Automatic Emotion Regulation by Executive Function

（実行系機能による自動的感情制御）

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Declaration

The research in this thesis is the author's own original work. I hereby declare that this thesis has not been submitted, either in the same or different form, to this or any other University for a degree.

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Abstract

This thesis is concerned with the automatic emotion regulation by executive function. It has been reported that engagement in several kinds of executive function tasks can successfully inhibit unpleasant emotions. Until very recently, however, the effect of executive function has received much less empirical attention. The present study focused on the role of executive function in emotion regulation and sought to answer two main questions. The first question is whether activation of executive function is an important component in attenuation of emotional responses. The second question was how prior activation of executive function attenuates subsequent emotion.

To answer the first question, four experiments were comprised. Experiment 1 revealed that engagement in an executive function task can implicitly attenuate subsequent emotion. Experiment 2 revealed that the prior executive function task performance enhanced executive function, and that this activated executive function affected the subsequent task performance. These results supported the notion that activated executive function implicitly attenuates subsequent emotional responses. To exclude other explanations, Experiment 3 revealed that lack of resources following a prior executive function task performance could not attenuate subsequent emotion. Finally, this notion was also supported by Experiment 4 examining ERPs. Taken together, the results supported the notion that the activation of executive function is an important component in the attenuation of emotional responses.

To answer the second question, two experiments were comprised. First, Experiment 5 sought to test whether prior executive function task performance modulates both up- and down-regulation. This experiment established that executive function task performance can affect only the inhibitory aspects of subsequent emotion processing. Next, Experiment 6 was conducted to investigate whether prior activation of

executive function modulates bottom-up processes of emotion and found that the activation of executive function can affect the bottom-up processes of emotion. Taken together, the two experiments supported the notion that the enhancement of executive function mainly helps the sensory control of emotions only.

In the final part of this thesis, these findings were combined to clarify the role of executive function in emotion regulation. With the consequence of this study, I sought to discuss the mechanism of emotion regulation.

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Chapter 1

Introduction

1. Emotion and emotion regulation

In daily life, emotions play the important roles. For example, emotions ready necessary behavioral responses, tune decision making, enhance memory for important events, and facilitate interpersonal interactions. However, when they occur at the wrong time or at the wrong intensity level, emotions can hurt as well as help (Gross, 2007). When emotions seem to be ill-matched with a given situation, we frequently try to regulate emotional responses.

2. An integrative review of emotion regulation

The field of emotion regulation has begun to emerge as a relatively independent research domain only in the past two decades. The past decade has witnessed an explosion of emotion regulation research (for a comprehensive overview, see Gross, 2007). This tremendous increase in research volume has rendered the study of emotion regulation one of the most vibrant areas in contemporary psychology. At the same time, it has become increasingly critical to integrate the rapidly accumulating findings and insights. Referring to Koole's (2009) review, first, the emotion regulation was defined. Next, findings and insights of previous emotion regulation research was summarized. Finally, a new approach to emotion regulation was reviewed.

2.1 What is emotion regulation?

Emotion regulation can be defined as the set of processes whereby people redirect or attenuate the spontaneous flow of their emotions (Koole, 2009). The prototype of emotion regulation is a deliberate, effortful process that seeks to override people’s spontaneous emotional responses. Some forms of emotion regulation indeed fit this prototype, by drawing upon the same psychological and neurobiological systems that the effortful control involves (Ochsner & Gross, 2005, 2008; Tice & Bratslavsky, 2000). However, other forms of emotion regulation are relatively automatic and effortless (Bargh & Williams, 2007; Koole & Kuhl, 2007; Mauss, Bunge, & Gross, 2008); for example, hiding one's disappointment at an unattractive present (Cole, 1986), or turning one's attention away from potentially upsetting material (Boden & Baumeister, 1997).

2.2 Summary of previous research on emotion regulation

Research on emotion regulation began with investigating the effects of some emotion regulation strategies. Emotion regulation strategies refer to the concrete approach that people take in managing their emotions. For instance, after a romantic break-up, people may focus their attention on a neutral activity (Van Dillen & Koole, 2007), cognitively reframe the situation (Tugade & Frederickson, 2004), write about their feelings (Pennebaker & Chung, 2007), or eat tasty but fattening foods for comfort (Tice, Bratslavsky, & Baumeister, 2001). However, this research approach faced some significant issues. The underlying process of each strategy was still unclear, although the notion of strategies seemed to imply conscious deliberation. The potential variety of emotion regulation strategies is enormous, given that any activity that impacts people’s emotions may (at least, in principle) be recruited in the service of emotion regulation.

Several approaches have been suggested to promote understanding of emotion regulation (Gross, 1998). The first approach is to spell out exactly what people do when they try to regulate emotion or mood. For example, Rippere (1977) asked participants what they thought a person did if that person felt depressed. Thayer and colleagues (Thayer, Newman, & McClain, 1994) asked participants in highly general terms what they did to change their moods. In a similar vein, Parkinson and colleagues (Parkinson et al., 1996) identified over 200 mood regulatory strategies using both interview and questionnaire methods. It has the advantage of staying close to the phenomenon of interest. However, when the focus is broad —on affective processes including mood and emotion— there is an infinite number of behavioral acts that might qualify as affect regulatory. Although the description of behavior is an essential first step, it eventually may prove to be too low a level of analysis.

The second approach is to categorize emotion regulatory efforts on the basis of the emotion component targeted for regulation, such as experience, expression, or physiology (e.g., Walden & Smith, 1997). This approach has the advantage of parsimony. However, it has the disadvantage of lumping diverse ways of achieving change in each domain. For example, inhibiting emotion-expressive behavior may be accomplished by changing the way one thinks about a situation or by relaxing one's facial muscles (Gross, 1998). Grouping these processes together obscures notable differences in the causes, consequences, and underlying mechanisms of action. This approach is also limited by the fact that individuals often try to change multiple aspects of the emotion at once, rather than just one aspect. Although the specification of the target system is indispensable, it too may not be quite the right level of analysis.

A third approach is to undertake a conceptual analysis of the processes underlying diverse emotion regulatory acts (Frijda, 1986). In the response-tendency conception of emotion, emotional response tendencies are generated once stimuli have been evaluated as significant. Then, once emotional response tendencies have been generated, they may be modulated in various ways. Within this framework, emotion regulatory acts may be seen as having their primary impact at different points in the emotion generative process. Of course, what individuals do to regulate their emotions often involves multiple regulatory processes. However, a process-oriented approach may bring us closer to understanding the causes, consequences, and underlying mechanisms of emotion regulation than the other two approaches. At present, most studies of emotion regulation have sought to elicit the mechanism of emotion regulation according to this process-oriented approach. The followings are some common frameworks used to clarify the processes of emotion regulation.

Bottom-up versus top-down

In psychological terms, instinctive reactions to threat and subsequent regulatory responses are often referred to as bottom-up and top-down processes, respectively. The interplay between these two processes is exemplified by the following example: If one encounters a snake at a zoo, its appearance drives an initial reaction (i.e., bottom-up saliency), but the response is then implicitly controlled by the determination that the snake presents no immediate danger because it is behind a sheet of Plexiglas (i.e., top-down control). Of course, the context is critical as the same snake encountered in a field would evoke an initial freezing response followed by a different top-down control in the form of running (or screaming in some cases). Thus, interactions between bottom-up and top-down processes will determine the adaptiveness of behavior in a given situation.

Process model

Gross (1998, 2001) suggested an influential model. This process model has proposed that emotion regulation strategies may be classified by the time at which they intervene in the emotion generation process. This process model assumes five sets of emotion regulatory processes: situation selection, situation modification, attention deployment, cognitive change, and response modulation. The temporal order of the emotion generation process offers no basis for systematically relating emotion regulation strategies to different classes of emotion responses. Attention, cognitive appraisals, or behavior may each occur early or late in the emotion generation process. For instance, bodily movements may directly activate emotional experiences (Niedenthal et al., 2005; Strack, Martin, & Stepper, 1988), and merely attending to emotional stimuli may directly trigger emotional behavior without any intervening cognitive appraisals (e.g., Neumann, Förster, & Strack, 2003). However, regardless of considerations about the timing of emotion generation processes, this process model still calls attention to the targets of emotion regulation. Emotion regulation always directs some emotional response. It is plausible that the targeted emotional response for regulation will at least partially determine which emotion regulation strategy is engaged in and their effects. As a higher order category, the emotion-generation system that is targeted for regulation may thus serve to classify different emotion regulation strategies.

The process-oriented approach allows the various emotion regulation strategies to be organized by their targets of emotion regulation. The most notable contribution of this approach is that the process model specifically addresses two emotion regulation strategies; expressive suppression and cognitive reappraisal (e.g., Butler et al., 2003; Gross, 1998; Gross & Levenson, 1997; Richards & Gross, 1999; 2000). Expressive suppression, one of the response-focused strategies, refers to the inhibition of external cues to one's internal emotional state (e.g., facial expression), while cognitive reappraisal, an antecedent-focused strategy, involves "construing a potentially emotion-eliciting situation in a way that changes its emotional impact" (Gross & John, 2003). The research examining the correlates and consequences of these two emotion regulation strategies supports the considerable growth in the number of emotion regulation studies in recent year.

At the same time, because this process-oriented approach enables us to focus on two concrete emotion regulation strategies, the research works seeking to elicit the biological bases of emotion regulation were developed. These kinds of investigations on emotion regulation mainly appeared in the neuroscience field. The followings are some detailed descriptions of the emotion regulation research developments.

Neural bases of emotion regulation

Although multiple strategies for conscious control of emotion exist (Lazarus, 1991; Gross, 1999), extant neuroimaging research on the neural correlates of emotion regulation has concentrated on two empirical approaches—suppression and reappraisal (Ochsner & Gross, 2005; Quirk & Beer, 2006). Functional brain imaging of both suppression-based (voluntary inhibition of reaction to emotional stimuli) and reappraisal-based (cognitive re-interpretation of evocative stimuli to reduce negative affect) paradigms have shown that specific frontal brain regions such as the orbitofrontal cortex (OFC), dorsolateral prefrontal cortex (DLPFC), dorsomedial prefrontal cortex (DMPFC), ventrolateral prefrontal cortex (VLPFC), and anterior cingulate cortex (ACC) are engaged (Beauregard, Levesque, & Bourgouin, 2001; Ochsner et al., 2002; Levesque et al., 2003; Ochsner et al., 2004; Phan et al., 2005; Urry et al., 2006). Moreover, the recruitment of these frontal regions occurs when subjects engage in active self-regulation, and is associated with modulation of amygdala reactivity (Beauregard, Levesque, & Bourgouin, 2001; Ochsner et al., 2002; Schaefer et al., 2002; Phan et al., 2005; Urry et al., 2006). The amygdala is a region critical to the generation, expression, and experience of negative emotions as demonstrated by both animal and human lesion studies (Aggleton, 1993; Angrilli et al., 1996; Davis and Whalen, 2001; Adolphs, 2002; Amaral et al., 2003; Phelps, 2004), and human imaging studies (Phan et al., 2002; Murphy, Nimmo-Smith, & Lawrence, 2003; Phillips et al., 2003; Wager et al., 2003; Zald, 2003).

The role of the PFC in emotion regulation

The interactions between the amygdala and prefrontal cortex (PFC) may hold key information on the mechanism of emotion regulation. Imaging studies further supported evidence of frontal involvement in the regulation of emotion. In the imaging studies, similar frontal regions are observed to be important for the control of emotion-related behavior. For example, the ACC, VLPFC and DLPFC have been found to activate into response inhibition during cognitive-emotion interference tasks (Whalen et al., 1998; Bush, Luu, & Posner, 2000; Etkin et al., 2006). The ACC, VLPFC, DMPFC, and OFC were engaged when subjects diverted their attention from threatening and/or painful stimuli (Bantick et al., 2002; Tracey et al., 2002; Bishop et al., 2004). Moreover, cognitive labeling (i.e., appraisal) of negative emotional stimuli similarly engages VLPFC, DLPFC and DMPFC (Hariri et al., 2000, 2003; Taylor et al., 2003). As above, these indirect forms of emotion modulation are also associated with attenuation of limbic-amygdala responses (Hariri et al., 2000; Pessoa, Kastner, & Ungerleider, 2002; Taylor et al., 2003; Etkin et al., 2006).

However, anatomical connectivity studies of the amygdala and PFC suggest that communication between these regions is not direct. Within the PFC, more ventral and medial regions are thought to be more similar across species, and the amygdala's connectivity with the PFC is primarily through these regions (McDonald, Mascagni, & Guo, 1996; Stefanacci & Amaral, 2002). Some studies have explored the role of the PFC in the inhibition of emotion and amygdala function in nonhuman animals. They have emphasized the involvement of ventromedial PFC (VMPFC) areas (Milad & Quirk, 2002; Morgan & LeDoux, 1995). These studies have primarily examined the extinction of conditioned fear. Once a conditioned fear is acquired, the fear response can be changed through extinction. During a typical extinction procedure, the conditioned stimulus (CS) is no longer paired with the unconditioned stimulus (US). The animal eventually learns that the CS does not predict the US, and the expression of conditioned fear is diminished. A number of studies in nonhuman animals 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 mediates the diminished expression of conditioned fear with extinction (see Milad & Quirk 2002 for a review). Results from a brain imaging study in humans examining the neural mechanisms of extinction learning were consistent with this animal model (Phelps et al. 2004). 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 et al. 2004). Both means of changing emotional responses involve interactions between the amygdala and PFC, but the precise region of the PFC seems to vary.

These results suggest that conscious emotion regulation strategies might act to diminish negative emotional responses by virtue of their influence on medial PFC regions. The medial PFC regions have been shown to inhibit the amygdala during extinction. The most typical neurological and psychological term for functions carried out by the frontal lobe is the executive function (Smith & Jonides 1999). Recent neuroimaging works suggest that executive functions are localized in discrete parts of the PFC.

Executive function and emotion regulation

The findings in neuroscience field suggested that the PFC activation has a key role of emotion regulation. Similarly, in the behavioral studies, engagement in the executive function task was often observed as a part of emotion regulation strategy. For example, Erber and Tesser (1992) reported that participants who engaged in a mathematical task after watching a sad movie were less sad than participants in a control group who did not undertake the task. Erk, Abler, and Walter (2006) reported that participants who engaged in an n-back task after a cue depicting a schematic "frowny" or neutral "smiley" induced anticipatory anxiety exhibited less anxiety than a control group who did not carry out the n-back task. Hence, it has been reported that a wide range of emotion-regulation strategies that rely on executive function succeed in inhibition of negative emotion (e.g. Hariri et al., 2003; Liberzon et al., 2000; Monk et al., 2003). In addition, psychological studies also suggested that executive function contributes to emotion regulation in realms such as anticipating outcomes, planning, and executing responses (e.g., Banfield et al., 2004; Denckla, 1996). Recently, Gyurak and colleagues (2009) provided the first empirical evidence that an aspect of executive function (cognitive flexibility as measured by a test of verbal fluency) predicts the ability to down-regulate emotional responses, both when the demand for suppressing was implicit and explicit. Taken together, this study focused on the role of executive function in emotion regulation. This is because the executive function activation was thought to be a one of the most significant factors in emotion regulation beyond the difference of the emotion regulation strategies. In other words, considering the prior studies, the activation of executive function might be a crucial process for various emotion regulation strategies.

Executive function is recognized as a crucial but ill-understood umbrella term for a diverse set of high-level cognitive processes. They include (but not limit to) planning, working memory, set shifting, error detection and correction, and the inhibitory control of prepotent responses (e.g., Roberts, Robbins, & Weiskrantz, 1998; Stuss & Benson, 1986; Tranel, Anderson, & Benton, 1994). In addition, different tasks that were designed to isolate executive processes engaged common regions of localized activation (e.g., Thompson-Schill et al., 1997). There are three well-known tests of executive function, the go/no-go task, the n-back task, and the Wisconsin Card Sorting Task (WCST). The go/no-go task involves inhibitory control of a response, and the suppression of prepotent responses activates the left ventral prefrontal region (e.g. Jonides et al., 1998). The n-back task requires on-line monitoring, updating, and manipulation of remembered information and is, therefore, assumed to place considerable demands on a number of key processes within working memory. Activation of the dorsolateral and ventral frontal regions and the parietal region were often reported (for a review; Owen et al., 2005). The WCST depends primarily on shifting. Neuroimaging studies of the WCST have especially reported activation of the dorsolateral prefrontal and right inferior frontal regions (although sometimes there is co-activation of left frontal cortex; e.g. Nagahama et al., 2001). Although the tasks require slightly different cognitive abilities, all are considered to be tasks of executive function. Both the go/no-go task and WCST involve detection of a change in the experimental milieu, inhibiting the tendency to use the current action schema, and replacing it with a new one. Studies using functional neuroimaging techniques suggest that many tasks defined as measuring executive function commonly activate a network of prefrontal brain regions including the mid-dorsolateral PFC, mid-ventrolateral PFC, and dorsal, anterior cingulate gyrus. In short, the sub-processes of executive function are clearly distinct and include broadly overlapping cognitive processes.

2.3 A new approach to emotion regulation

The considerable growth and vitality of modern research on emotion regulation has certainly elicited some understanding of emotion regulation. However, some significant issues remain. One of the most significant issues is that to date there have been few attempts to reflect these findings in behavioral studies. For studies of emotion regulation, traditionally, researchers have conducted their experiments in a manner that tries to measure the effects of some emotion regulation strategies using various measurements such as subjective reports, physiological responses, and neural responses. Then they tried to integrate their results into a theoretically plausible model. There is no doubt that these research works improved understanding of emotion regulation. Indeed, this approach found out that the interaction between the amygdala and the PFC was suggested as one of the common neural bases among various emotion regulation strategies. This notion that the interaction between the amygdala and the PFC is one of the most fundamental underlying neural bases of emotion regulation achieved broad consensus. However, there were few research works, which were inspired by and started from this notion.

3. The present study

The present study focused on the common neural network underlying the various emotion regulation strategies, and sought to examine the effect of prior activation of executive function on emotion regulation. Thinking of the neural network underlying the emotion regulation, the activation of executive function might cause the attenuation of emotional responses automatically.

3.1 Is it possible to activate executive function intentionally for emotion regulation?

In prior studies, both executive function and emotional tasks were concurrently conducted to examine the interaction between cognition and emotion. Specifically, the executive function task with emotional stimuli has often been conducted (e.g., Hariri et al., 2000; 2003, Keightley et al., 2003; Lange et al., 2003). These studies showed that conducting executive function and emotional tasks concurrently attenuates emotional responses mediated by the interaction between the amygdala and the PFC. However, in emotion regulation studies, the PFC activity cannot always be enhanced by the explicit engagement of cognitive activity during emotion was already elicited. Even when the emotion regulation appeared implicitly, PFC activation was founded (for a review, Mauss, Bunge & Gross, 2007). Moreover, to examine the role of the activation of executive function in emotion regulation strictly, the activation of executive function should be separated from concomitant cognitive effort.

Executive function tasks should be set before emotions are elicited to exclude cognitive effort during emotional processing. However, to achieve this, the activation of executive function needs to be sustained even after the executive function task is completed. Most of the research focusing on understanding executive function has involved assessing the neural activity during dynamic events, such as attention or working memory (e.g., Fuster & Alexander, 1971; Wilkins et al, 1987). The idea that plasticity, or experience-induced lasting changes is a component of executive function has historically received little attention. This is because a lasting effect is somewhat inconsistent with the dynamic and flexible executive function of the PFC. However, the sustained effects of executive function task engagement have been repeatedly examined (e.g., Bargh, et al. 2001; Rothmund, 2003). For example, some researchers have suggested that cognitive load has been commonly assumed to deteriorate task performance in general and information integration in particular (e.g. Hinson, Jameson, & Whitney 2003; Shiv & Fedorikhin 1999). On the contrary, others have suggested that 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 while (Carver & Scheier, 1990; Solomon, 1980). One of the most plausible models for 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 (an effect that was called ego depletion; Muraven, Tice, & Baumeister, 1998). However, given the value and importance of the capacity for self-control, it would be dangerous for a person to lose that capacity completely, and so ego depletion effects may occur because people start conserving their remaining strength. When people do exert themselves on the second task, they deplete the resource even more, as reflected in severe impairments on a third task that they have not anticipated (Muraven et al., 2006). As reviewed above, to date, it is examined that prior executive function task has some impact on subsequent tasks. Sometimes the performance of an executive function task improved the performance of a subsequent task, and other times it interfered. Some researchers suggested that, explaining these inconsistent results, tasks that engage overlapping brain mechanisms should be susceptible to behavioral transfer effects that could enhance or reduce performance (e.g., Kinsbourne, 1980). This idea has only been examined in animals and is just a speculation for humans. However, recently, cortical activity has been shown to reflect patterns of activity induced by a recent task while humans are awake and performing an unrelated task (Peigneux et al., 2006). Although the behavioral effects of these phenomena are unclear (Buckner & Carroll, 2007), the activation of executive function could be sustained after the executive function task was finished.

According to prior studies, the activation of executive function can attenuate emotional responses. However, in these prior studies, the effect of the activation of executive function was examined in a paradigm that is overlapped with the effects of cognitive effort. Hence, to exclude the effects of cognitive effort, in the present study, the executive function task was set before the emotion was elicited. Therefore, the effect of the activation of executive function on emotional processing could be examined without interference.

3.2 How does the activation of executive function affect emotional processing?

Another merit to separate the cognitive effort from emotional processing is that the flexibility of the emotional task is heightened. Prior studies examining the interaction of cognition and emotion sought to conduct the executive function and emotional tasks concurrently. In these instances, the experimental task tended to be an executive function task with emotional stimuli. From these studies, it was clearly examined that emotional responses to the emotional stimuli were attenuated. However, it seems difficult to examine how the performance of an executive function task attenuates emotional responses.

A possible model of the role of prior executive function task performance in emotion regulation is illustrated in figure 1, referring to the cascade-of-control model of executive function in the frontal cortex (Banich et al., 2000; Milham & Banich, 2005; Milham et al., 2002; 2003; see Figure 1). In this cascade model, posterior regions of the DLPFC impose an attentional set toward task-relevant processes. This region activates when it is difficult to ignore information that engages a task-irrelevant process, regardless of the task-irrelevant process or the nature of the process that is required for the task (e.g. Banich et al., 2000). In contrast, the mid-DLPFC selects among the representations identified as task relevant. Posterior portions of the dorsal ACC tend to be involved in late-stage aspects of selection, being especially sensitive to response-related factors. This

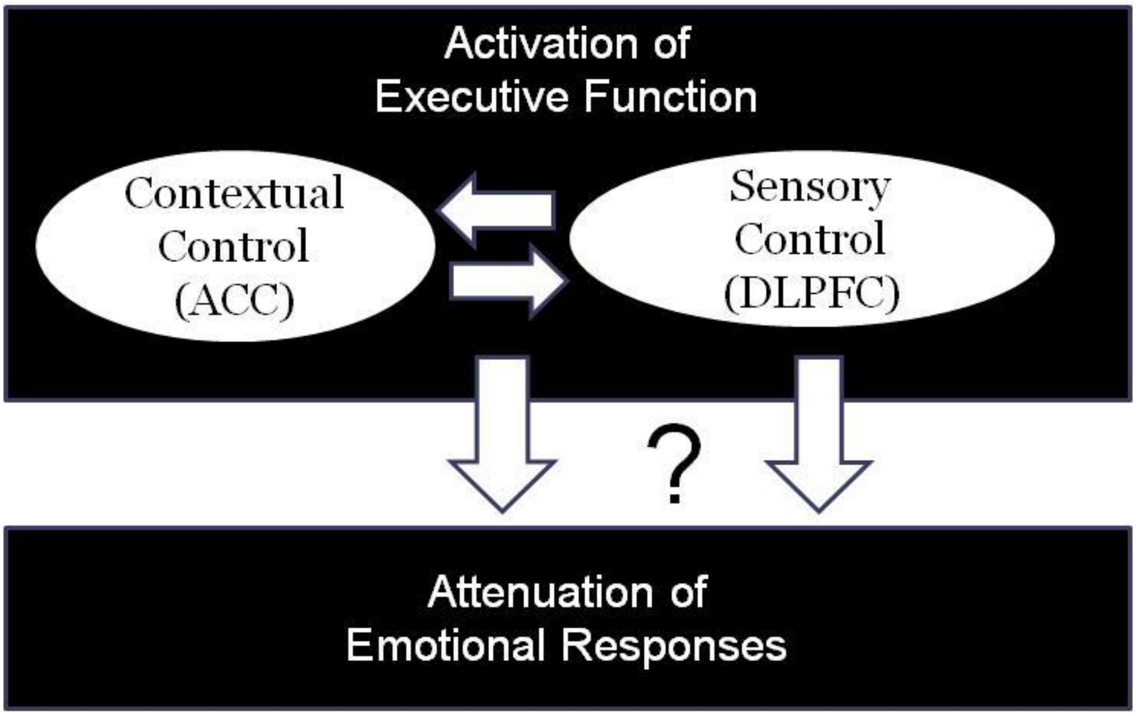

Figure 1. The hypothetic model. Referring to the cascade-of-control model of executive function in the frontal cortex, the two possible paths are set to explain the attenuation of emotion by executive function. One is that the enhancement of executive function mainly helps the sensory control with the DLPFC only. The other is that the enhancement of executive function helps both sensory and contextual control with the DLPFC and ACC.

region shows the greatest activity when stimuli lead to two competing responses and is less sensitive to semantic types of conflict (Milham et al., 2001). Finally, anterior regions of the dorsal ACC appear to be involved in processes related to response evaluation, as activity in this region increases when the probability of making an error increases (Miham & Banich, 2005). An important part of this model is that what executive control gets engaged depends on how effectively control is applied at earlier stages. In other words, in executive control, how well regions of the DLPFC achieve control affects the activity in the ACC. The ACC is involved in response evaluation. If such an evaluation suggests that an incorrect response was made, the ACC sends a signal back to the DLPFC, telling it to assert top-down control. According to this model, the proposed model sets two possible paths. One is that the enhancement of executive function mainly helps the sensory control with the DLPFC only. It was shown that the performance of executive function task caused the elimination of the attentional interference of negative stimuli (Van Dillen & Koole, 2009), an effect that has previously been regarded as automatic (Pratto & John, 1991). As the anatomical studies reviewed above suggested, activation of the PFC might only cause automatic attenuation of emotion. The other possible path is that the enhancement of executive function helps both sensory and contextual control with the DLPFC and ACC. Hence, the enhancement of executive function should improve emotion regulation as a goal-oriented behavior. Prior studies showed that people who had a high level of emotion regulation ability reduced prejudiced behaviors (von Hippel, Silver, & Lynch, 2000) and biased opinions (Payne, 2005), refrained from expressing disgust in a socially unacceptable setting (von Hippel & Gonsalkorale, 2005), and delayed gratification (Eigsti et al., 2006).

3.3 Framework

The present study consisted of two parts. The first part of this study comprised four experiments investigating whether activation of executive function is a crucial component in attenuation of emotional responses. Experiment 1 sought to examine the automatic attenuation of emotion following the completion of an executive function task. However, from this experiment, even though the attenuation of emotion was observed expectedly, there still remained some other possible explanations. At least, there was no direct evidence that showed the activation of executive function. Moreover, although this activation of executive function occurred expectedly, there was no evidence that showed that the activation was sustained till the emotional task finished. Then, Experiment 2 was conducted to provide evidence that showed activation of executive function and sustainment of activated executive function. However, though this experiment was necessary to connect executive function task engagement to activation of executive function, this experiment showed merely that activation of executive function concurrently occurred while the attenuation of emotion occurred. To exclude other possible explanations, in Experiment 3, the effects of executive function task on emotion were compared with those of non-executive function task. If the activation of executive function was quite a key factor of emotion attenuation, the non-executive function task engagement should not cause the attenuation of emotion. At the same time, to examine the activation of executive function from physiological aspect, in Experiment 4, the attenuation of emotion by activation of executive function was examined with the event-related potential (ERP). This is because that activation of executive function is closely related to neural activity. If the activation of executive function successfully occurred, some changes must have occurred also in the neural activity. From these four experiments, the notion that the activation of executive function attenuates emotion was examined.

Next, from studies of neuroscience, it was easy to assume that attenuation of emotion by activation of executive function. However, it is still unclear how the activation of executive function attenuates emotion. Strictly, though some possible answers have been already speculated to this question, there are few studies that examined this question directly. Focusing on the cascade-of-control model of executive function, two possible answers were prepared for the present study. One is that the enhancement of executive function mainly helps the sensory control. The other is that the enhancement of executive function helps both sensory and contextual controls. Two experiments were conducted to clarify this point. Experiment 5 was conducted to investigate whether the activation of executive function improved the contextual control or not. Setting the goal of emotion regulation in two directions; up-regulation and down-regulation, it was examined whether the activation of executive function could improve both up- and down-regulation of emotion or only down-regulation. If the activation of executive function improves the contextual control, this finding suggests that the activation of executive function enhances the emotion regulation in response to the task demand. Experiment 6 was conducted to investigate whether activation of executive function improved the sensory control or not. Sensory control was conducted automatically and almost without will. To achieve this attempt, the subliminal affective priming procedure was conducted as an emotional task. In the subliminal affective priming procedure, emotional stimuli are presented subliminally. If the activation of executive function improves sensory control, automatic attenuation of emotion should be also observed, though participants could not recognize what is presented to them. From these two experiments, the possible model for the attenuation of emotion by activation of executive function was discussed.

3.4 Contributions

Emotion generating system

If the attenuation of emotion is predictably examined, this study can confirm more clearly the mechanism of emotion regulation. Emotion regulation is so tightly intertwined with emotion generation that some theorists view emotion regulation as part and parcel of emotion (Campos et al., 2004; Frijda, 1986). This perspective is consistent with the observation that adult emotions are almost always regulated (Tomkins, 1984) and that the prefrontal cortex continually restrains emotion-generative brain centers (Stuss & Benson, 1986). However, the process-oriented approach needs to distinguish between emotion and emotion regulation. The notion of emotion regulation presupposes that it is possible to separate emotion generation from emotion regulation. It is true that a two-factor approach that distinguishes emotion from emotion regulation is a useful approach for analyzing basic processes, individual differences, and fashioning clinical interventions. To improve understanding of the mechanisms underlying daily behavior, a new approach proposed in this study should be the next focus for emotion research.

Emotion regulation strategies

If the automatic attenuation of emotion by activation of executive function is successfully observed in this study, we can apply this finding to the daily life, as one of the useful emotion regulation strategies. This new emotion regulation strategy is fully automated. Therefore, it can be wholly free from the cognitive or physiological costs. In addition, it can be unfailing because the costs or the inverse effects of emotion regulation are thought to be caused by the conscious effort (e.g., Mauss, Bunge, & Gross, 2008). In addition, because this new strategy need not face to emotions directly, this new strategy can be also used for prophylactic purposes. As we know, once the emotion elicited, it is not so easy to regulate them. Studies about pro-active emotion regulation draw more and more attention today.

Chapter 2

Implicit Attenuation of Emotion by Activated Executive Function

Aim

It has been reported that a wide range of emotion-regulation strategies that rely on executive function are effective for the inhibition of negative emotions (e.g., Erk et al., 2006; Hariri et al., 2003; Liberzon et al., 2000; Monk et al., 2003). Until very recently, however, the effects of executive function alone have received little empirical attention. The links between executive function and emotional responses suggest that the activation of executive function may be an important component of the attenuation of emotional responses. In the first part of this study, four experiments were conducted to test the hypothesis that decrements in emotional responses could be caused in part by the activation of executive function. First, in Experiment 1, the implicit attenuation of emotion by prior executive function task performance was examined. Three typical executive function tasks were administered in this experiment, and the effects of each task performance on subsequent emotion were investigated. Next, Experiment 2 sought to examine the sustainment of the activation of executive function. From this experiment, it was shown that the activation of executive function was sustained during the emotional processing in Experiment 1. Experiment 3 sought to investigate whether a non-executive function task performance also attenuates subsequent emotional responses. From this experiment, to exclude some other possible explanations for the attenuation of emotion by executive function task performance, the link between prior activation of executive function and subsequent emotional attenuation was more clearly examined. Experiment 4 was conducted to examine the involvement of the neural activity. The activation of executive function is intimately related to the PFC activity. Considering that the brain works as a network, this activation should cause some changes in other brain activities. The effects of prior performance of an executive function task were examined with the ERP. From these results, the phenomenon that prior executive function activation attenuates subsequent emotional processing was examined.

Experiment 1

Implicit attenuation of emotion by prior engagement in executive function task

Experiment 1 was designed to test whether executive function activity implicitly attenuated emotional responses. To investigate various aspects of the effects of prior executive function activity on emotion, both self-reports and physiological responses, including heart rate (HR) and skin conductance level (SCL) were measured and three typical executive function tasks, the n-back task, the go/no-go task, and a modified version of the WCST (Grant & Berg, 1948) were administered. Each executive function task requires slightly different cognitive abilities. The n-back task requires the maintenance and permanent update of relevant pieces of information in working memory. The go/no-go task requires inhibitory control of a response. The WCST requires task-shifting. To control the workload of these various executive function tasks, the National Aeronautics and Space Administration (NASA) Task Load Index was employed.

Method

Participants

Sixty healthy graduate and undergraduate students (47 male, 13 female) who had no history of major neurological or psychiatric disorders volunteered to take part in this experiment. Each participant gave informed consent. They were randomly divided into four groups (the n-back group, the go/no-go group, the WCST group and the control group). The average age of all participants was 24.1 years (range 21-28; SD 2.1).

Procedure

After an instruction about the procedure of the experiment, physiological sensors were attached to participants. The participants underwent four testing stages within a single experimental session: baseline (10 min), executive function task (5 min), emotional task (10 min), and recovery (10 min). In the baseline stage, participants were asked to stay calm. The n-back group, go/no-go group, and WCST group were then asked to perform their respective tasks, and the control group was again asked to stay calm. After the executive function task stage, all participants performed the emotional task. In the recovery stage, the participants were again asked to stay calm. Data of participants' self-reports about their negative emotions was collected after each stage. Autonomic responses were measured throughout the experimental session.

Executive function task

A sequence of one-digit numbers was presented in a random order. This sequence included 50 even numbers and 100 odd numbers. Half of them were colored black, and the others were blue. Each number was shown for 1 sec after an asterisk was displayed for 1 sec at the center of a screen as the point of gaze. For the control group, participants were asked to view the numbers passively. The n-back group was asked to press the "target key" when the presented number was identical to the number that preceded it by two numbers. Otherwise, they were to press the "non-target key." The go/no-go group was asked to press the "target key" if the presented number was an odd number. For the WCST group, there were two rules. First, participants were instructed to focus on the color of the number and press the "target key" if the number was blue, and otherwise press the "non-target key". Second, participants were instructed to focus on whether the number was odd or even and press the “target key” if the number was odd and the “non-target key” otherwise. All experimental groups received feedback regarding the accuracy of their key-pressing. Responses were collected using an RB-730 response pad (Cedrus Corporation).

Emotional task

Forty unpleasant pictures and ten neutral pictures from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1999; IAPS) were used for the emotional task. In the preliminary study, the two categories significantly differed from each other with respect to their normative valence ratings [mean=2.8 and 5.4 for unpleasant and neutral contents on a 9-point scale (1, unpleasant; 9, pleasant); $t(45.7)=38.9$, $p< .01$, $r= .27$]. There was no significant difference in the mean arousal levels between the two categories [5.9 and 5.6 for unpleasant and neutral contents on a 9-point scale (1, calm; 9, excited); $t(15.8)=2.72$, *n.s.*, $r= .11$]. Both the unpleasant and neutral pictures were divided into two groups and shown in a random sequence before and after a short rest, respectively. The neutral pictures were used to prevent habituation of the emotional responses to the unpleasant pictures. Each picture was shown for 1 sec, and the instruction “How negative is this picture?” was presented for 2 sec. Participants were asked to evaluate the negativity of the pictures on a 5-point scale (1, neutral; 5, negative) before the instruction disappeared. This task was designed to keep participants’ attention directed toward the pictures. The results revealed no significant difference in the evaluation of the negativity of unpleasant pictures among the four groups [$F(3, 56)=2.38$, *n.s.*, $\eta^2= .11$]. After 10 sec, the next trial began. The responses were collected with an RB-730 response pad (Cedrus Corporation).

Measures

Self-reports The negative emotion induced by the emotional task was measured in terms of the negative affect scores in the Positive and Negative Affect Schedule (PANAS, Japanese version; Sato and Yasuda, 2001). The negative affect scores included eight items, which were measured on a 5-point scale (1, not at all; 5, exactly). To measure and match the workload of each executive function task, the NASA Task Load Index (Japanese version; Haga & Mizukami, 1996) was empoyed. The NASA Task Load Index includes six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. The use of these six subscales to compute an overall workload score has been found to reduce variability among subjects, relative to a one-dimensional workload rating (Hart & Staveland, 1988). A 20-point scale is used to obtain ratings for these dimensions. A score from 0 to 100 is obtained. An overall workload score was assessed using an unweighted average of the subscale values because high correlations have been shown between weighted and unweighted scores (Byers, Bittner & Hill, 1989). PANAS scores were collected after each stage. NASA Task Load Index scores were collected after the experimental session was completed.

Autonomic responses HR was recorded using an MP-100 psychophysiological monitoring system (BioPac Systems, Santa Barbara, CA) with a 35 Hz low-pass filter and 0.5 Hz high-pass filter. For each participant, Ag/AgCl electrodes filled with isotonic NaCl unibase electrolyte were attached to the right side of the neck and the inner surface of the left forearm for measuring an electrocardiogram. SCL was recorded using an SCL/R unit (Vega Systems) and electrodes (Vitrode P-150) were attached to the volar surface of the second phalanx of the forefinger and the middle finger of the left hand. The SCL/R unit used a 5 Hz high-pass filter, and the sampling rate was 1000 Hz. HR and SCL were measured continuously throughout the experimental session and the resulting data were analyzed offline using the Acknowledge software (BioPac Systems, Santa Barbara, CA). Measures of HR and SCL were averaged over each experimental stage.

Data analysis

All analyses were carried out with IBM SPSS Statistics 19. For self-reports, mean PANAS scores for each sampling time and overall workload score were calculated. For the mean PANAS score, the analyses of variance (ANOVA) was conducted with Stage (post-baseline, pre-emotional task, post-emotional task, post-recovery) as a repeated measure and Group (control, n-back, go-no-go, WCST) as a between-participants factor. For the overall workload score, the ANOVA was conducted with Group (control, n-back, go-no-go, WCST) as a between-participants factor. For autonomic responses, the mean values of HR and SCL data were calculated for each experimental stage. The ANOVA was conducted with Stage (baseline, executive function task, emotional task, recovery) as a repeated measure and Group (control, n-back, go-no-go, WCST) as a between-participants factor. The Huynh-Feldt epsilon correction factor was used where appropriate. In cases where a significant interaction effect or main effect was found by ANOVA, post hoc analyses were conducted using Bonferroni tests to examine which combinations of data points differed significantly.

Results

Self-reports Analysis of the PANAS scores revealed a significant interaction between Stage and Group [$F(9, 168)=6.06$, $p< .01$, $\eta^2= .27$]. After the emotional task, the experimental groups showed significantly lower score than the control group

($p <$ .01). All experimental groups exhibited less negative affect than the control group (see Figure 2). The performance of all three executive function tasks inhibited subsequent negative emotion, despite clear differences in aspects of the tasks.

Analysis of the overall work load score revealed a significant main effect between Group [$F(3, 56)=12.75$, $p < .01$, $\eta^2 = .21$]. The experimental groups showed significantly higher score than the control group ($p <$ .01). There was no significant difference among the experimental groups (see Figure 3).

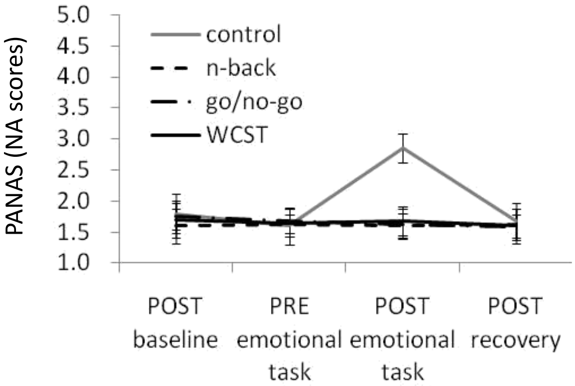

Figure 2. Self-reports of negative emotion at post-baseline, pre/post-emotional task, and post-recovery stages for each group. Error bars indicate standard errors.

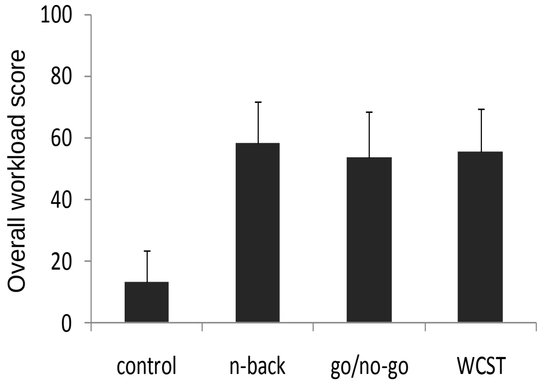

Figure 3. Overall workload score of the NASA Task Load Index for each task. Error bars indicate standard errors.

Autonomic responses A significant interaction was found between Stage and Group for both HR and SCL [$F(9, 168)=7.24$, $p < .01$, $\eta^2 = .25$; $F(9, 168)=2.03$, $p < .05$, $\eta^2 = .20$]. The control group showed significantly higher HR than the experimental groups in the emotional task ($p <$ .01), and the experimental groups showed significantly higher SCL than the control group in the executive function task. In addition, while the experimental groups showed significantly higher SCL in the executive function task stage than in the other stages, the control group showed significantly higher SCL in the emotional task stage than in the other stages. Thus, regardless of the nature of the executive function task, engagement in an executive function task inhibited the increase in HR in the emotional task (see Figure 4).

There was no significant difference in SCL between the control group and experimental groups in the emotional task. However, although the control group showed a significant increase in SCL in the emotional task, the experimental groups tended to show a decrease in SCL, regardless of the nature of the executive function task (see Figure5).

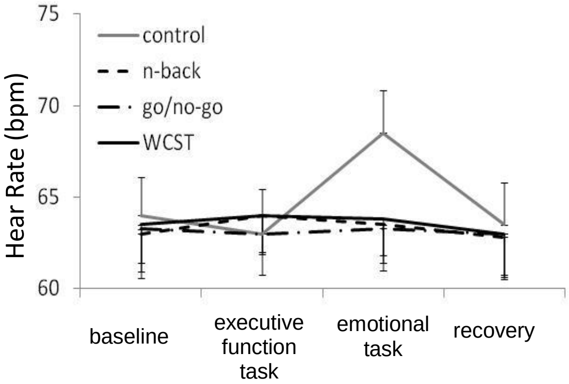

Figure 4. Heart rate in the experimental groups at baseline, executive function task, emotional task and recovery stages. Error bars indicate standard errors.

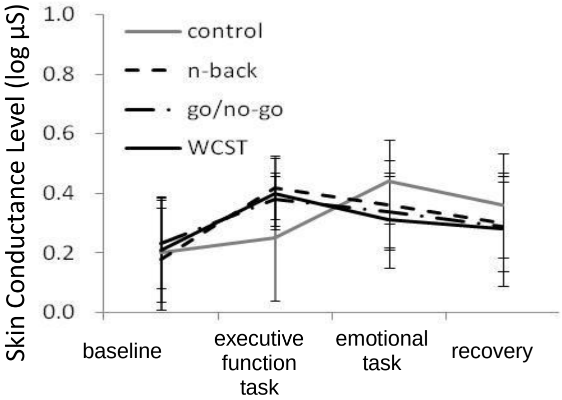

Figure 5. Skin conductance level in the experimental groups at baseline, executive function task, emotional task and recovery stages. Error bars indicate standard errors.

Discussion

The results were consistent with the notion that the activation of executive function attenuates subsequent emotional responses. Compared with the control group, HR during the emotional task and self-reports of negative emotions were similarly reduced in all three experimental groups. The control group showed significantly higher SCL during the emotional task than the other stages, while the experimental groups did not show such an increase at all. Therefore, the engagement in executive function tasks appeared to attenuate subsequent emotion successfully in a similar way regardless of its nature. It must be acknowledged that this experiment included no direct measures of the enhancement of executive function, and is thus unable to provide direct evidence that activated executive function implicitly attenuates subsequent emotional responses.

Experiment 2

Sustainment of the activation of executive function

Experiment 2 was designed to test whether the activation of executive function would be sustained even after the executive function task was completed. Two tests were used to assess the change in participants' executive function: The verbal fluency test and the reading span test. The verbal fluency test was identified as the best neuropsychological measure of executive function based on factor loadings (Salthouse et al., 2003). The verbal fluency test involves semantic knowledge of lexical items and the ability to search semantic memory using phonological or categorical rules. Moreover, it also involves the executive skills required to track prior responses and block intrusions from other semantic categories. The reading span task was the first task used to study working memory capacity and its relationship with high-order cognition (Daneman & Carpenter, 1980). Working memory capacity is primarily an index of executive functioning that may or may not be allocated to subsequent tasks of self-control (Engle, 2002). Considerable research has shown that executive functioning depends on a limited supply of executive function resources (for a review, see Baumeister, Schmeichel, & Vohs, 2007). Recent work has linked this limited supply of executive function resources to working memory capacity. Working memory capacity is broadly defined as a capacity which temporarily store and manipulate information (Baddeley, 1986; Just & Carpenter, 1992). The verbal fluency test was administered to assess the change of executive function during the subsequent task. Therefore, for the verbal fluency test, the duration and temporal relation with the executive function task were set as the same as the emotional task in Experiment 1. The reading span test was used to examine the sustainment of the activation of executive functioning until the end of the experimental session.

Method

Participants

Seventy-two healthy graduate and undergraduate students (17 male, 55 female) who had no history of major neurological or psychiatric disorders volunteered to take part in this experiment. Each participant gave informed consent. The average age of all participants was 30.2 years (range 21-38; SD 5.6).

Procedure

First, all participants engaged in the reading span test after providing written informed consent. Then they were asked to schedule another experiment at a future date. According to the results of this reading span test, controlling the individual differences in working memory capacity, participants were divided into four groups (the n-back task/verbal fluency test group, the n-back task group, the verbal fluency test group, and the control group). On the second day, participants underwent three testing stages within a single experimental session: the executive function task (5 min), the verbal fluency test (10 min) and the reading span test. In the executive function task, n-back task/verbal fluency test group and n-back task group were asked to engage in the two-back task. The other two groups were asked to remain in calm for 5 minutes. Then, n-back task/verbal fluency test group and verbal fluency test group were asked to engage in the verbal fluency test. The other two groups were asked to remain in calm for 10 minutes. After that, all participants were asked to engage in the reading span test again.

Executive function task

A sequence of one-digit numbers was presented in a random order. Each number was shown for 1 sec after an asterisk (fixation point) was presented at the center of a screen for 1 sec. The executive function task group had to press the "target key" when the presented number was identical to the first of the two previous numbers. Otherwise, they were to press the "non-target key." Responses were collected using an RB-730 response pad (Cedrus Corporation). This is just the same task as n-back task group in Experiment 1.

Verbal fluency test

Participants asked to generate words starting with letters that were presented on the computer display for 3 minutes, and write down as many generated words as they could generate during 3 minutes. The three letters were "a," "ka," and "shi" (Ito et al, 2002). Word generation performed at a self paced rate without vocalization. Participants took 30 seconds rest until the new letter was presented.

Reading span test

Participants individually received a revised version of the Japanese Reading Span Test (Osaka et al., 2002). Participants were required to read each sentence aloud at their own pace and memorize the target word. Once they finished reading a sentence, that sentence disappeared, and the next sentence was presented in the same place. The sentences were arranged in 20 sets (i.e., five sets each of two, three, four, and five sentences). The order of sentences was settled not to form a meaningful context. Participants were required to recall the target words of the set and write them down after reading through all sentences in a set. The test started with two-sentence set and proceeded to three-, four-, and five- sentence set.

Data analysis

For the verbal fluency test, the number of generated words was collected. For the reading span test, the average of correct rate was calculated. The t-test on the number of generated words of verbal fluency test with Group (n-back task/verbal fluency test group, verbal fluency test group) as a between-participants factor was conducted. The ANOVA on the correct rate of the reading span test with Day (first, second) as a repeated measure and Group (n-back task/verbal fluency test group, n-back task group, verbal fluency test group, control group) as a between-participants factor was conducted. The Huynh-Feldt epsilon correction factor was used where appropriate. When a significant interaction effect or main effect was found in the ANOVA, post hoc analyses using Bonferroni tests were conducted to examine which combinations of data exhibited significant differences.

Results

Regarding the verbal fluency test scores, the n-back task/verbal fluency test group was significantly higher than verbal fluency test group [$t(34)=3.94$, $p< .05$; see Figure 6]. For the reading span test, a significant interaction between Day and Group were seen [$F(3, 68)=12.61$, $p< .01$, $\eta^2= .10$]. In the second day, the n-back task group was significantly higher than the n-back task/verbal fluency task group ($p< .05$) and the verbal fluency test group ($p< .05$). In the n-back task group, the correct rate was significantly higher in the second day than in the first day. On the contrary, in the n-back task/verbal fluency task group and the verbal fluency test group, the correct rate was significantly lower in the second day than in the first day (p< .05; p< .05; see Figure 7).

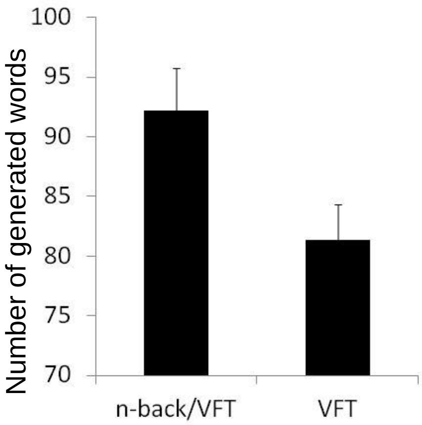

Figure 6. Number of generated words for verbal fluency test in the n-back task/verbal fluency test group and the verbal fluency test group. Error bars indicate standard errors.

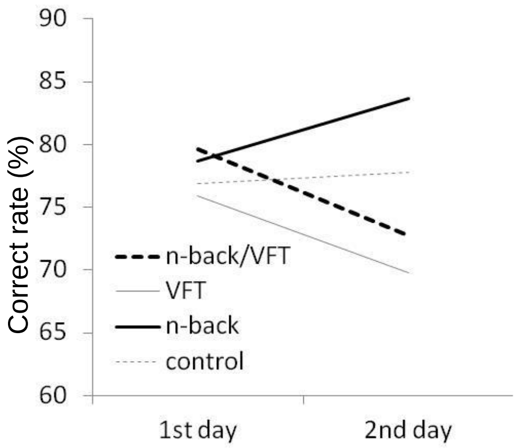

Figure 7. Correct rates of reading span test in the experimental groups in the 1st and the 2nd day.

Discussion

This experiment investigated whether or not the activation of executive function would be sustained even after the executive function task was completed. In the verbal fluency task, participants who preliminarily engaged in the executive function task generated a significantly higher number of words than those who did not. In addition, the n-back task group who preliminarily engaged in the executive function task showed a significant increase in working memory capacity. These results showed that prior executive function task performance enhanced executive function and that the activated executive function affected the subsequent task performance. These results supported the notion that the activation of executive function carried the implicit attenuation of subsequent emotional responses in Experiment 1.

However, unexpectedly, working memory capacity decreased after participants engaged in the verbal fluency test regardless of engagement in the n-back task. Although unexpected, it is not uncommon that intensive performance of one or more complex tasks involving multiple executive processes can subsequently results in reduced performance on other tasks (e.g. Van der Linden, Frese, & Meijman, 2003). This alternative explanation is related to cognitive fatigue or resource consumption (e.g., Parasuraman, 1998; Wickens, 1984). For example, the SCL results in Experiment 1 indicated that the executive function task performance required at least some psychophysiological resources. This result suggested that even if the executive function task is separated from the emotional task, the effects of workload on emotion attenuation still remains as one of the possible explanations. Just as well as the activation of executive function was sustained and affected the subsequent emotional processing, the effects of workload also remained even after the executive function task was completed. Thus, drawing on the results of Experiments 1 and 2, the possibility that attenuation of subsequent emotion is influenced by a lack of resources still remains.

Experiment 3

Comparison of the executive function and non-executive function tasks

Experiment 3 investigated whether the consumption of resources could account for the attenuation of emotion. From the aspect of resource depletion (e.g., Muraven & Baumeister, 2000), non-executive function task performance might have the same effects on subsequent emotional responses as executive function task performance. The handgrip squeezing task was administered as a non-executive function task that did not require executive function, but it consumes the same level of resources. To investigate various aspects of such resources, the level of resource consumption was measured for autonomic responses and the NASA Task Load Index, as in Experiment 1. Therefore, if prior resource-consumption causes the attenuation of subsequent emotion, the same results in the executive function task group and a handgrip squeezing group were expected. On the other hand, if prior activation of executive function, specifically, is important for the attenuation of subsequent emotion, this effect should be seen in the executive function task group but not in the handgrip squeezing group.

Method

Participants

Forty-five healthy graduate and undergraduate students (30 male, 15 female) who had no history of major neurological or psychiatric disorders volunteered to take part in this experiment. Each participant gave informed consent. They were randomly divided into three groups (the executive function task group, the non-executive function task group, and the control group). The average age of all participants was 25.3 years (range 21-29; SD 3.4).

Procedure

After instructions regarding the task had been provided, physiological sensors were attached to each participant. Participants underwent four testing stages within a single experimental session: baseline (10 min), executive function task/non-executive function task (5 min), emotional task (10 min) and recovery (10 min). In the baseline stage, participants were asked to remain in a calm and relaxed state. The executive function task group and non-executive function task group were then asked to perform their respective tasks, and the control group was again asked to remain in a calm and relaxed state. After completing the first task (or rest period), all subjects undertook an emotional task. In the recovery stage, participants were again asked to remain in calm and relaxed state for 10 min. Self-reports of negative emotion were collected between each stage. Physiological responses were measured throughout the experimental session.

Executive function task

The executive function task was the same as in Experiment 2. The two-back task was administered as an executive function task.

Non-executive function task

The non-executive function task group was instructed to squeeze a 15 kg handgrip of a type that is commonly used to train hand muscles. The handgrip consists of two handles connected by a wound spring, and is designed to build muscles in the forearm. Individuals grasp the handgrip, which brings the handles together and compresses the spring, thereby creating resistance. Participants were asked to squeeze the handgrip once every two seconds for 5 minutes.

Emotional Task

The emotional task was the same as in Experiment 1. The negativity evaluation of affective pictures was administered.

Measures

The same measures as in Experiment 1 were conducted for both self-reports and autonomic responses. For self-reports, the negative emotion induced by the emotional task was measured in terms of negative affect scores of the PANAS. The NASA Task Load Index was employed to measure the workload of each task. PANAS scores were collected after each stage, and the Task Load Index scores were collected after the experiment session was completed. For autonomic responses, HR and SCL were recorded, as in Experiment 1. HR and SCL were measured continuously throughout the experimental session, and the data were analyzed offline using the Acknowledge software (BioPac Systems, Santa Barbara, CA, USA).

Data analysis

For self-reports, the mean PANAS scores for each sampling period were calculated. For autonomic responses, the mean HR and SCL were calculated for each experimental stage. The ANOVA was conducted on each dependent variable, with Stage (baseline, executive function task/non-executive function task, emotional task, recovery) as a repeated measure, and Group (control, executive function task, non-executive function task) as a between-participants factor. The Huynh-Feldt epsilon correction factor was used where appropriate. When a significant interaction effect or main effect was found in an ANOVA, post hoc analyses using Bonferroni tests were conducted to examine which combinations of data exhibited significant differences.

Results

Self-reports Regarding the PANAS scores, a significant interaction was observed between Stage and Group [$F(6, 126)=4.56$, $p < .01$, $\eta^2 = .24$]. At the post emotional task stage, the control group showed significantly higher score than the executive function task group showed ($p < .01$; see Figure 8). This indicated that the executive function task, but not the non-executive function task, attenuated negative emotion.

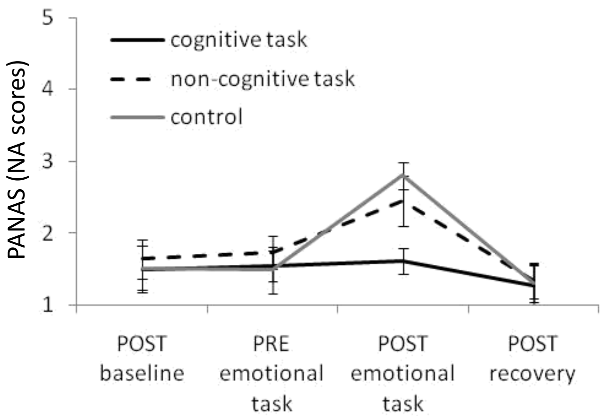

Figure 8. Self-reports of negative emotion at post-baseline, pre/post-emotional task, and post-recovery stages for each group. Error bars indicate standard errors.

Task Load Index scores revealed a significant main effect of Group [$F(2, 42)=67.82$, $p < .01$, $\eta^2 = .37$]. The control group was significantly lower than the executive function task ($p < .01$) and non-executive function task groups ($p < .01$). While the executive function task and non-executive function task groups showed a higher workload than the control group, there was no significant difference between the executive function task and non-executive function task groups (see Figure 9). This result indicated that the workload for each task was well controlled.

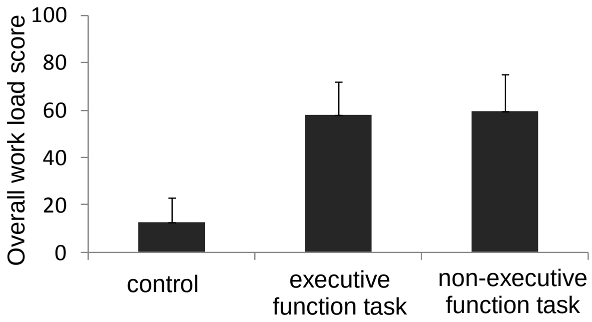

Figure 9. Overall workload score of the NASA Task Load Index for each task. Error bars indicate standard errors.

Autonomic responses Significant interactions between Stage and Group were observed for both HR and SCL [$F(6, 126)=6.83$, $p < .01$, $\eta^2 = .21$; $F(6, 126)=4.17$,

$p < .01$, $\eta^2 = .16$]. In the executive function/non-executive function task stage, the control group was significantly lower than the executive function task (HR: $p < .05$, SCL: $p < .01$) and non-executive function task (HR: $p < .01$, SCL: $p < .01$) groups, for both HR and SCL. In the emotional task, regarding both measures the executive function task group was significantly lower than the control (HR: $p < .05$, SCL: $p < .05$) and non-executive function task (HR: $p < .05$, SCL: *n.s.*) groups (see Figures 10 & 11). These results indicate that the non-executive function task group, like the executive function task group, showed an enhanced autonomic response during the executive function/non-executive function task. However, in the emotional task, the non-executive function task did not attenuate emotional responses.

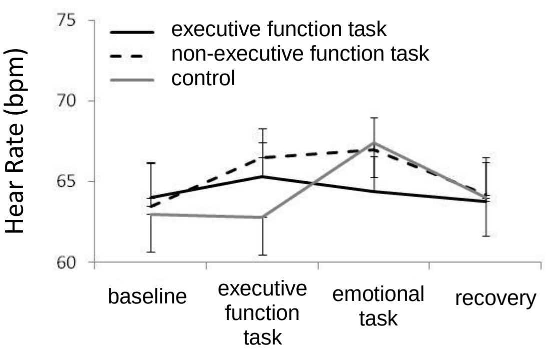

Figure 10. Heart rate in the experimental groups at baseline, cognitive task, emotional task and recovery stages. Error bars indicate standard errors.

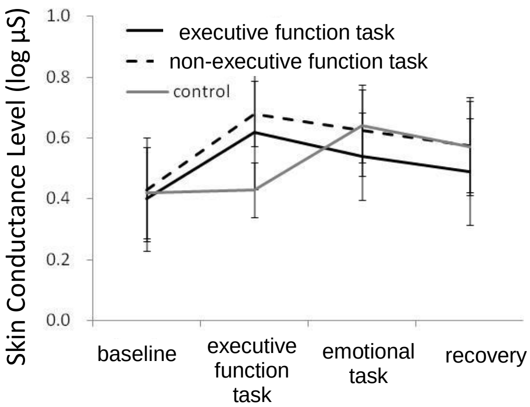

Figure 11. Skin conductance level in the experimental groups at baseline, cognitive task, emotional task and recovery stages. Error bars indicate standard errors.

Discussion

This experiment investigated whether or not the consumption of resources was an important factor causing the attenuation of subsequent emotion. Although the executive function task group exhibited results similar to those in Experiment 1, neither physiological responses nor subjective, negative emotions were attenuated in the non-executive function task group. These findings indicate that the conservation of resources theory cannot explain the effect of executive function task performance on subsequent emotion that was repeatedly observed in this study.

Experiment 4

Effects of executive function task engagement on neural activities -an ERP study-

From the results of Experiments 1, 2, and 3, the significant key factor in subsequent emotional attenuation was thought to be the prior activation of executive function. To examine this notion, Experiment 4 was conducted to examine whether this implicit attenuation was correlated with a change in brain activity. The activation of executive function is intimately related to PFC activity. Because of their excellent temporal resolution, the event-related brain potential (ERP) was used to assess the effect of prior executive function performance on emotional stimuli sequentially. The late positive potential (LPP) is one of the ERPs that reflects facilitated attention to emotional stimuli (Cuthbert et al., 2000; Schupp et al., 2000; 2004). The magnitude of the LPP is greater when individuals view emotionally arousing pictures than when they view neutral pictures. Recently, it has been demonstrated in adults that the LPP to unpleasant pictures is reduced when a more neutral interpretation of the picture is given (Foti & Hajcak, 2008). The reduced LPP following a directed reappraisal, therefore, may reflect reduced emotional responses owing to emotion regulation instructions. Such reductions may result from shifts in meaning as well as the recruitment of the PFC associated with effective cognitive control (Ochsner & Gross, 2005).

Method

Participants

Twenty-two healthy graduate and undergraduate students (11 male, 11 female) who had no history of major neurological or psychiatric disorders volunteered to take part in this experiment. Each participant gave informed consent. They were randomly divided into two groups (the executive function task group and the control group). The average age of all participants was 22.8 years (range 19-28; SD 4.2).

Procedure

After instructions regarding the task had been provided, physiological sensors were attached to each participant. Participants underwent four testing stages within a single experimental session: baseline (5 min), executive function task/non-executive function task (5 min), emotional task (10 min) and recovery (5 min). In the baseline stage, participants were asked to remain in a calm and relaxed state. The executive function task group was then asked to perform their task, and the control group was again asked to remain in a calm and relaxed state. After completing the first task (or rest period), all subjects undertook an emotional task. In the recovery stage, participants were again asked to remain in a calm and relaxed state for 5 min. Self-reports of negative emotion were collected between each stage. EEG was measured continuously throughout the experimental session.

Executive function task

The executive function task was the same as in Experiments 2 and 3. The two-back task was administered as an executive function task.

Emotional task

The emotional task was the same as in Experiments 1 and 3. The negativity evaluation of affective pictures was administered. However, the number of pictures and the ISI were modified to meet the EEG measurement. Sixty unpleasant pictures and 60 neutral pictures from the IAPS were used in emotional task. In the preliminary study, the two categories differed significantly from each other in their normative valence ratings of the preliminary research (mean=3.2 and 5.8 for unpleasant and neutral contents on a 9-point scale [1, unpleasant; 9, pleasant; $t(118)=6.56$, $p< .01$, $r= .23$]. There was no significant difference in the mean arousal levels between the two categories [6.0 and 5.6 for unpleasant and neutral contents on a 9-point scale (1, calm; 9, excited); $t(118)=1.64$, *n.s.*, $r= .14$]. Both of unpleasant and neutral pictures were divided in half and shown in a random sequence before and after a little rest, respectively. The neutral pictures were used to prevent habituation of the emotional responses to the unpleasant pictures. Each picture was shown for 1 sec, and the instruction "How negative is this picture?" was presented for 1 sec. Participants were asked to evaluate the negativity of the picture on a 5-point scale (1, neutral; 5, negative) before the instruction disappeared. This task was designed to keep participants' attention directed toward the pictures. Then the black cross was presented for 1400 msec. This black cross was followed by the red cross presented for 500 msec. Participants were asked to inhibit their eye blink after the red cross was presented and before the evaluation started. The responses were collected with an RB-730 response pad (Cedrus Corporation).

Measures

For self-reports, as the prior experiments, the negative emotion induced by the emotional task was measured in terms of negative affect scores on the PANAS. PANAS scores were collected after each stage throughout the experiment. On the basis of the International 10-20 system, EEG was recorded with BIOPAC (Goleta, CA) MP100. 16 EEG recording units from three sites by using Ag/AgCl electrodes: the sites were Fz, Cz, and Pz. Reference electrodes were initially placed on the tip of the nose and later an average reference method was applied. Electro-oculogram (EOG) activity was monitored at the electrodes on the canthus and lower orbital ridge of the left eye. Impedance was kept below 10 kΩ, typically below 5 kΩ. Signals were recorded with a 0.1Hz high-pass filter and 100Hz low-pass filter. The sampling rate was 500Hz with a 16-bit A/D conversion. EEG data analysis was performed using EEGLAB 5.02 (Delorme & Makeig, 2004; http://www.sccn.ucsd.edu/eeglab) that was running under Matlab 7.1 (The Mathworks). EEG of correctly responded trials were segmented to obtain epochs starting from 100ms before the stimulus onset until 1000ms after stimulus (baseline -100 to 0ms). All trials were inspected visually, and only artifact-free trials were retained.

Data analysis

For self-reports, the mean PANAS scores for each sampling period were calculated. For the EEG, single-trial epochs were extracted offline for a period that started 100 msec prior to picture onset and continued for the duration of stimulus presentation. EEG epochs were then averaged to form stimulus-locked ERPs. Referring to Dennis and Hajcak (2009), the LPP was defined as the mean amplitude in three time windows following stimulus onset for the affective picture: 300-600 msec (early window), 600-800 msec (middle window), and 800-1000 msec (late window). Subtraction ERP (Unpleasant picture - Neutral picture) was calculated. For each participant, the amplitude of the LPP was defined as the average signal value at electrode Fz, Cz, and Pz in a time window. The ANOVA was conducted on each dependent variable. The Huynh-Feldt epsilon correction factor was used where appropriate. When a significant interaction effect or main effect was found in the ANOVA, post hoc analyses using Bonferroni tests were conducted to examine which combinations of data exhibited significant differences.

Result

Self-reports Regarding the PANAS scores, ANOVA was conducted with Group (control, executive function task) as a between-participant factor and Stage (post-baseline, pre-emotional task, post-emotional task, post-recovery) as a repeated measure. A significant interaction was observed between Stage and Group [F(3, 60)=8.58, p< .01, η^2= .21]. The executive function task group was significantly lower than the control group (p< .01) after the emotional task (see Figure 12). This result was successfully replicated the result of prior experiments.

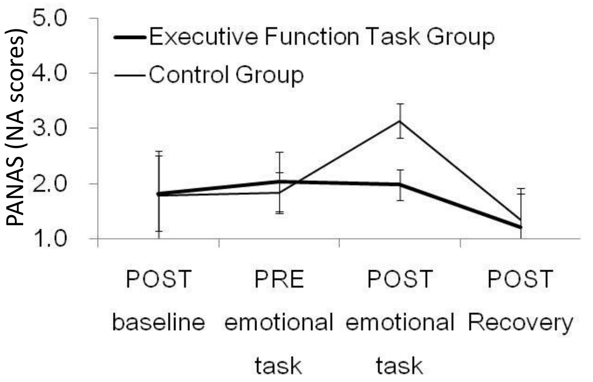

Figure 12. Self-reports of negative emotion at post-baseline, pre/post-emotional task, and post-recovery stages for each group. Error bars indicate standard errors.

The EEG The ANOVA was conducted with Group (control, executive function task) as a between-participant factor, and Valence (negative, neutral), Window (300-600 msec, 600-800 msec, 800-1000 msec) and Electrode (Fz, Cz, Pz) as a repeated measure. There was no significant effect. For the subtraction ERP, ANOVA was conducted with Group (control, executive function task) as a between-participant factor and, Window (300-600 msec, 600-800 msec, 800-1000 msec) and Electrode (Fz, Cz, Pz) as a repeated measure. There was no significant second-order interaction. A significant interaction between Window and Group was founded [F(2, 40)=5.19, p< .05, η^2= .18]. In the window of 800-1000 msec, the executive function task group was significantly lower than the control group (p< .05; see Figure 13).

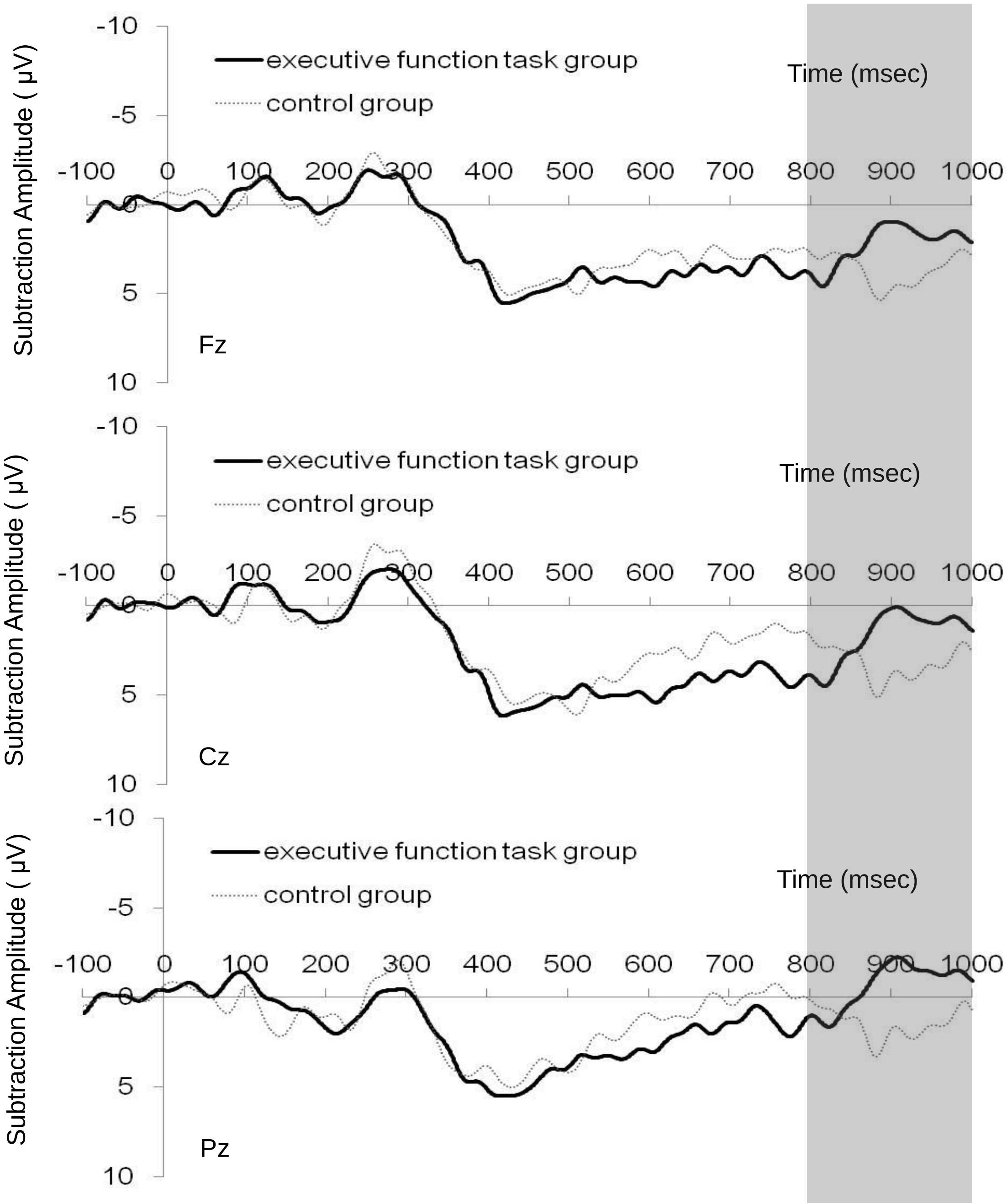

Figure 13. Subtraction ERP waveforms (negative stimuli-neutral stimuli) in executive function task group and control group. Note that negative voltage changes are plotted as upward deflections. ※up: Fz, middle: Cz, down: Pz

Discussion

This experiment investigated whether implicit attenuation was correlated with a change in brain activity. Replicating the results of Experiments 1 and 3 in subjective reports, significant difference in ERP was found between the executive function task group and control group.

However, the effects of emotion regulation on the LPP appeared from 250 msec after the affective pictures were presented and the LPP was reduced compared with the control group (e.g., attentional control, Dunning et al., 2009; cognitive reappraisal, Hajcak & Nieuwenhuis, 2006; suppression, Moser et al., 2006). Such reductions may result from shifts in meaning as well as recruitment of the PFC associated with effective cognitive control (Ochsner & Gross, 2005). Although reduced LPP was found in this study, it occurred much later than that in other emotion regulation strategy studies. It appeared after 800 msec.

One possible explanation for this inconsistency is that the behavior of the LPP did not directly reflect the emotional level, such as arousal level or limbic activity. The reduced LPP did not simply reflect the inhibition of emotion by PFC activity. Rather, the LPP reflects emotional processing more globally. In the present study, even though the executive function task group showed higher amplitude of LPP in the middle stage, in the late stage the difference between the negative stimuli condition and neutral stimuli condition was diminished. This might reflect that activation of executive function helps process the emotional stimuli more effectively and rapidly. This is reflected in the sustained LPP. Following this, the emotional processing finished, and the difference between unpleasant and neutral stimuli was diminished in the 800-1000 msec stage. This is pure speculation and requires further investigation.

Conclusion

The first part of this study was designed to test the hypothesis that the activation of executive function is an important component in the attenuation of emotional responses. All the experiments provided evidence in support of this notion. Experiment 1 revealed that engagement in an executive function task can implicitly attenuate subsequent emotion. However, Experiment 1 included no direct measures of the enhancement of executive function, and is thus unable to provide direct evidence that activated executive function implicitly attenuates subsequent emotional responses. Hence, Experiment 2 investigated whether or not the activation of executive function would sustain even after the executive function task was completed. It was shown that prior executive function task performance enhanced executive function and the activated executive function affected the subsequent task performance, as expected. These results are considered to support the notion that activated executive function implicitly attenuates subsequent emotional responses as demonstrated in Experiment 1. However, unexpectedly, working memory capacity decreased after participants engaged in the verbal fluency test, regardless of engagement in the n-back task. Therefore, although behavioral results in this study support the notion that prior executive function activity attenuates subsequent negative emotion, it is necessary to consider possible alternative interpretations of the results. Another possible explanation is the conservation of resources theory. According to this theory, prior executive function activity is thought to reduce psychophysiological resources and disrupt resources for subsequent emotion elicitation. Therefore, Experiment 3 examined whether a lack of resources resulting from a prior executive function task caused the attenuation of subsequent emotion. Although the executive-function-task-group showed results similar to those in Experiment 1, the non-executive function task group did not. These findings indicate that the activation of executive function is an important factor in the implicit attenuation of subsequent emotion. Finally, Experiment 4 tested this notion with ERPs. This experiment examined whether implicit attenuation was correlated with changes in brain activity. The activation of executive function is intimately related to PFC activity. As expected, a significant difference was found between the executive function task group and control group. From the findings of the first part of this study, the attenuation of emotion by prior executive function task performance was confirmed, and for the key factor of this phenomenon, the activation of executive function was suggested with some empirical data.

Chapter 3

How does Activated Executive Function attenuate Emotional Responses?

Aim

The first part of this study was conducted to examine whether the activation of executive function might be an important component in the attenuation of emotional responses, and provided evidence supporting this notion. However, further research is required to clarify the mechanism by which activated executive function affects subsequent emotion. Focusing on the cascade-of-control model of executive function, two possible answers were prepared for the present study. The first was that the enhancement of executive function mainly helps only the sensory control. The second was that the enhancement of executive function helps both sensory and contextual controls. Sensory control involved in selecting motor actions in response to stimuli. Contextual control involved in selecting premotor representations (that is, stimulus-response associations) according to external contextual signals accompanying stimulus occurrences. To clarify this point, in the second part of this study, two experiments were conducted. Experiment 5 investigated whether the activation of executive function improves the contextual control or not. Setting the goal of emotion regulation in two directions; up-regulation and down-regulation, it is examined whether the activation of executive function can improve both up- and down-regulation of emotion or only down-regulation. If the activation of executive function improves the contextual control, the activation of executive function might enhance the emotion regulation in response to the task demand. Experiment 6 investigated whether activation of executive function improves the sensory control or not. Sensory control was conducted automatically and almost without will. To achieve this attempt, the subliminal affective priming procedure was administered as an emotional task. If the activation of executive function improves the sensory control, the activation of executive function might even attenuate unconscious emotion automatically.

Experiment 5

Effects of activated executive function on goal pursuit in emotion regulation

As the mechanism of implicit attenuation of emotion, the cascade-of-control model of executive function suggested one possible explanation. That is, the activation of executive function improves both sensory and contextual controls. In line with this idea, Gyurak and colleagues (2012) indicated that higher executive function group was related to greater ability to regulate emotion in both the down-regulation and up-regulation conditions. Experiment 5 was designed to examine whether the activation of executive function regulates emotion whether only in the direction of the down-regulation or both in the down- and up-regulation directions flexibly following the instruction. Clarifying this point, one of the most popular emotion regulation tasks was administered. That is, participants were instructed to increase or decrease their negative emotions in response to negative affective pictures, or just watch the negative affective pictures (e.g. Hajcak & Nieuwenhuis, 2006; Ochsner et al., 2002; 2004). For indices of the negative emotion, both self-report and autonomic response were measured to confirm and compare with the results of the first part of this study.

Method

Participants

Forty healthy graduate and undergraduate students (22 male, 18 female) who had no history of major neurological or psychiatric disorders volunteered to take part in this experiment. Each participant gave informed consent. They were randomly divided into two groups (the executive function task group and the control group). The average age of all participants was 25.3 years (range 23-29; SD 2.1).

Procedure

After the instructions for the task were given, physiological sensors were attached to the participant. Participants underwent four testing stages within a single experimental session: baseline (10 min), executive function task (5 min), emotional task (25 min) and recovery (10 min). In the baseline stage, participants were asked to stay calm. Next, the participants in executive function task group were asked to engage in the executive function task, and the participants in control group were asked to stay calm again. All of the participants were then asked to engage in an emotional task. In the recovery stage, participants were asked to stay calm for 10min. Self-reports of negative emotions that measured by the negative affect scores of the PANAS were collected between the stages throughout the experiment. Physiological responses were measured throughout the experimental session.

Executive function task

The executive function task was the same as in Experiments 2, 3, and 4. The two-back task was administered as an executive function task.

Emotional task

Sixty unpleasant pictures and 60 neutral pictures from the IAPS were used in emotional task. In the preliminary study, the two categories differed significantly from each other in their normative valence ratings of the preliminary research [mean=3.2 and 5.8 for unpleasant and neutral contents; $t(118)=6.56$, $p< .01$, $r= .23$]. There was no significant difference in the mean arousal levels between the two categories [6.0 and 5.6 for unpleasant and neutral contents; $t(118)=1.64$, *n.s.*, $r=.14$]. Both of unpleasant and neutral pictures were divided in half and shown in a random sequence before and after a little rest, respectively. The neutral pictures were used to prevent habituation of the emotional responses to the unpleasant pictures. Each trial began with the presentation of the word "increase", "look", or "decrease" for 1000 msec. After this instruction had been presented, asterisk in the center of the screen as the point of gaze followed for 1000 msec, after which the unpleasant or neutral picture was presented for 2000 msec. After the presentation of each picture, the participants were asked to rate the negativity of each picture and own negative feelings to each picture on a scale from 1 (neutral) to 5 (unpleasant). After these evaluations for 2000 msec for each, asterisk in the center of the screen as the point of gaze followed for 2000 msec. The order of the trials "increase", "look", and "decrease" was randomized, and the assignment of unpleasant pictures to the three conditions was counterbalanced across participants. Participants were instructed to increase and decrease their negative emotions following the instruction. To increase their emotion, participants were instructed to think about the personal relevance of each picture as it appeared. To decrease their emotion, they were instructed to increase their sense of objective distance, viewing pictured events from a detached, third-person perspective. Participants were asked to look at the picture naturally if the word "look" was presented. The responses were collected by the RB-730 response pad (Cedrus Corporation).

Measures

Self-report The negative emotion induced by the emotional task was measured in terms of the negative affect scores in PANAS. The negative affect scores included eight items, which were measured on a 5-point scale. PANAS scores were collected after each stage throughout the experiment. The participants were asked to rate the negativity of the picture and their current feelings. Rating scales appeared immediately after the presentation of the negative affective pictures. These scales served as a self-report index of the success of emotion regulation.

Autonomic response HR was recorded using an MP-100 psychophysiological monitoring system (BioPac Systems, Santa Barbara, CA) with a 35 Hz low-pass filter and 0.5 Hz high-pass filter. For each participant, Ag/AgCl electrodes filled with isotonic NaCl unibase electrolyte were attached to the right side of the neck and the inner surface of the left forearm for measuring an electrocardiogram. HR was measured continuously throughout the experimental session and the resulting data were analyzed offline using the Acknowledge software (BioPac Systems, Santa Barbara, CA). Measure of HR was averaged over each experimental stage.

Data analysis

Rating scores were measured on a 5-point scale (1, neutral; 5, negative), and the mean score for each condition was calculated. Heart rate was stored on a hard disc and analyzed offline using the software (Acknowledge; Biopac Systems, Santa Barbara, CA). Inter-beat intervals were obtained from deviations between R-waves and converted into beats per minute (bpm). HR in bpm was averaged in 1 sec intervals and deviated from the 1 sec baseline preceding the offer onset. Initial deceleration was assessed as the minimum value in the 0-3 sec, and late acceleration was the maximum value in the 4-6 sec in each trial (Bradley et al., 2001). The mean PANAS score for each sampling time was calculated, and the mean value of HR data for each experimental stage was also calculated to confirm the results of the first part of this study. To determine the effect of the executive function task engagement on the up- and down-regulation, for the rating score, mixed design analysis of variance (ANOVA) was conducted with Condition (increase, look, decrease) as a repeated measure and Group (control, executive function task) as a between-participants factor. For the HR, mixed design analysis of variance (ANOVA) was conducted with the Condition (increase, look, decrease) as repeated measures and the Group (control, executive function task) as a between-participants factor for the minimum value in the 0-3 sec (deceleration) and the maximum value in the 4-6 sec (acceleration). The Huynh-Feldt epsilon correction factor was used where appropriate. In cases where significant interaction effect, or main effects were found in the ANOVAs, post hoc analyses using Bonferroni tests was conducted to examine which combinations of data points differed significantly.

Results

Confirmation of results of the first part of this study

Regarding the PANAS scores, a significant interaction between Group and Stage was found [$F(3, 114)=12.80$, $p< .01$, $\eta^2= .24$]. After the emotional task, the PANAS (NA) score was significantly higher than the other stages in the control group ($p< .01$). In the executive function task group, there was no significant difference among stages. Only after the emotional task, the control group was significantly higher than the executive function task group ($p< .01$; see Figure 14). These results showed that the emotional task worked successfully and replicated the effect of the executive function task performance on the subsequent task shown by the first part of this study. Regarding mean HR values, a significant interaction between Group and Stage was found [$F(3, 114)=6.34$, $p< .01$, $\eta^2= .19$]. In the emotional task, the mean HR was significantly lower in the executive function task group than in the control group ($p< .01$). In the executive function task group, there was no significant difference among stages. In the emotional task,

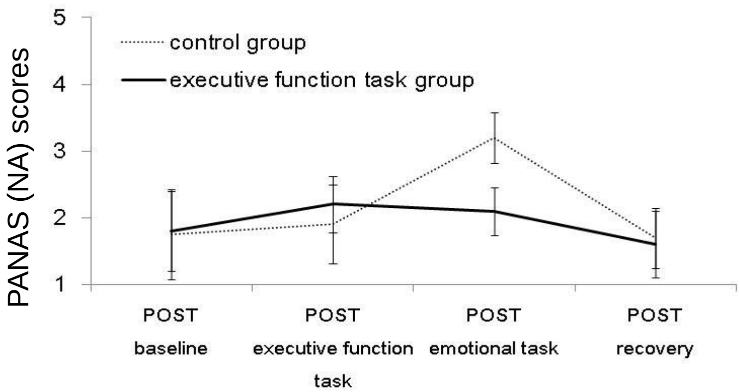

Figure 14. Self-reports of negative emotion at post-baseline, post-executive function task, post-emotional task, and post-recovery for each group. Error bars indicate standard error.

the mean HR was significantly higher than in the baseline (p< .01; see Figure 15). These results also replicated the effect of the executive function task performance on the subsequent emotional task shown in the first part of this study.

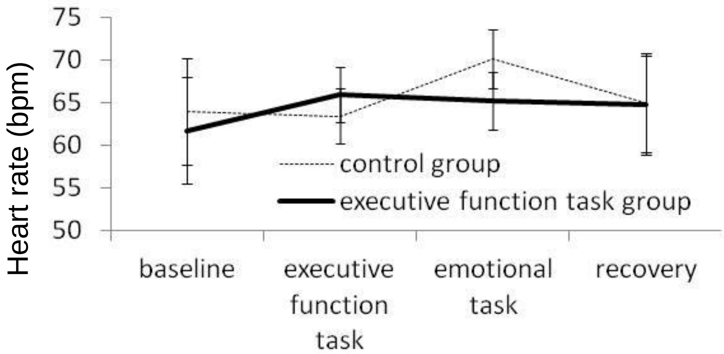

Figure 15. Heart rate at the baseline, executive function task, emotional task and recovery stages for each group. Error bars indicate standard error.

The direction of emotion regulation: Down-regulation and up-regulation

With regard to rating scores of the negativity of the affective pictures, the significant interaction effect between Condition and Group was shown [F(2, 36)=13.42, p< .01, η^2= .16]. All groups showed significant differences between three conditions. The negativity scores in the increase condition were significantly higher than the scores in the other conditions, and the scores in the decrease condition was significantly lower than the score in the other conditions (p< .01). The difference between the control group and the executive function task group was shown in all conditions (p< .05, increase and look; p< .01, decrease; see Figure 16). The executive function task group showed less negativity to the unpleasant pictures than the control group. With regard to rating scores of the current strength of their negative feelings, a significant interaction effect between Condition and Group was shown [F(2, 36)=9.01, p< .01, η^2= .13]. In the control group, the increase condition showed significantly higher than the decrease condition (p< .05), while the executive function task group showed no significant difference. The difference between the control group and the executive function task group was shown in the increase condition (p< .01) and the look condition (p< .05). In both conditions, the executive function task group showed significantly less negativity to the affective pictures than the control group (see Figure 17). These results indicated that the manipulation for setting goals of emotion regulation successfully worked. While the significant difference was shown in the different manner between two rating scores, both results showed that the executive function task group showed less negativity of the affective pictures and their feelings than the control group.

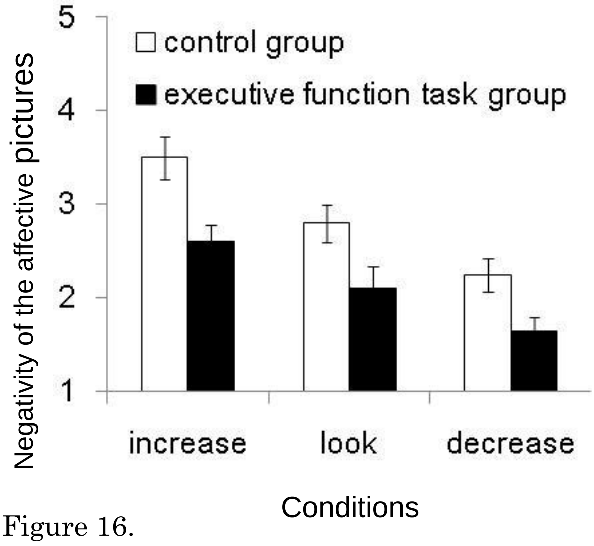

Figure 16.
Evaluation score of the negativity of the affective pictures during the emotional task in each condition for the control and executive function task groups. Error bars indicate standard errors.

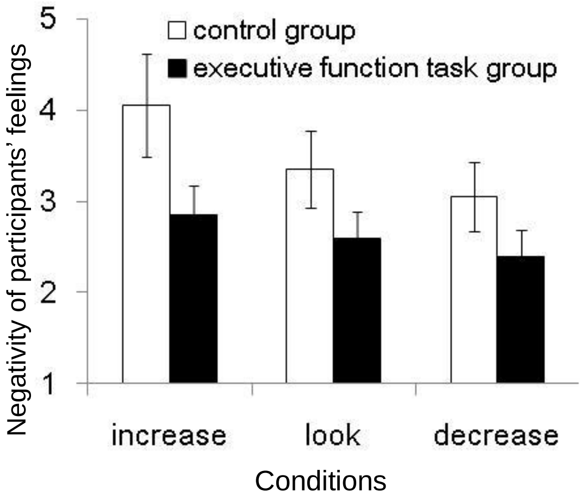

Figure 17.
Evaluation score of the negativity of participants' feelings during emotional task in each condition for the control and executive function task groups. Error bars indicate standard errors.

Regarding HR deceleration, interaction between Condition and Group was significant [$F(2, 36)=5.48$, $p< .01$, $\eta^2= .18$]. There were significant differences between the executive function task group and the control group in all conditions ($p< .01$, $p< .01$, $p< .01$). In all conditions, heart rate decelerated more clearly in the control group. In the executive function task group, there is also significant difference between the decrease condition and the look condition ($p< .01$), and the increase condition and the look condition ($p< .01$). Heart rate decelerated more clearly in the decrease condition and the increase condition. Regarding heart rate acceleration, only a main effect of the groups was significant [$F(1, 18)=4.43$, $p< .05$, $\eta^2= .13$]. Heart rate accelerated more clearly in the control group (see Figure 18). These results indicated that the effects of prior executive function task performance started shortly after the picture presentation, and the executive function task performance weakened both deceleration and acceleration of heart rate. In addition, the difference among conditions was only found in the executive function task group. However, even in the executive function task group, there was no significant difference between the increase condition and the decrease condition.

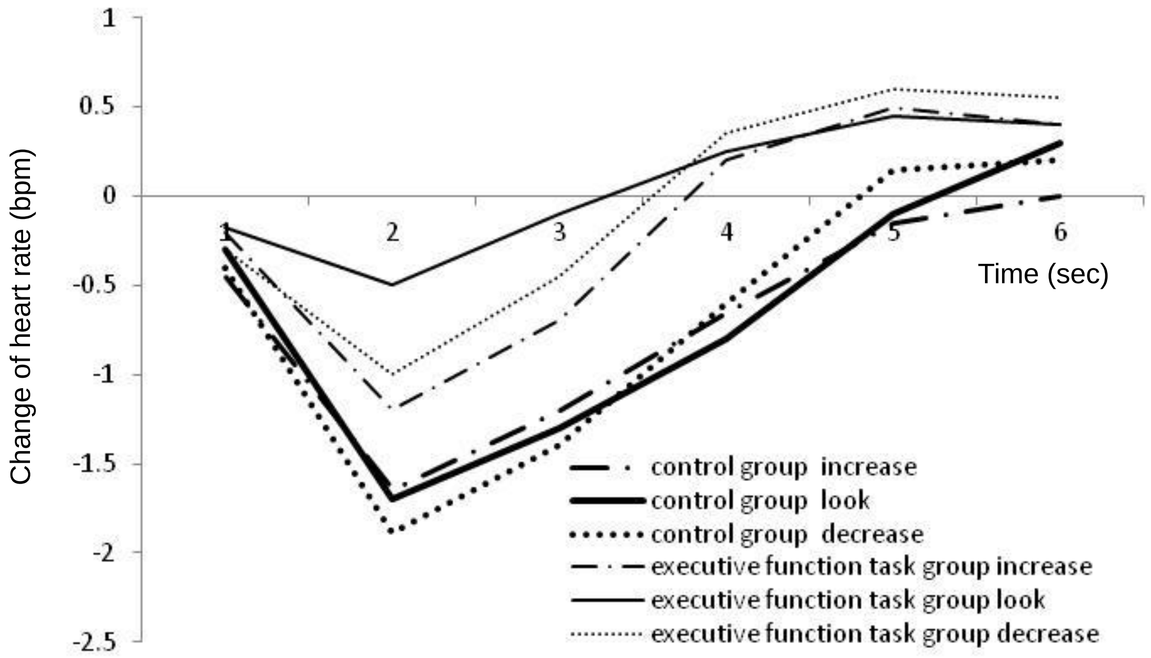

Figure 18. Change of heart rate after the emotional stimulus. HR in bpm was averaged in 1 sec intervals and deviated from the 1 sec baseline preceding the offer onset.

<u>Discussion</u>

Drawing on these prior studies, one possible explanation for this implicit attenuation is that prior activation of executive function modulates attention at a very early stage, before the emotional stimuli were sufficiently appraised. In other words, prior activation of executive function modulated attentional deployment or attentional capacity before the emotional stimuli were presented, and preliminarily prepared for a buffering of the impacts of emotional stimuli.

Experiment 6

Effects of activated executive function on bottom-up process of emotion

The attenuation of negative emotions may involve mediating interference between bottom-up appraisals of stimuli and neutralizing top-down reappraisals of them (Ochsner et al., 2004). In general, top-down control is conceptual in origin, being closely linked to current intentions, plans, and schemas. Bottom-up control is more stimulus-based, relying on sensory system information.

One possible explanation in this study was denied from Experiment 5. Remaining explanation is that activation of executive function improves the sensory control. Hence, Experiment 6 focused on the bottom-up process. The bottom-up processing of emotion affects some very early and fundamental processes of emotion generation, such as selection or integration of information (Friese et al., 2010). This experiment was conducted to investigate whether the prior performance of an executive function task could affect the subsequent bottom-up control of emotion. To exclude involvement of the top-down process of emotion regulation, the subliminal affective priming (e.g., Jostmann et al., 2005) was administered. In this task, participants are first exposed to positive or negative affective stimuli (the prime) for very brief durations that preclude conscious detection followed by neutral stimuli (the target).

Method

Participants

Sixty healthy graduate and undergraduate students (22 male, 18 female) who had no history of major neurological or psychiatric disorders volunteered to take part in this experiment. Each participant gave informed consent. They were randomly divided into three groups (the executive function task group, the non-executive function task group, and the control group). The average age of all participants was 25.4 years (range 21-31; SD 2.4).

Procedure

After the participants had been instructed on how to perform the task, physiological sensors were attached. Participants underwent four testing stages within a single experimental session: baseline (5 min), executive function / non-executive function task (5 min), emotional task (10 min) and recovery (5 min). In the baseline stage, participants were asked to stay calm. The executive function task group and non-executive function task group were then asked to perform their respective tasks, and the control group was again asked to stay calm. When they were finished, all of the subjects participated in the emotional task. In the recovery stage, participants were again asked to stay calm. Self-reports of negative emotion were collected between all of the stages. Physiological responses were measured throughout the experimental session.

Executive function task

The executive function task was the same as in Experiments 2, 3, 4, and 5. The two-back task was administered as an executive function task.

Non-executive function task

The non-executive function task was the same as in Experiment 3. The handgrip squeezing task was administered as a non-executive function task.

Emotional task

For the prime stimuli, 60 unpleasant pictures and 60 neutral pictures from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1999; IAPS) were used in the emotional task. In the preliminary research study, the two categories differed significantly from each other in their normative valence ratings [mean=3.2 and 5.8 for unpleasant and neutral contents on a 9-point scale; $t(118)=6.56$, $p< .01$, $r= .23$]. There was no significant difference between the two categories in the mean arousal levels [6.0 and 5.6 for unpleasant and neutral contents on a 9-point scale; $t(118)=1.64$, *n.s.*, $r= .14$], and in the mean visual complexity ratings [6.8 and 6.7 for unpleasant and neutral contents on a 9-point scale; $t(118)=1.38$, *n.s.*, $r= .09$]. For the target stimuli, 60 novel figures were selected from the set of Novel Shapes, which were validated by evaluation of the level of verbalization, association, and simplicity (Endo, Saiki, & Saito, 2001). First, participants saw a fixation point (a black and then a red cross) for 1900 msec. Then the prime stimulus was shown subliminally for 15 msec. It was followed by an 85 msec masking stimulus and then the target stimulus, which was presented for 1000 msec. Finally, participants evaluated the negativity both of the target stimulus and their feelings on a 5-point scale. Then the next trial began. 120 trials were prepared. The responses were collected by the RB-730 response pad (Cedrus Corporation).

Manipulation check

To check awareness of subliminal stimuli, the Forced-Choice Test was administered after all the experimental stages were finished. First, participants saw the fixation point (the black cross followed by the red cross) for 1900 msec. Then a prime (negative, neutral) was presented for 15 msec and immediately followed by an 85 msec masking stimulus presentation. After the masking stimulus had disappeared, two pictures were flashed on the screen for 2 seconds: a picture of the actual prime on one side of the screen and an alternate picture (a distractor) on the other side of the screen. Participants indicated which of the two pictures they thought the prime was by pressing buttons on a response box. The screen position of the correct picture was randomized. The

120 prime stimuli used in the emotional task were all tested.

Measures

Self-reports The negative affect scores of the PANAS measured the negative emotion induced by the emotional task. The negative affect scores included 8 items, which were on a 5-point scale. PANAS scores were collected after each stage throughout the experiment. The mean PANAS score for each sampling period was calculated. In the emotional task, to examine the effect of the prime stimulus, the evaluation scores of negativity for the target picture and their current feelings were collected. The evaluation scores were averaged for each condition. To measure and match the workload of each task, NASA Task Load Index (Japanese version; Haga & Mizukami, 1996) was employed. The NASA Task Load Index includes six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. The use of these six subscales to compute an overall workload score has been found to reduce variability among subjects, relative to a one-dimensional workload rating (Hart & Staveland, 1988). A 20-point scale is used to obtain ratings for these dimensions. A score from 0-100 is obtained on each scale. An overall workload score was assessed using an unweighted average of the subscale values because high correlations have been shown between weighted and unweighted scores (Byers, Bittner & Hill, 1989). The NASA Task Load Index scores were collected after the experimental session was completed.

Heart Rate HR was recorded using an MP-100 psychophysiological monitoring system (BioPac Systems, Santa Barbara, CA) with a 35Hz low-pass filter and 0.5Hz high-pass filter. For each participant, Ag/AgCl electrodes filled with isotonic NaCl unibase electrolyte were attached to the right side of the neck and to the inner surface of the left forearm for recording an electrocardiogram. HR was measured continuously throughout the experimental session and the resulting data were analyzed offline using the Acknowledge software (BioPac Systems, Santa Barbara, CA). Interbeat intervals were converted to HR as beats per minute (bpm) per real time epoch (500 msec). To assess the phasic HR responses, 2 epochs (1 sec) before and 6 epochs (3 sec) after the onset of the prime stimulus were analyzed. The average of the 2 post-prime stimulus epochs (1 sec) subtracting the average of the pre-stimulus epochs served as the emotional response to the prime stimuli for each group.

Data analysis

All analyses were carried out with IBM SPSS Statistics 19. The Analyses of variance (ANOVA) were conducted for each index. The Huynh-Feldt epsilon correction factor was used where appropriate. When a significant interaction effect or main effects were found in ANOVA, post hoc analyses using Bonferroni tests were conducted to examine which combinations of data were significantly different.

Results

Task Load Index scores revealed a significant main effect of Group [$F(2, 42)=64.36$, $p< .01$, $\eta^2= .34$]. The control group was significantly lower than the executive function task group ($p< .01$) and non-executive function task group ($p< .01$). While the executive function task and non-executive function task groups showed a higher workload than the control group, there was no significant difference between the executive function and non-executive function task groups (see Figure 19). This result indicated that the workload for each task

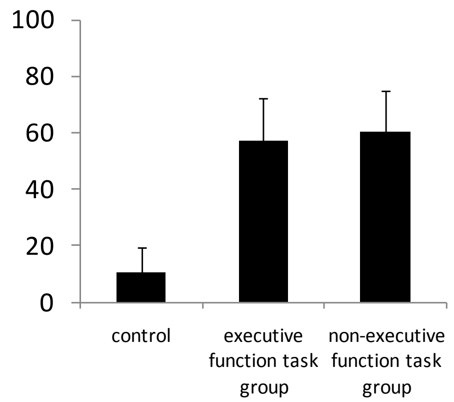

Figure 19. Overall workload score of the NASA Task Load Index for each task. Error bars indicate standard errors.

was well controlled.

Data from the forced-choice test of prime recognition indicated that the subliminal presentation procedures were successful. The recognition ratio (i.e. the number of correct recognitions of the prime divided by the total number of recognition judgments made) was 0.52, *SD* = 0.13, which is not significantly different from the chance expectation of 0.50. The recognition ratio did not differ as a function of the prime (negative, neutral).

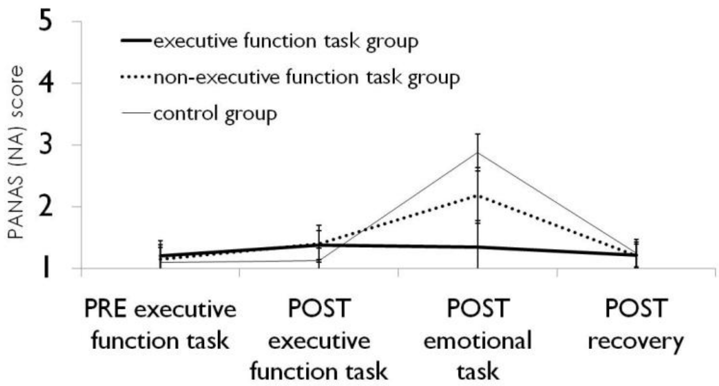

Figure 20. Self-reports of negative emotion at pre/post executive function task, post emotional task, and post recovery stages for each group. Error bars indicate standard deviation.

Regarding the PANAS scores, the ANOVA with Group (control, executive function task, non-executive function task) as a between-participants factor and Stage (pre/post-executive function task, post-emotional task, post-recovery) as a repeated measure was conducted. A significant interaction between Group and Stage was found [$F(6, 171)=9.00$, $p < .01$, $\eta^2 = .23$). After the emotional task, the PANAS score was significantly higher than the other stages in the control ($p < .01$) and non-executive function task ($p < .05$) groups. This result showed that the emotional task worked successfully as expected. In the executive function task group, there were no significant differences among stages. Moreover, after the emotional task, the control group showed significantly higher score than the executive function task group ($p < .01$; see Figure 20).

For the evaluation of negativity, the ANOVA was conducted with Group (control, executive function task, non-executive function task) as a between-participants factor and Prime (negative, neutral) as a repeated measure. A significant interaction between Group and Prime was shown for the negativity of target stimuli [$F(2, 57)=8.74$, $p < .01$,

η^2= .24]. The negative prime was significantly higher than the neutral primes in the control group (p< .01), but not in the executive and non-executive function task groups. There was no significant interaction (F(2, 57)=2.85, *n.s.*, η^2=0.18) and main effects (Prime: F(1, 57)=1.68, *n.s.*, η^2=.15, Group: F(2, 57)=2.12, *n.s.*, η^2=0.19) for the negativity of their feelings (see Figures 21 & 22).

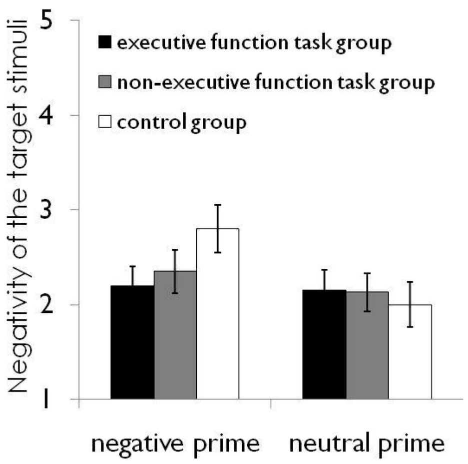

Figure 21. Evaluation score of the negativity of the target stimuli for group by prime. Error bars indicate standard deviations.

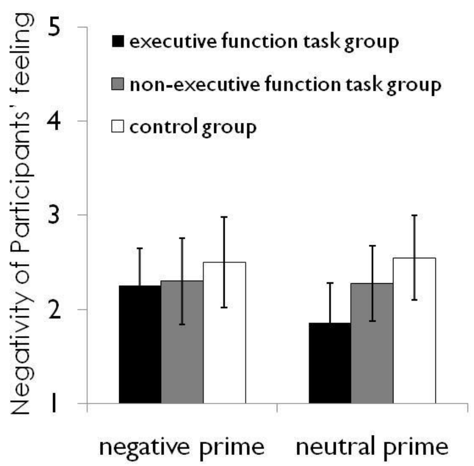

Figure 22. Evaluation score of participants' feelings for group by prime. Error bars indicate standard deviations.

To assess phasic HR response, the ANOVA was conducted with Time (-1--0.5 sec, -0.5-0 sec, 0-0.5 sec, 0.5-1 sec, 1-1.5 sec, 1.5-2.0 sec, 2.0-2.5 sec, 2.5-3.0 sec) as a repeated measure, Group (control, executive function task, non-executive function task) as a between-participants factor, and Prime (negative, neutral) as a repeated measure. A significant second-order interaction among Time, Group, and Prime stimuli was shown [F(14, 399)=3.93, p< .01, η^2= .24]. In the negative prime condition, in the control and non-executive function task groups, after 0.5 sec, heart rate was maintained at a significantly higher level until 3.0 sec, compared with that of 0-0.5 sec (p< .05). In the neutral prime condition, in the non-executive function task group, after 0.5 sec, HR was maintained at a significantly higher level until 2.0 sec, compared with that of 0-0.5 sec (p< .05). In the executive function task group, there was no significant difference among time points in both prime conditions. Significant differences between the negative and neutral primes were seen at the 1.0-2.0 sec period in the control group ($p< .05$). The HR in the negative prime condition showed significantly higher level than that in the neutral prime condition. Significant differences between the control and executive function task groups were shown after 0.5 sec in the negative prime condition ($p< .05$). Control group showed higher HR than executive function task group in the negative prime condition. A significant difference between the executive function task group and the non-executive function task group was shown at the 1.0-1.5 sec point in the negative prime condition ($p< .05$). Non-executive function task group showed higher HR than executive function task group in the negative prime condition. There was no significant difference between the non-executive function task group and the control group (see Figure 23).

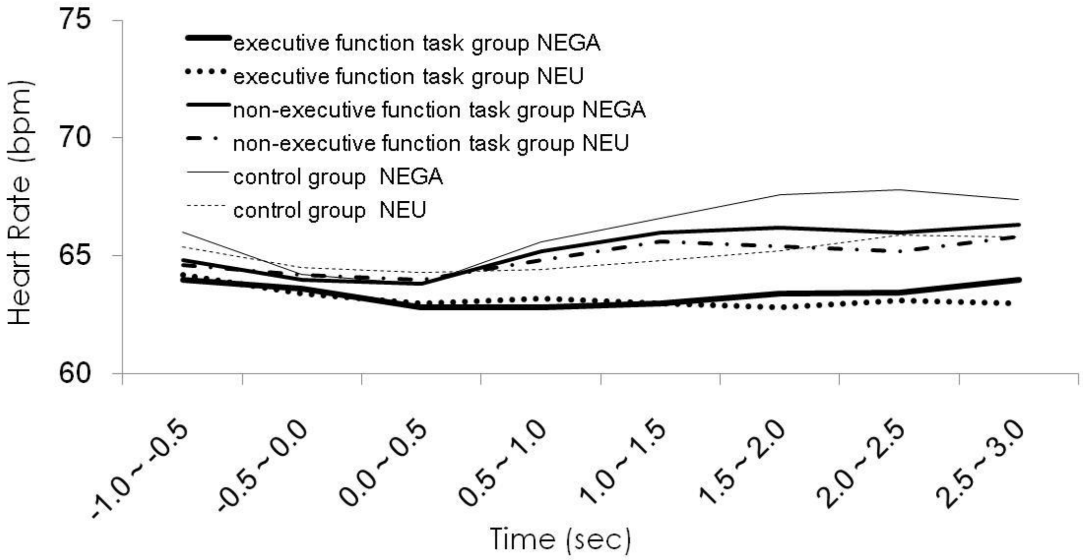

Figure 23. Temporal sequence of heart rate after the prime stimulus

To examine the differences of the emotional responses to the prime stimuli, the ANOVA was conducted with Group (control, executive function task, non-executive function task) as a between-participants factor and Prime (negative, neutral) as a repeated measure. A significant interaction between Group and Prime was shown [$F(2, 57)=11.28$, $p< .01$, $\eta^2= .26$]. The negative prime condition in the executive function task group was significantly lower than that in the other groups ($p < .05$). In the executive function task group, the negative prime condition showed significantly lower than the neutral prime condition ($p < .01$). On the contrary, in the control group, the negative prime condition showed significantly higher than the neutral prime ($p < .05$). However, in the non-executive function task group, there was no significant difference between the negative prime condition and the neutral prime condition (see Figure 24).

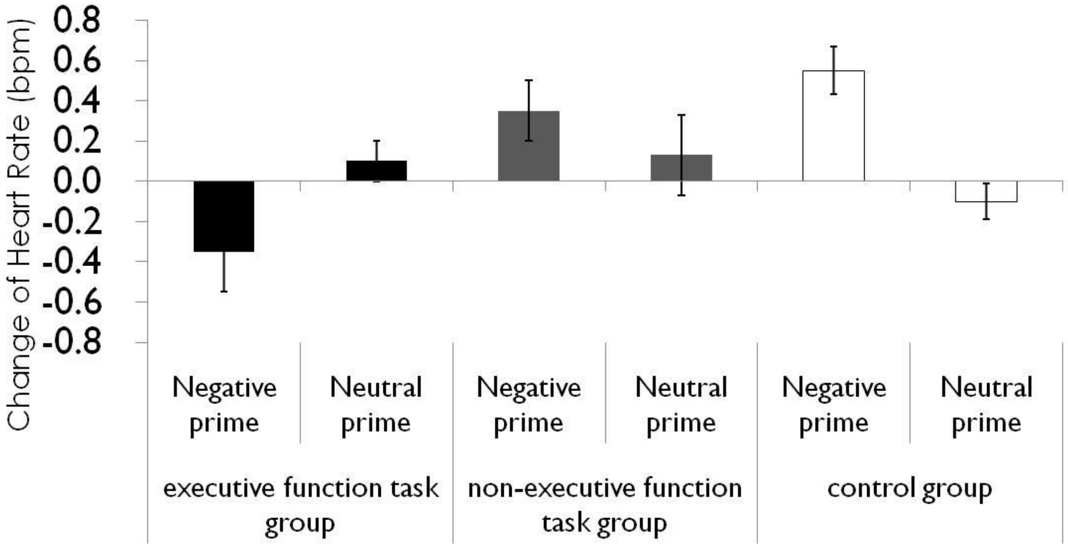

Figure 24. Change of heart rate after the prime stimulus by Prime and Group. Error bars indicate standard deviation

<u>Discussion</u>

In the control group, subliminal presentation of a negative affective picture (prime) shifted subsequent affective evaluation of a novel and neutral figure (target) to the direction that is affectively congruent with the prime stimulus. This result was consistent with previous studies (e.g., Payne et al., 2005) and confirmed the validity of the experimental paradigm in this study. On the other hand, in the executive function task group, as expected, subliminal presentation of a negative affective picture did not shift the affective evaluation of a target. This result supported the idea that the prior performance of an executive function task could inhibit the subliminal affective priming effect. In addition, participants in the executive function task group reported significantly lower negative affects after the emotional task than the control and non-executive function task groups. Furthermore, the executive function task group showed significantly reduced responses in phasic HR than the control and non-executive function task groups, whereas there was no significant difference in phasic HR responses between the control and non-executive function task groups. These results suggested that prior executive function activity attenuated physiological responses to subsequently presented emotional stimuli. These self-report and HR results successfully replicated the findings of the first part of this study and Experiment 5, and expanded them by showing that attenuation of emotional responses can occur even when emotional stimuli were presented subliminally. Taken together, the present study provides further evidence that executive function activity is an important factor in the implicit attenuation of subsequent emotions. Most importantly, going beyond previous studies, Experiment 6 showed that executive function activity can affect the bottom-up appraisal of emotional stimuli.

We should see differences in effects of the executive function task and the non-executive function (hand grip) task on the emotional task. While the non-executive function task did not affect subjective, affective states and HR responses to the emotional task, it did reduce the subliminal affective priming effect in the evaluation of target stimuli, as did the executive function task. To understand this result, it might be helpful to recognize that the subliminal affective priming effect has been thought to consist of two automatic processes: emotion elicitation and misattribution (e.g., Zajonc, 1980). That is to say, if there is interference in either process the subliminal affective priming effect is diminished. In the executive function task group, the automatic emotion elicitation was possibly attenuated as described above. On the other hand, as the non-executive function task showed similar subjective, affective states and HR responses in the emotional task as the control group, it can be considered that emotion elicitation was not interfered. Thus, the lack of the affective priming effect of the non-executive function task group should be attributed to interference in the process of misattribution. One possible explanation for this might be that engagement in the non-executive function task elicited motivation towards self-control, which was carried over into the subsequent emotional task. One of the ingredients of self-control is motivation to achieve a goal or to meet a standard (Baumeister & Vohs, 2007). Some previous studies have shown that this motivation could be carried over into a subsequent self-control task and could improve task performance in a subsequent task (e.g., Martijn et al., 2007). Indeed, the hand grip task that we used as a non-executive function task in this study has been thought of as a typical task requiring self-control (e.g. Muraven, Tice, & Baumeister, 1998). In the affective priming task, we asked participants to evaluate the negativity of target stimuli. As all target stimuli were emotionally neutral, if the motivated participants tried to engage in this task, the affective influence could be canceled, and the affective priming effect could be diminished. Since emotion elicitation is a fully automatic process, participants could not attenuate these emotional responses even with enhanced self-control motivation.

Conclusion

The second part of this study was designed to clarify the way that prior activation of executive function attenuates subsequent emotion. Experiment 5 revealed that engagement in an executive function task can only attenuate subsequent emotion. That is to say the activation of executive function can help down-regulation of emotion, but it cannot help up-regulation. This result showed that the prior activation of executive function in this study did not directly enhance the performance of subsequent goal-oriented behavior, including emotion regulation. Experiment 6 focused on the bottom-up process and was conducted to investigate whether the prior performance of an executive function task could affect subsequent bottom-up processing of emotion. As results, the activation of executive function can affect the bottom-up control of emotion. That is to say the previous executive function task was thought to modulate the way participants processed subsequent stimuli, such that a negative mood inducing stimulus never elicited an emotional response in the first place.

Chapter 4

General Discussion

1. Summary

The present study sought to examine the effects of prior activation of executive function on emotion regulation, focusing on the common neural network underlying various emotion regulation strategies. The first part of this study comprised four experiments to investigating whether activation of executive function is an important component in attenuation of emotional responses. Experiment 1 revealed that engagement in an executive function task can implicitly attenuate subsequent emotion. Experiment 2 revealed as expected that the prior executive function task performance enhanced executive function and that this activated executive function affected the subsequent task performance. These results supported a notion that activated executive function implicitly attenuates subsequent emotional responses. To exclude other explanations for this phenomenon, Experiment 3 examined whether the lack of resources following a prior executive function task caused attenuation of subsequent emotion. Although the executive function task group showed results similar to those in Experiment 1, the non-executive function task group did not. This finding indicated that activation of executive function is a critical factor in the implicit attenuation of subsequent emotion. Finally, Experiment 4 tested this notion with ERPs. This experiment was conducted to examine whether this implicit attenuation was correlated with changes in brain activity. The activation of executive function is intimately related to PFC activity. As expected, a significant difference was found between the executive function task group and the control group. Taken together, the results from the first part of this study supported the notion that the activation of executive function is an important component in the attenuation of emotional responses.

The second part of this study comprised two experiments clarifying how the activation of executive function attenuates subsequent emotional responses. Referring to the cascade-of-control model of executive function in the frontal cortex, two possible pathways for the activation of executive function to effect subsequent emotional processing were suggested. One is that enhancement of executive function mainly helps sensory control only. The other is that enhancement of executive function helps both sensory and contextual controls. Two experiments were conducted to examine which is the more plausible path underlying this attenuation of emotion by activation of executive function. First, Experiment 5 sought to test whether a prior executive function task performance modulates both up- and down- regulation. If contextual control is also enhanced by activation of executive function, the prior activation of executive function should enhance not only down-regulation but also up-regulation. However, this experiment established that executive function task performance can affect only the inhibitory aspects of subsequent emotion processing. Next, Experiment 6 sought to examine whether prior activation of executive function correlated with sensory control. In other words, this experiment was conducted to investigate whether prior activation of executive function modulates bottom-up processes of emotion. It was found that the activation of executive function can affect the bottom-up processes of emotion. That is to say a previous executive function task was thought to modulate the way participants process subsequent stimuli. Taken together, the two experiments supported the notion that the enhancement of executive function mainly helps the sensory control of emotions only.

1.1 Implicit attenuation of emotion by activation of executive function

From a psychological view, a previous executive function task was thought to modulate the way participants perceive emotional stimuli, such that negative stimuli never elicit an emotional response. To support this notion, Wadlinger and Isaacowitz

(2011) showed that prior executive function activity can modulate attention deployment to subsequent emotional stimuli, or broaden attentional capacity, as applied in various attentional training programs (e.g., See, MacLeod & Bridle, 2009; Sohlberg & Mateer, 1987). In line with this suggestion, Friese et al. (2010) reported pertinent findings about gaze behaviors. They hypothesized that working memory capacity might be crucial for counteracting the bottom-up orienting and maintenance mechanisms triggered by automatic affect. In line with their predictions, automatic emotion influenced only the gaze behavior of those low in working memory capacity. That is to say high working memory capacity reduced the attentional bias, specifically the automatic orientation and fixation of attention to the emotional stimuli. In support of this notion, in the present study, the phasic HR in Experiment 4 showed significantly lower deceleration in the executive function task group compared with the control group. In general, a triphasic pattern of HR responses to novel stimuli including emotional stimuli is observed, that is the initial deceleration, then acceleration followed by the second deceleration (Graham, 1992; Cook and Turpin, 1997; Lang et al., 1998). For the deceleration, Murakami et al. (2010) showed that highly anxious individuals tended to show greater HR deceleration in response to unpleasant stimuli, possibly reflecting maladaptive attentional bias for threat stimuli. Results from the present study suggested that the activation of executive function might enhance one's ability for attentional control and inhibit the influence of automatic emotion on attention deployment, especially attentional fixation on emotional stimuli.

From a neuro-scientific view, several recent studies have found the increased, prefrontal and parietal brain activity following a single session of cognitive training (Olesen, Westerberg & Klingberg, 2004; Browning et al., 2010). Moreover, it has been shown the potential involvement of the OFC, especially lateral and medial portions, and lateral and ventromedial portions of the PFC, and the basal ganglia in implicit emotion regulation. As Mauss, Bunge and Gross (2007) reviewed, these regions have been implicated in emotion regulation, cognition–emotion interactions, top-down direction of attention in response to negative emotional stimuli, and encoding of affective expectations in relation to conditioned stimuli (Beer et al., 2003; Davidson, 2002; Elliott, Dolan & Frith, 2000; Gottfried, O'Doherty & Dolan, 2003; Hamann et al., 2002; Lieberman, 2000; Rolls, 2000). These results support the possibility that the recruitment of executive function plays an important role in the attenuation of emotion. From study 2, the prior activation of executive function affected only down-regulation of emotion at a very early stage. According to Ochsner and Gross (2007), bottom-up systems of emotion regulation are located in subcortical areas. The top-down processes are conceptualized to regulate emotions by relying on higher cognitive processes associated with regions of the PFC, and attentional areas in the ACC (e.g. Ochsner et al., 2004; Phan et al., 2004). These processes are not deemed independently. The present study suggested that following activation of executive function, top-down systems of emotion regulation can be employed to attenuate emotion without high cognitive processing, similar to the way bottom-up systems of emotion regulation operate. This attenuation of emotion by activation of executive function should be supported by the sequential interaction of these two systems.

Referring to the cascade-of-control model of executive function in the frontal cortex, I suggested a possible model of the role of prior executive function task performance in emotion regulation. An important part of this model is that what executive control gets engaged depends on how effectively control is applied at earlier stages. Specifically, how much the ACC activation involves in control depends on how well the DLPFC imposes control. In other words, the ACC is involved in response evaluation. If such an evaluation suggests that an incorrect response was made, the ACC sends a signal back to the DLPFC, telling it to assert top-down control. In accordance with this model, the proposed model in this study sets two possible paths for the role of executive function. One is that enhancement of executive function mainly helps the sensory control with the DLPFC only. The other is that the enhancement of executive function helps both sensory and contextual control with the DLPFC and ACC. The results in the present study supported the former pathway (see Figure 25).

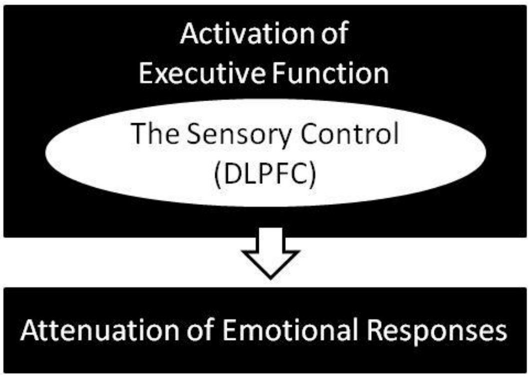

Figure 25. Interpretive model of implicit attenuation of emotion by executive function. Underlying basis of attenuation of emotion by activated executive function might be the DLPFC activation, and the activation of executive function mainly improves sensory control of emotional stimuli.

Considering the findings of animal studies, it is not surprising that the activation of executive function implicitly attenuates emotional responses, and the way it attenuates emotional responses is automatic regardless of the context. As Phelps et al. (2004) reviewed, voluntary emotion regulation, which is thought to be unique to humans and seems to depend on regions of the PFC that differ in humans, might inhibit emotional responses by co-opting the mechanisms of fear extinction that are similar across species. While the PFC region is often associated with higher cognitive processes or top-down processes (e.g. Ochsner et al., 2004; Phan et al., 2004), this notion is supported by evidence that was examined in the opposite direction. That is, when people engaged in some high level cognitive activity, PFC activity was often observed. Therefore, like the observations of the present study, when the activation of executive function is separated from any other cognitive effort, activation of executive function should solely automatically affect some linked brain regions. It is no wonder that like other animals, the neural connections that lead the diminishment of emotional responses in human have some priority over other neural connections. However, at present, this suggestion is just a speculation that requires further investigation.

1.2 Where from here?

This study successfully showed implicit attenuation of emotion by engagement in an executive function task. If there were no evidences with neuroscience, this study should be never attempted. However, this study goes beyond the mere confirmation of prior speculation in neuroscience. This is the first step to examine the neural activity dynamically.

In the psychological studies, many models have been suggested. For the emotion regulation, there are some models not only the most famous Gross's process model (e.g., Fredrickson, 1998; Frijda, 1986; Roseman, 2001). These models help understand emotion regulation dynamically. However, in the psychological studies, it is hard to overcome and rebuild the framework which we have acquired in daily life to understand emotion regulation. On the contrary, the studies in neuroscience are not good at integrating their knowledge into a dynamical model without some speculations now. However, they have shown some unexpected coincidence and given us some chances to break the barrier of the common sense or belief. They become help to get closer to the truth.

The prior studies about emotion regulation in neuroscience have focused on and accumulated a large amount of knowledge about which regions in the brain were activated during emotion regulation. For example, when an emotion was elicited, activation of the limbic area, especially the amygdala was observed. When the emotion was regulated, both decrease in the amygdala activity and increase in the PFC activity were observed. Therefore, prior studies suggested one possible explanation that an interaction between the PFC and amygdala has a key role for emotion regulation. Anatomical studies and animal studies supported this possible explanation certainly. This study also provided additional supportive evidence for this notion. However, to clarify the mechanism of emotion regulation, there still remain some questions. First of all, it is still unclear that relationship between emotion and emotion regulation. Next, it is also still unclear that the relationship between the emotion regulation and executive behaviors. More specifically, we do not know how the interaction between the amygdala and the PFC is regulated.

To answer these questions, this study suggested that it seems necessary to broaden the scope to include prior activation and set an adjustment process to think of emotion regulation more dynamically (see Figure 26). By shedding light on the adjustment process, we can focus on the transition phase. The transition phase has been paid less attention. However, this phase might have important hints, which until very recently

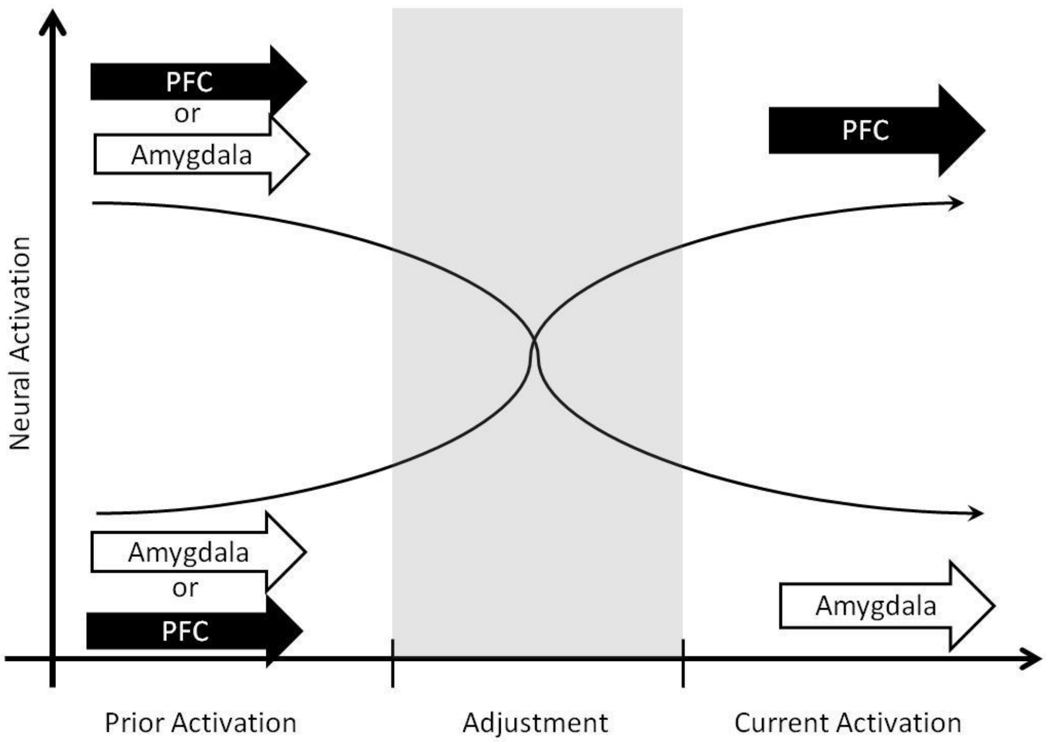

Figure 26. Neural activation model of emotion regulation. This model sought to explain the time-oriented interaction between the amygdala and the PFC. As many prior studies showed, this interaction results in the decrease of the amygdala activity and the increase of the PFC activity. However, before this interaction leads up to this result, there should be two possible paths. One is the most common path that prior activation of amygdala was observed. The other is the path that the present study examined, that prior activation of PFC was observed.

have overlooked. For example, it might help us understand how we prepare for emotion regulation, and what the necessary and sufficient condition of emotion regulation is. If these points become clearer, we can improve our understanding of emotion regulation in a broader context. Moreover, we can suggest some effective strategy to regulate our emotion successfully.

1.3 Future tasks

First of all, the neural bases of implicit attenuation of emotion, which was observed in this study have to be examined. The notion that the interaction between the amygdale and the PFC might have a key role for this implicit attenuation is just a speculation. Next, it should be clarified that how the prior executive function task attenuates subsequent emotional responses. Fortunately, this study showed that the executive function task performance can affect emotional responses even after the executive function task was completed. That is, we can examine this implicit attenuation with time-oriented data, including the adjustment process. From this examination, it would become clear that what the prior executive function task performance leads in the neural, behavioral, and cognitive levels for the subsequent emotion regulation. Finally, we might have to understand what prior executive function task performance leads in a broader context, overcoming the framework of “the activation of executive function.”

2. Implications

Emotion generating system

In the studies of emotion generating systems to date, neuroscientists have focused primarily on the bottom-up processes involved in simple forms of affective perception, learning, and memory (LeDoux, 2000; Phelps, 2006). In doing so, they have successfully identified brain systems—such as the amygdala—involved in the learning and bottom-up triggering of emotion in various species. On the other hand, they have paid less attention to cognitive processes involved in top-down emotion generation (Wager et al., 2008). However, recent neuroimaging studies have begun to examine top-down processes (e.g., Phelps et al., 2001; Teasdale et al., 1999). As Ochsner et al. (2009) showed, top-down emotion generation activates left prefrontal, cingulate, and temporal regions (Badre & Wagner, 2007), as well as the left amygdala and a dorsal medial PFC region involved in making attributions about mental—and especially emotional—states (Lane & McRae, 2004; Ochsner et al., 2004). Working together, these systems may support cognitive appraisals that generate emotions from the top down. Considering of that almost the same regions are involved in both emotion generation and emotion attenuation without intention, emotion regulation is so tightly intertwined with emotion generation that some theorists view emotion regulation as part and parcel of emotion (Campos, Frankel, & Camras, 2004; Frijda, 1986). To improve our understanding of what the emotion is, an integrative model of the emotion system was needed in the near future.

Emotion Regulation Strategies

The present study revealed a new strategy for the implicit regulation of emotion, involving engagement in an executive function task before the unpleasant emotion is elicited. In addition, the attenuation of unpleasant emotion requires only the activation of executive function, and is independent of the nature of the executive function task and how the participant engages in the task. This new strategy is simple enough to also be used for anticipatory emotion regulation, or training of the ability to regulate emotion. It was recently reported that executive function can be trained by engaging in specific kinds of executive function tasks (e.g., Fisher & Happé, 2005; Olesen, Westerberg & Klingberg, 2004). If executive function is a critical factor in emotion regulation, the routine application of this novel strategy may be used to strengthen executive function and the ability to regulate emotion. Some might fear that if the people boost the capacity for emotion regulation, this boosted capacity will inevitably narrow their emotional experience. However, research suggests just the opposite. Drawing from Chinese poetics and Confucian philosophy, Frijda and Sundararajan (2007) described how emotional restraint contributes to a deeper and more differentiated appreciation of one's emotions. In line with this, empirical evidence indicates that individuals with high emotion regulation competencies are characterized by greater self-reflexivity and a more profound awareness of their emotions (Barrett et al., 2001; Brown, Ryan, & Creswell, 2007). People's emotional lives are thus likely to become enriched as people learn new and more powerful ways of regulating their emotions.

Clinical Applications

The great importance of executive function in much of human life has motivated researchers to design methods for improving executive function. In recent work, this attempt was applied to intervention. For example, Klingberg and colleagues (Klingberg, Forssberg & Westerberg, 2002; Klingberg et al., 2005) showed that children with ADHD can improve working memory, inhibitory control and reasoning ability by intense working memory training. Two other training studies of school-aged children with ADHD (Kerns, Eso & Thomson, 1999; Shalev, Yehoshua & Mevorach, 2007) investigated the effects of attentional training. The findings in the present study suggested that this training might also be able to improve emotion regulation ability. Impairment in the expression and recognition of emotion is among the more prominent clinical features of the social deficit of autism (Kanner, 1943). People with autism generally have some difficulty in understanding what the emotion is, and how they can regulate it (e.g., Baron-Cohen, 1991). Unusual or inappropriate emotional reactions are frequently observed in people with autism, as are apparent failures to react appropriately to the emotions of others or even themselves. These findings in the present study might be instrumental in developing some emotion regulation training method to them.

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Appendix

The National Aeronautics and Space Administration (NASA) Task Load Index

Name	Task	Date

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low Very High

Reference: http://humansystems.arc.nasa.gov/groups/TLX/

Instructions for each subscale of NASA-TLX in Japanese (Miyake & Kumashiro, 1993)

付表１　NASA-TLX 評定尺度の定義．Hart and Staveland[8] の Figure 8(p. 169) を翻訳

項　目	端　点	説　明
精神的要求	低い/高い	どの程度、精神的かつ知覚的活動が要求されましたか？（例．思考、意思決定、計算、記憶、観察，検索など）　作業は容易でしたか、それとも困難でしたか．単純でしたか、それとも複雑でしたか．苛酷でしたか，それとも寛大でしたか．
身体的要求	低い/高い	どの程度、身体的活動が必要でしたか？(例．押す、引く，回す，操作，活動するなど）　作業は容易でしたか，それとも困難でしたか．ゆっくりしていましたか，それともきびきびしていましたか．ゆるやかでしたか、それとも努力を要するものでしたか．落ち着いたものでしたか，それとも骨の折れるものでしたか．
時間的圧迫感	低い/高い	作業や要素作業の頻度や速さにどの程度、時間的圧迫感を感じましたか？　作業ペースはゆっくりしていて暇でしたか，それとも急速でたいへんでしたか．
作業達成度	良い/悪い	実験者（あるいは，あなた自身）によって設定された作業の達成目標の遂行について，どの程度成功したと思いますか？　この目標達成における作業成績にどのくらい満足していますか？
努　力	低い/高い	あなたの作業達成レベルに到達するのにどのくらい一所懸命（精神的および身体的に）作業を行わなければなりませんでしたか？
不　満	低い/高い	作業中，どのくらい不安，落胆，いらいら、ストレス，不快感，あるいは安心，喜び，満足，リラックス，自己満足を感じましたか？

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