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Modulation of Emotion by Cognitive Activity

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Abstract

While emotions themselves are beneficial for our survival, they are also the targets to be regulated appropriately to adapt to social environments. Previous studies have demonstrated that cognitive strategies such as cognitive reappraisal and expressive suppression can effectively enhance and attenuate emotions. Such cognitive strategies of emotion regulation are based on cortical modulation of sub-cortical emotion-related brain regions. Though in the prior studies emotion regulation was conducted in parallel with or after the emotion elicitation, a series of our studies showed that prior cognitive activities can automatically and unintentionally attenuate subsequent emotional responses. In this article, after reviewing the previous findings about emotion regulation, we introduce our empirical findings showing that cognitive activities where the neural system of emotion regulation would be recruited can unintentionally and automatically dampen psychological and physiological emotional responses. Finally, we propose possible neural mechanisms underlying modulation of emotion by cognitive activity.

Keywords: emotion regulation, cognitive activity, resting state brain activity

Introduction

How can we regulate our emotions appropriately? This is a crucial issue for adaptive living within human societies. As everyone knows, sometimes emotions

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muster enough clout to interfere with our goal achievement though they will prove to be a major help to us. Given the importance of this question, the interest in emotion regulation has burgeoned in the past few decades. Previous studies have demonstrated that cognitive strategies such as cognitive reappraisal and expressive suppression can effectively enhance and attenuate emotions. Such cognitive strategies of emotion regulation are known to be supported by cortical modulation of sub-cortical emotion-related regions. Though prior studies have paired cognitive tasks with emotional tasks or asked participants to engage in cognitive tasks after emotion elicitation, we assert that prior cognitive activities can automatically and unintentionally attenuate subsequent emotional responses. In this article, we first reviewed the previous findings about emotion regulation. After that, a series of our studies were introduced. Our studies showed that cognitive activities can unintentionally and automatically attenuate psychological and physiological emotional responses. Finally, one possible neural mechanism underlying this implicit attenuation of emotion by cognitive activity was proposed.

Process-oriented Approach to Emotion Regulation

Emotion regulation has been conceptualized as processes through which individuals modulate their emotions consciously and non-consciously (for detailed reviews see Gross, 2013; Gross & Thompson, 2007; Gyurak, Gross, & Etkin, 2011; Mauss, Bunge, & Gross, 2007). On the basis of such conceptualization, theoretical and empirical exploration on emotion regulation has been accumulated.

Strategy-oriented Approach to Emotion Regulation

Emotion regulation first gained currency as a distinct construct in developmental psychology (Campos, Campos, & Barrett, 1989; Thompson, 1990, 1991). This line of studies began with investigating effects of several emotion regulation strategies that we take in managing our emotions. Integrating a series of these studies, Larsen (2000) presented a preliminary taxonomy of strategies and behaviors for remediating negative emotions. Two dimensions seemed to provide an organizing scheme. One dimension was cognitive versus behavioral, as some emotion regulation strategies were cognitive strategies whereas others were clearly behavioral activities. The second dimension concerned the "directedness" of the emotion regulation strategies. That is, the emotion regulation strategies could be divided into behaviors directed at changing the person versus the situation. As the potential variety of emotion regulation strategies is enormous, finding an appropriate classification of emotion regulation strategies represents a formidable scientific challenge (for reviews see Koole, 2009).

Process-oriented Model of Emotion Regulation

Another line of studies on emotion regulation began with a proposal of the process model of emotion regulation (Gross, 1998b, 2002). This model explains emotion regulation in terms of a sequence of emotion generation processes (e.g., Frijda, 1986; Izard, 1977; Lazarus, 1991; Levenson, 1994; Scherer, 1984; Tomkins, 1984). The model argues that an emotion begins with evaluations of external or internal stimuli, and the evaluations trigger a coordinated set of behavioral and physiological emotional response tendencies. Each stage of such processes can be affected by emotion regulation strategies; by governing attention to, evaluating, and responding to a stimulus (Gross, 1998b). In other words, the process-oriented approach can place various emotion regulation strategies, such as attention, cognitive appraisals, or behavior modulation, into the sequence of processes of emotion generation.

The most notable contribution of this approach is that the process model specifically addresses two major emotion regulation strategies: expressive suppression and cognitive reappraisal. Expressive suppression, as one of the response-focused strategies, refers to inhibition of external cues to one's internal emotional state (e.g., facial expression). In contrast, cognitive reappraisal, as one of the antecedent-focused strategies, involves construing a potentially emotion-eliciting situation in a way that changes its emotional impact. Generally, inducing expressive suppression can lead to impaired interpersonal communication (Butler et al., 2003), increased sympathetic nervous system arousal (Gross, 1998a; Gross & Levenson, 1997; Harris, 2001), and impaired memory (Richards, Butler, & Gross, 2003; Richards & Gross, 2000). Cognitive reappraisal decreases negative emotion and neither impairs memory nor increases arousal (Egloff, Schmukle, Burns, & Schwerdtfeger, 2006; Gross & Thompson, 2007; Richards et al., 2003; Richards & Gross, 2000) and may actually lessen physiological arousal (Dandoy & Goldstein, 1990).

Focusing on these two emotion regulation strategies facilitated studies about the neural bases of the emotion regulation processes. Functional neuroimaging studies of both expressive-suppression-based paradigm and cognitive-reappraisal--based paradigm showed the involvement of specific frontal brain regions such as orbitofrontal cortex (OFC), dorsolateral prefrontal cortex (dlPFC), dorsomedial prefrontal cortex (dmPFC), ventrolateral prefrontal cortex (vlPFC), and anterior cingulate cortex (ACC) (e.g., Beauregard, Levesque, & Bourgouin, 2001; Levesque et al., 2003; Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner & Gross, 2005; Ochsner et al., 2004; Ohira et al., 2006; Phan et al., 2005; Quirk & Beer, 2006; Schaefer et al., 2002; Urry et al., 2006). Moreover, these frontal regions are recruited when individuals engage in active self-regulation, which is associated with emotion modulation (e.g., Ochsner et al., 2002, 2004). Reviews and meta-analyses of functional imaging studies (e.g., Kober et al., 2008; Ochsner, Silvers, & Buhle, 2012; Wager et al., 2008) showed four emotional regions that have been most frequently discussed in studies of emotion regulation: amygdala (e.g., Murphy, Nimmo-Smith, & Lawrence, 2003; Phan, Wagner, Taylor, & Liberzon, 2002; Phillips, Drevets, Rauch, & Lane, 2003; Zald, 2003), ventral striatum (e.g., Knutson & Cooper, 2005; O'Doherty, 2004; Schultz, 2007), ventromedial prefrontal cortex (vmPFC; e.g., Oya et al., 2005; Roy, Shohamy, & Wager, 2012; Schoenbaum, Saddoris, & Stalnaker, 2007), and insula (e.g., Calder, Lawrence, & Young, 2001; Craig, 2009). The interactions between the emotional neural system and prefrontal cortex (PFC) are thought to be a key mechanism of emotion regulation. Indeed, a number of studies have demonstrated the correlation between the PFC activity and emotional responses such as amygdala activity and self-report (e.g., Ochsner et al., 2004; Phan et al., 2005). Moreover, results of mediation analysis suggested that effective cognitive reappraisal involves PFC → vmPFC → amygdala pathway (Johnstone, van Reekum, Urry, Kalin, & Davidson, 2007; Urry et al., 2006) or PFC→ subcortex → emotion change (Kober et al., 2010; Wager et al., 2008).

Emotion Regulation by Cognitive Activity

If the PFC controls the substantial principle of emotion regulation over emotion-related brain regions such as amygdala, it seems that the enhancement of cognitive activities can work to regulate emotions. Some previous empirical findings support this hypothesis. For example, Erber and Tesser (1992) reported that participants who engaged in a mathematical task after watching a sad movie reported less experiences of sad emotion than participants in the control group who did not undertake the task (also see Erk, Abler, & Walter, 2006; Erthal et al., 2005; Glynn, Christenfeld, & Gerin, 2002; Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003; Liberzon et al., 2000; Monk et al., 2003; Pessoa, Kaastner, & Ungerleider, 2002). In addition, less negative feelings were reported in responses to negative pictures when participants solved math equations during viewing the pictures (Van Dillen & Koole, 2007), suggesting that cognitively demanding tasks can down-regulate emotional responses to previously displayed stimuli. Co-activation analysis suggested that the activity in the right dorsolateral frontal cortex was negatively correlated with the activity in the amygdala and the right insula during task. It suggests that the more prefrontal regions were activated by the arithmetic task, the more emotional brain responses were attenuated. Taken together, these findings indicate that cognitive load is capable of tuning down the emotional brain (Van Dillen, Heslenfeld, & Koole, 2009).

Implicit Attenuation of Subsequent Emotion by Prior Cognitive Task

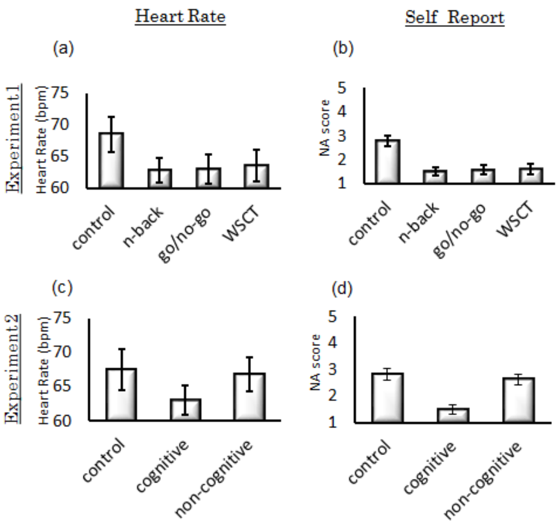
Although the previous findings described above suggest that engagement in a cognitive task can directly attenuate emotional responses, probably via inhibitory control by the PFC over emotion-related brain regions, we have to note an alternative explanation. Namely, participants might utilize the cognitive tasks as a distracter against emotional responses. This explanation is plausible because in the previous studies cognitive tasks were conducted concurrently with the emotional tasks or conducted after the exposure to emotional stimuli. To exclude this alternative explanation, we conducted a series of studies (Iida, Nakao, & Ohira, 2011, 2012), where the cognitive tasks were conducted prior to the exposure to emotional stimuli. Our specific interest was whether the prior cognitive task engagement can cause attenuation of subsequent emotional responses. In such an experimental paradigm, there is no intention to regulate emotions during the emotional tasks, because the cognitive task engagement was finished before the emotional tasks. Thus, if the prior cognitive task activity can attenuate subsequent emotions, such emotional attenuation can be considered a fully automatic process.

To confirm this hypothesis, we need to explain how the effects of prior cognitive task engagement (or activation of the PFC) can be sustained even after the cognitive task is terminated. The sustained effects of cognitive task engagement have been repeatedly examined. For example, people under high cognitive load gradually generate opponent processes that help them cope with the challenge. When the load is suddenly relaxed, the adaptive opponent process prevails for a brief duration (e.g., Carver & Scheier, 1990; Solomon, 1980). One of the plausible models explaining this sustained effect is the self-control strength model (Muraven, Tice, & Baumeister, 1998). This model states that exerting self-control decreases self-control capacity in subsequent situations (an effect called “ego depletion”). Cognitive tasks are generally understood to have some impact on subsequent tasks. Some cognitive tasks may improve performance on a subsequent task, while others may cause interference.

Empirical Studies

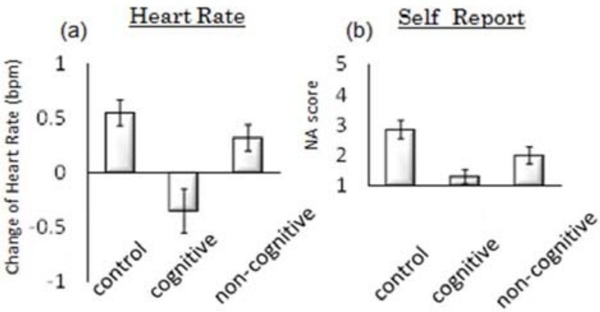
Based on a premise that effects of prior cognitive task engagement (or activation of the PFC) are sustained and affect subsequent emotions, Iida et al. (2011) conducted two experiments to test the hypothesis that execution of a prior cognitive task can decrement following emotional responses. Three typical cognitive tasks, which use executive functions (n-back task, go/no-go task, and Wisconsin Card Sorting Task - WCST) were administered in Experiment 1, and effects of each task on a subsequent emotional task were investigated. Compared with the control group, heart rate during the emotional task and self-reports of negative emotions were reduced in all of the three cognitive task groups. The control group showed a significant elevation of skin conductance level during the emotional task, while the cognitive task groups did not show such increase of skin conductance level (Figure 1). Therefore, the engagement in cognitive tasks appeared to attenuate subsequent emotions successfully regardless of detailed characteristics of the cognitive tasks. Although results in this study support the notion that prior cognitive task performance attenuates subsequent negative emotions, it is necessary to consider alternative interpretations of the results. Another possible explanation is cognitive fatigue or resource consumption (e.g., Parasuraman, 1998; Wickens, 1984). In Experiment 1, the emotion attenuation might be due to reduction of mental resources which might be caused by the prior cognitive tasks. Wherein, in Experiment 2, we addressed the question of whether or not the consumption of resources caused the attenuation of subsequent emotions. For this purpose, the effects of a cognitive task were compared to those of a non-cognitive hand-grip squeezing task. The hand-grip squeezing task was introduced as a non-cognitive task that consumes the same level of mental resources. The results showed that neither physiological responses nor subjective negative emotions were attenuated in the non-cognitive task group although the cognitive task group exhibited results similar to those in Experiment 1 (Figure 1). Taken together, these findings indicate that the prior cognitive task activity attenuates subsequent emotions implicitly even after the prior cognitive task is finished. Iida et al. (2012) tried to replicate their previous findings and to further investigate whether prior cognitive task activity can attenuate implicit emotional processes triggered by subliminal emotional stimuli. The cognitive task group reported less negative emotions after the subliminal affective priming task and a substantial reduction in their heart rate responses, as compared with the control groups (Figure 2). These results provide evidence that engagement in cognitive task can attenuate subsequent emotional processes in an automatic and unconscious manner.

Figure 1. *Implicit Attenuation of Subsequent Emotion by Cognitive Activity*



Note. In Experiment 1, participants who engaged in cognitive task (a) showed significantly lower heart rate during emotional task and (b) reported significantly lower negative feelings after emotional task finished, regardless of the nature of cognitive task. In Experiment 2, neither (c) physiological responses nor (d) subjective negative emotions were attenuated in the non-cognitive task group although the cognitive task group exhibited results similar to those in Experiment 1. These figures shared data with Iida et al. (2011).

Figure 2. *Cognitive Activity Attenuates Subsequent Emotion Triggered by Subliminal Stimuli*



Note. Participants who engaged in cognitive task showed (a) a substantial reduction in their heart rate at the onset of subliminal emotional stimulus presentation, and (b) lower negative experiences after the subliminal affective priming task. These figures shared data with Iida et al. (2012).

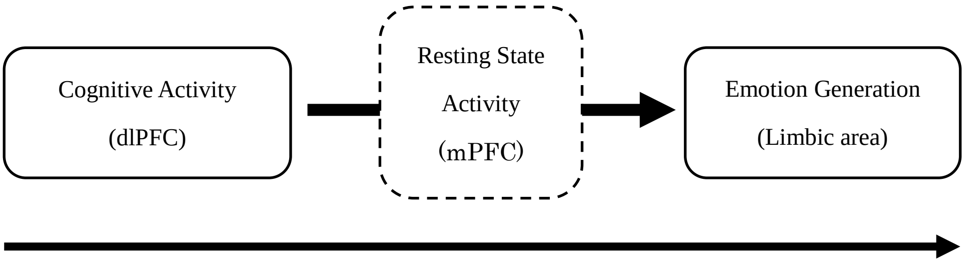
These studies showed that cognitive task performance can attenuate emotional responses whenever the cognitive task performance was held, and revealed a new strategy for the implicit regulation of emotion, involving engagement in a cognitive task before the unpleasant emotion is elicited. This new strategy is simple enough to be used for anticipatory emotion regulation. However, before introduction of this new strategy of emotion regulation into applied fields, mechanisms underlying this phenomenon have to be clarified. To be precise, how does the prior cognitive task affect a subsequent task even after the cognitive task is finished?

Possible Neural Mechanism

Within sub-divisions of the PFC, roles of the medial area of the PFC are specifically important in emotion regulation by cognitive activity, because the dlPFC, which is most intimately related to cognitive activity, does not directly project to the amygdala (Barbas, 2000; McDonald, Mascagni, & Guo, 1996). A number of studies of non-human primates have demonstrated that the vmPFC plays a crucial role in the retention of extinction learning and inhibiting the amygdala response. This inhibition of the amygdala activity mediates the diminished expression of conditioned fear with extinction (for a review see Milad & Quirk, 2002). These results were consistent with those of human neuroimaging studies, which examined the neural mechanisms of extinction learning (Phelps, 2004, 2006). A recent study investigated whether the conscious regulation of emotion, which is unique to humans and which depends on cognitive strategies, is linked to the mechanisms of extinction learning (Delgado, Stenger, & Fiez, 2004). In addition, the vmPFC regions have strong connections with the amygdala (Urry et al., 2006). Together, these results suggest that conducting conscious emotion regulation strategies causes decrement of negative emotional responses mediated by the activity of the vmPFC.

The medial PFC (mPFC) regions are a part of the default mode network (DMN) of the brain. The concept of the DMN was initially introduced to describe a set of regions that show a consistent pattern of deactivation during a task, especially a cognitively demanding task (Raichle et al., 2001). The regions of the DMN include anterior and posterior cortical midline regions such as the vmPFC, the dmPFC, the ACC, the posterior cingulate cortex, and the precuneus, along with certain regions along the midline such as the lateral parietal cortex and hippocampus (Greicius & Menon, 2004). These regions show high activity and a high degree of intrinsic functional connectivity in the resting state. In spite of controversy (Morcom & Fletcher, 2007), functions of the resting state activity might be important to understand mechanisms of the sustained brain activity after cognitive tasks and subsequent effects of emotional dampening. Pyka et al. (2009) showed that activity levels in the DMN regions were significantly higher during resting-state periods following the 1- and 2-back tasks than following the 0-back task. Schneider et al. (2008) investigated how the psychological features of preceding emotional picture perception predicted the degree of activity in a subsequent resting-state period. Based on these findings, Northoff, Qin, and Nakao (2010) reviewed that both resting-state activity and task-induced activity can modulate mutually each other. In line with this concept, we speculate that, after finishing a cognitive task, even if the task-related brain activity was attenuated, the effects of the task might persist in the resting state brain activity. We hypothesized that such sustained activity during resting state, especially in the mPFC, might attenuate activation of the emotion-related brain regions in response to an input of an emotional stimulus (Figure 3). At present, this is just a speculation and it is necessary to collect more empirical data to support this hypothesis, especially about the whole dynamical processes, in which both resting-state and task-related activities are alternately affected by one another.

Figure 3. *The Hypothetical Framework for Cognitive Modulation of Subsequent Emotion*



Note. After termination of a cognitive task, effects of the cognitive task engagement might remain at least in the resting state brain activity. We hypothesized that such sustained activity during resting state, especially in the mPFC, might attenuate activation of the emotion-related brain regions in response to input of an emotional stimulus.

This hypothetical framework of ours is consistent with the concept of emotion proposed by Damasio (1994). Damasio (1994) has proposed three differentiated classes of emotions: primary emotions, secondary emotions and background emotions. Primary emotions are the basic emotions like happiness, anger or sadness. Secondary emotions are social emotions related to the self-in-relationships, such as empathy, shame, pity, or pride. Background emotion is called as emotional resting state, emotional homeostasis (Damasio, 2003) and the regulation of primary or secondary emotion by the background emotion is conceptualized as a type of homeostatic regulation (Damasio, 2000). Resting state activity in the brain can reflect the background emotion proposed by Damasio, and clarification of dynamisms of such phenomenon might shed a new light on research of emotion regulation.

Conclusion

Our studies showed that (1) prior cognitive activities can automatically and unintentionally attenuate subsequent emotional responses, and (2) non-cognitive motor activity does not have this effect, thus this effect is specific to cognitive task activity, and (3) this effect can emerge even when emotional stimuli are presented subliminally, thus this effect is fully implicit. To explain this effect of implicit emotion attenuation by prior cognitive task engagement, we proposed a hypothesis that cognitive task activity can affect resting state activity in the brain which might be responsible for attenuation of emotional responses. This hypothetical framework drawn in Figure 3 can be provoking not only in understanding emotional regulation but also in considering structure and characteristics of emotion.

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