <https://doi.org/10.1093/cercor/bhq216>.
- Katsumi, Y., Dolcos, S., 2018. Suppress to feel and remember less: neural correlates of explicit and implicit emotional suppression on perception and memory. *Neuropsychologia*. <https://doi.org/10.1016/j.neuropsychologia.2018.02.010>.
- Klemanski, D.H., Curtiss, J., McLaughlin, K.A., Nolen-Hoeksema, S., 2017. Emotion regulation and the transdiagnostic role of repetitive negative thinking in adolescents with social anxiety and depression. *Cogn. Ther. Res.* 41 (2), 206–219.
- Kober, H., Barrett, L.F., Joseph, J., Bliss-Moreau, E., Lindquist, K., Wager, T.D., 2008. Functional grouping and cortical-subcortical interactions in emotion: a meta-analysis of neuroimaging studies. *NeuroImage* 42 (2), 998–1031.
- Kober, H., Mende-Siedlecki, P., Kross, E.F., Weber, J., Mischel, W., Hart, C.L., Ochsner, K.N., 2010. Prefrontal–striatal pathway underlies cognitive regulation of craving. *Proc. Natl. Acad. Sci. U. S. A.* 107 (33), 14811–14816.
- Kobylińska, D., Kusev, P., 2019. Flexible emotion regulation: how situational demands and individual differences influence the effectiveness of regulatory strategies. *Front. Psychol.* 10, 72.
- Kohn, N., Eickhoff, S.B., Scheller, M., Laird, A.R., Fox, P.T., Habel, U., 2014. Neural network of cognitive emotion regulation — an ALE meta-analysis and MACM analysis. *NeuroImage* 345–355. <https://doi.org/10.1016/j.neuroimage.2013.11.001>.
- Kryptos, A.M., Eftting, M., Kindt, M., Beckers, T., 2015. Avoidance learning: a review of theoretical models and recent developments. *Front. Behav. Neurosci.* 9, 189.
- Lazarus, R.S., 2001. Relational meaning and discrete emotions. In: *Appraisal Processes in Emotion: Theory, Methods, Research*, pp. 37–67.
- Leotti, L.A., Delgado, M.R., 2011. The inherent reward of choice. *Psychol. Sci.* 22 (10), 1310–1318.
- Leotti, L.A., Iyengar, S.S., Ochsner, K.N., 2010. Born to choose: the origins and value of the need for control. *Trends Cogn. Sci.* 14 (10), 457–463.
- Lindquist, K.A., Satpute, A.B., Wager, T.D., Weber, J., Barrett, L.F., 2016. The brain basis of positive and negative affect: evidence from a meta-analysis of the human neuroimaging literature. *Cereb. Cortex* 26 (5), 1910–1922.
- Martínez-Rivera, F.J., Bravo-Rivera, C., Velázquez-Díaz, C.D., Montesinos-Cartagena, M., Quirk, G.J., 2019. Prefrontal circuits signaling active avoidance retrieval and extinction. *Psychopharmacology* 236 (1), 399–406.
- McRae, K., Ochsner, K.N., Mauss, I.B., Gabrieli, J.J., Gross, J.J., 2008. Gender differences in emotion regulation: an fMRI study of cognitive reappraisal. *Group Process. Intergroup Relat.* 11 (2), 143–162.
- McRae, K., Hughes, B., Chopra, S., Gabrieli, J.D., Gross, J.J., Ochsner, K.N., 2010. The neural bases of distraction and reappraisal. *J. Cogn. Neurosci.* 22 (2), 248–262.
- McRae, K., Jacobs, S.E., Ray, R.D., John, O.P., Gross, J.J., 2012a. Individual differences in reappraisal ability: links to reappraisal frequency, well-being, and cognitive control. *J. Res. Pers.* 2–7. <https://doi.org/10.1016/j.jrp.2011.10.003>.
- McRae, K., Ciesielski, B., Gross, J.J., 2012b. Unpacking cognitive reappraisal: goals, tactics, and outcomes. *Emotion* 12 (2), 250–255.
- McRae, K., 2016. Cognitive emotion regulation: a review of theory and scientific findings. *Curr. Opin. Behav. Sci.* 10, 119–124.
- Milyavsky, M., Webber, D., Fernandez, J.R., Kruglanski, A.W., Goldenberg, A., Suri, G., Gross, J.J., 2019. To reappraise or not to reappraise? Emotion regulation choice and cognitive energetics. *Emotion* 19 (6), 964.
- Morawetz, C., Bode, S., Derrill, B., Heekeren, H.R., 2017. The effect of strategies, goals and stimulus material on the neural mechanisms of emotion regulation: a meta-analysis of fMRI studies. *Neurosci. Biobehav. Rev.* 72, 111–128.
- Moscarello, J.M., Maren, S., 2018. Flexibility in the face of fear: hippocampal–prefrontal regulation of fear and avoidance. *Curr. Opin. Behav. Sci.* 19, 44–49.
- Myerson, J., Green, L., 1995. Discounting of delayed rewards: models of individual choice. *J. Exp. Anal. Behav.* 64 (3), 263–276.
- Ochsner, K.N., Gross, J.J., 2005. The cognitive control of emotion. *Trends Cogn. Sci.* 9 (5), 242–249.
- Ochsner, K.N., Gross, J.J., 2007. The neural architecture of emotion regulation. In: *Handbook of Emotion Regulation*, pp. 87–109, 1(1).
- Ochsner, K.N., Gross, J.J., 2008. Cognitive emotion regulation: insights from social cognitive and affective neuroscience. *Curr. Dir. Psychol. Sci.* 17 (2), 153–158.
- Ochsner, K.N., Silvers, J.A., Buhle, J.T., 2012. Functional imaging studies of emotion regulation: a synthetic review and evolving model of the cognitive control of emotion. *Ann. N. Y. Acad. Sci.* 1251, E1–E24.
- Ohira, H., Nomura, M., Ichikawa, N., Isowa, T., Iidaka, T., Sato, A., Fukuyama, S., Nakajima, T., Yamada, J., 2006. Association of neural and physiological responses during voluntary emotion suppression. *NeuroImage* 29 (3), 721–733.
- Peters, J., Büchel, C., 2011. The neural mechanisms of inter-temporal decision-making: understanding variability. *Trends Cogn. Sci.* 15 (5), 227–239.
- Picó-Pérez, M., Alemany-Navarro, M., Dunsmoor, J.E., Radua, J., Albajes-Eizaguirre, A., Vervliet, B., Cardoner, N., Benet, O., Harrison, B.J., Soriano-Mas, C., Fullana, M.A., 2019. Common and distinct neural correlates of fear extinction and cognitive reappraisal: a meta-analysis of fMRI studies. *Neurosci. Biobehav. Rev.* 102–115. <https://doi.org/10.1016/j.neubiorev.2019.06.029>.
- Qi, S., Hassabis, D., Sun, J., Guo, F., Daw, N., Mobbs, D., 2018. How cognitive and reactive fear circuits optimize escape decisions in humans. *Proc. Natl. Acad. Sci. U. S. A.* 115 (12), 3186–3191.
- Ramirez, F., Moscarello, J.M., LeDoux, J.E., Sears, R.M., 2015. Active avoidance requires a serial basal amygdala to nucleus accumbens shell circuit. *J. Neurosci.* 35 (8), 3470–3477.
- Rangel, A., Hare, T., 2010. Neural computations associated with goal-directed choice. *Curr. Opin. Neurobiol.* 20 (2), 262–270.
- Roseman, I.J., Smith, C.A., 2001. Appraisal theory: overview, assumptions, varieties. In: *Appraisal Processes in Emotion: Theory, Methods, Research*, pp. 3–20.
- Scháfer, J.Ö., Naumann, E., Holmes, E.A., Tuschen-Caffier, B., Samson, A.C., 2017. Emotion regulation strategies in depressive and anxiety symptoms in youth: a meta-analytic review. *J. Youth Adolesc.* 46 (2), 261–276.
- Schutte, N.S., Manes, R.R., Malouff, J.M., 2009. Antecedent-focused emotion regulation, response modulation and well-being. *Curr. Psychol.* 28 (1), 21–31. Springer US.
- Sheppes, G., Meiran, N., 2008. Divergent cognitive costs for online forms of reappraisal and distraction. *Emotion* 870–874. <https://doi.org/10.1037/a0013711>.
- Sheppes, G., Scheibe, S., Suri, G., Gross, J.J., 2011. Emotion-regulation choice. *Psychol. Sci.* 22 (11), 1391–1396.
- Sheppes, G., Scheibe, S., Suri, G., Radu, P., Blechert, J., Gross, J.J., 2014. Emotion regulation choice: a conceptual framework and supporting evidence. *J. Exp. Psychol. Gen.* 143 (1), 163.
- Silvers, J.A., Guassi Moreira, J.F., 2019. Capacity and tendency: a neuroscientific framework for the study of emotion regulation. *Neurosci. Lett.* 35–39. <https://doi.org/10.1016/j.neulet.2017.09.017>.
- Silvers, J., Buhle, J.T., Ochsner, K.N., 2013. The neuroscience of emotion regulation. In: *Oxford Handbooks Online*. <https://doi.org/10.1093/oxfordhb/9780199988709.013.0004>.

- Silvers, J.A., Buhle, J.T., Ochsner, K.N., 2014. The neuroscience of emotion regulation: basic mechanisms and their role in development, aging, and psychopathology. In: Ochsner, K.N. (Ed.), *The Oxford Handbook of Cognitive Neuroscience*, vol. 1. Oxford University Press, New York, NY, US, pp. 52–78 xvi.
- Silvers, J.A., Weber, J., Wager, T.D., Ochsner, K.N., 2015. Bad and worse: neural systems underlying reappraisal of high- and low-intensity negative emotions. *Soc. Cogn. Affect Neurosci.* 10 (2), 172–179.
- Thuillard, S., Dan-Glauser, E.S., 2017. The regulatory effect of choice in situation selection reduces experiential, exocrine and respiratory arousal for negative emotional stimulations. *Sci. Rep.* 7 (1), 12626.
- Todd, R.M., Cunningham, W.A., Anderson, A.K., Thompson, E., 2012. Affect-biased attention as emotion regulation. *Trends Cogn. Sci.* <https://doi.org/10.1016/j.tics.2012.06.003>.
- Van Bockstaele, B., Atticciati, L., Hiekkaranta, A.P., Larsen, H., Verschuere, B., 2019. Choose change: situation modification, distraction, and reappraisal in mild versus intense negative situations. *Motiv. Emot.* <https://doi.org/10.1007/s11031-019-09811-8>.
- van den Bos, W., McClure, S.M., 2013. Towards a general model of temporal discounting. *J. Exp. Anal. Behav.* 99 (1), 58–73. Wiley Online Library.
- van den Bos, W., Rodriguez, C.A., Schweitzer, J.B., McClure, S.M., 2014. Connectivity strength of dissociable striatal tracts predict individual differences in temporal discounting. *J. Neurosci.* 34 (31), 10298–10310.
- Wager, T.D., Davidson, M.L., Hughes, B.L., Lindquist, M.A., Ochsner, K.N., 2008. Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron* 59 (6), 1037–1050.
- Webb, T.L., Lindquist, K.A., Jones, K., Avishai, A., Sheeran, P., 2018. Situation selection is a particularly effective emotion regulation strategy for people who need help regulating their emotions. *Cogn. Emot.* 32 (2), 231–248.
- Zilverstand, A., Parvaz, M.A., Goldstein, R.Z., 2017. Neuroimaging cognitive reappraisal in clinical populations to define neural targets for enhancing emotion regulation. A systematic review. *NeuroImage* 151, 105–116.