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Research report

Contribution of fronto-striatal regions to emotional valence and repetition under cognitive conflict

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ABSTRACT

Conflict processing mediated by fronto-striatal regions may be influenced by emotional properties of stimuli. This study aimed to examine the effects of emotion repetition on cognitive control in a conflict-provoking situation. Twenty-one healthy subjects were scanned using functional magnetic resonance imaging while performing a sequential cognitive conflict task composed of emotional stimuli. The regional effects were analyzed according to the repetition or non-repetition of cognitive congruency and emotional valence between the preceding and current trials. Post-incongruence interference in error rate and reaction time was significantly smaller than post-congruence interference, particularly under repeated positive and non-repeated positive, respectively, and post-incongruence interference, compared to post-congruence interference, increased activity in the ACC, DLPFC, and striatum. ACC and DLPFC activities were significantly correlated with error rate or reaction time in some conditions, and fronto-striatal connections were related to the conflict processing heightened by negative emotion. These findings suggest that the repetition of emotional stimuli adaptively regulates cognitive control and the fronto-striatal circuit may engage in the conflict adaptation process induced by emotion repetition. Both repetition enhancement and repetition suppression of prefrontal activity may underlie the relationship between emotion and conflict adaptation.

1. Introduction

Cognitive control, including conflict processing, is an important issue in the fields of cognitive neuroscience and cognitive psychology. Conflict processing which involves overcoming conflict and performing effectively (Kerns et al., 2004) has been investigated using the Stroop task, Simon task, and flanker task. In particular, the Simon task has been used to account for resolving response conflict using the sequential effect. There have been debates over the underlying process of cognitive control. One explanation is that conflict monitoring systems, which evaluate the current level of conflict, pass this information on to the cognitive control centers and adjust the strength of their influence on conflict processing (Botvinick et al., 2001). Another explanation is the feature integration viewpoint, which takes into account the binding and unbinding of stimuli and responses (Hommel et al., 2004). In this view, the sequential effect includes complete consistency, partial consistency, or complete inconsistency of stimuli and responses between preceding and current trials.

Fronto-striatal regions, including the anterior cingulate cortex (ACC), medial prefrontal cortex (MPFC), dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), and striatum, are considered to be essential for recruiting cognitive control and responding correctly in conflict trials (Botvinick et al., 1999; Kerns et al., 2004). Further, top-down control of the orbitofrontal cortex over the ventral striatum is an important component in decision making during uncertain conditions (Jung et al., 2010). In particular, ACC activation has been observed in cognitive control using various conflict-provoking tasks, such as the Simon task, flanker task, global-local paradigm, go/no-go paradigm, and other response override tasks (Botvinick et al., 2001, 2004). The ACC significantly contributes to executive functions through the detection of conflict occurring at response-related levels of processing (van Veen et al., 2001) and conflicts between plans of action (Botvinick et al., 2001). The PFC, including the MPFC, DLPFC, and VLPFC, is also involved in effective integration of information for complex behaviors (Miller, 2000), maintaining flexible cognitive

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state for task-dependent decision making (Stokes et al., 2013), and modulation of behavior adjustment (Ridderinkhof et al., 2004) through top-down influence on a variety of interconnected neocortical regions. In particular, the VLPFC engages in the cognitive evaluation of the emotional discrimination of ambivalent stimuli (Jung et al., 2008).

In terms of inter-regional relationships, conflict-related ACC activity may induce changes in prefrontal activity and behavioral adjustments. For example, increased ACC activity resulting from incongruence with preceding trials is associated with increased DLPFC activity through incongruence and decreased reaction time in the current trial (Kerns, 2006). In addition, fronto-striatal activations depend on a trial sequence or repetition of stimulus alternation (Botvinick et al., 1999; Ullsperger et al., 2005). Repeated exposure to stimuli leads to increased behavioral performance and this adaptation effect by repetition has been associated with repetition suppression in neural activity (Grill-Spector et al., 2006). For some cognitive variables, however, repetition effects may be related to neural responses towards enhancement instead of suppression (Segaert et al., 2013). In a previous study using the faces, repeated exposure to stimuli had an influence on neural activity in regions related to novelty detection and memory processing (Fischer et al., 2003).

Emotion interacts with executive functions responsible for dynamic behavioral adaptation (Padmala et al., 2011). In terms of conflict regulation, emotional processing includes a modulation through conscious application of top-down executive control and implicit modulation for processing of an emotional stimulus (Etkin et al., 2011). The affective quality of an event may provide important information about the amount and type of executive control needed to make sure that goals are reached as planned (van Steenbergen et al., 2009). Conversely, cognitive control strategies such as emotional reappraisal allow us to alter the strength and duration of emotions (Ochsner et al., 2012). In fact, a few studies have reported on the effects of emotion on cognitive control. For example, negative events can lead to a conflict response because of aversive stimuli (Dreisbach and Fischer, 2012a), whereas conflict-triggered adjustment of cognitive control is reduced by positive affect as a subjective experience and strengthened by reward as a motivational manipulation (Dreisbach and Fischer, 2012b).

The influence of emotional processing on cognitive control-related brain activity has also been studied. Negative emotions, compared to neutral and positive emotions, lead to less activation of the dorsal ACC (BA 24) and PFC (BA 9, BA 10) in interference processing (Sommer et al., 2008). In addition, emotional conflict is resolved through top-down inhibition of amygdala activity by the rostral ACC (Etkin et al., 2006). Meanwhile, the striatum is likely to interact with the ACC in cognitive processing for affective stimuli (Shackman et al., 2011; van Steenbergen et al., 2015). The integrated coding of cognitive and affective processing may moderate connections between the ACC and striatum (van Steenbergen et al., 2015). Therefore, functional connectivity between ACC and striatum may have an influence on behavioral adjustment under an affective state. In previous studies, however, emotional stimuli were used only as a conflict-provoking factor. Given that the sequential effect of congruence and incongruence may be an important factor in cognitive control, repetition and non-repetition of emotional properties would also be expected to influence cognitive control, but such sequential effects in terms of emotional consistency have not yet been studied. This effect may be important in the interaction between cognitive and emotional processing, resulting in adaptation to the environment and development of an executive strategy.

In order to examine the effects of emotion repetition on cognitive control in a conflict-provoking situation with sequentially presented stimuli, we designed an event-related fMRI study using a cognitive conflict task composed of emotional stimuli. The major objective of this study was to investigate an association between neural activity and behavioral responses and explain that an emotional context interacts with cognitive conflict processing. In this study, cognitive interference and emotion repetition were focused on the conflict adaptation effect by the repetition or non-repetition of congruency between the stimulus location and pressing hand, and prefrontal cortices were considered to be the *a priori* regions related to cognitive control. Our hypotheses on the processing of repetitive interfering emotional stimuli were (1) that current incongruence would lead to increased prefrontal activity compared to current congruence, and further post-incongruence interference would also lead to increased prefrontal activity compared to post-congruence interference, (2) positive emotion should lead to increased conflict adaptation effect compared to negative emotion, and (3) fronto-striatal functional connectivity would mediate the emotion-related conflict adaptation effect.

2. Results

2.1. Behavioral results

Behavioral results are shown in Table 1. Repeated measures ANOVA revealed no significant main effects or interactions in terms of error rate. Post-congruence interference (cI-cC) showed a difference among the emotional conditions: significantly larger under repeated positive (pP) than under non-repeated positive (nP) ($t_{20} = 2.36$, $p = 0.029$). Post-incongruence interference (iI-iC) and interference adaptation effect ([cI-cC]-[iI-iC]) were not significantly different among the emotional conditions. In addition, post-incongruence interference was significantly smaller only under repeated positive than post-congruence interference ($t_{20} = -2.61$, $p = 0.017$).

For reaction time, no main effects in congruency were observed, whereas there was a marginal trend toward a main effect of current emotion ($F_{1,20} = 4.10$, $p = 0.056$, $Eta^2 = 0.17$) and significant main effect of preceding emotion ($F_{1,20} = 38.57$, $p = 0.0001$, $Eta^2 = 0.66$). Significant interaction was observed between the current and preceding congruency types ($F_{1,20} = 10.78$, $p = 0.004$, $Eta^2 = 0.35$), but not between the current and preceding emotion types. As shown in Fig. 1, reaction time was significantly shorter for repeated congruence (cC) than for non-repeated congruence (iC) and non-repeated incongruence (cI) ($t_{20} = -2.28$, $p = 0.034$; $t_{21} = -2.13$, $p = 0.046$, respectively) and for repeated incongruence (iI) than for non-repeated incongruence (cI) ($t_{20} = -2.65$, $p = 0.015$). Repeated positive (pP) showed a significantly shorter reaction time than non-repeated negative (pN) ($t_{20} = -2.85$, $p = 0.01$), non-repeated positive (nP) ($t_{20} = -5.59$, $p = 0.0001$), and repeated negative (nN) ($t_{20} = -4.06$, $p = 0.001$), but a difference between non-repeated negative (pN) and repeated negative (nN) was not significant. Post-congruence interference (cI-cC), post-incongruence interference (iI-iC), and interference adaptation effect ([cI-cC]-[iI-iC]) showed no significant difference among the emotional conditions. Additionally, post-incongruence interference was significantly smaller than post-congruence interference, under non-repeated positive ($t_{20} = -2.89$, $p = 0.009$), and smaller at a marginal significance under non-repeated negative and repeated negative ($t_{20} = -1.94$, $p = 0.067$; $t_{20} = -2.05$, $p = 0.054$, respectively).

2.2. Imaging results

2.2.1. Cognitive interference-related activity

As shown in Table 2, there were no significant differences between the current congruence and incongruence trials and between the preceding congruence and incongruence trials.