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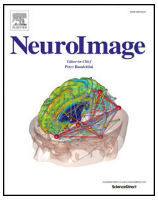

Q1 Alertness function of thalamus in conflict adaptation☆

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ABSTRACT

Conflict adaptation reflects the ability to improve current conflict resolution based on previously experienced conflict, which is crucial for our goal-directed behaviors. In recent years, the roles of alertness are attracting increasing attention when discussing the generation of conflict adaptation. However, due to the difficulty of manipulating alertness, very limited progress has been made in this line. Inspired by that color may affect alertness, we manipulated background color of experimental task and found that conflict adaptation significantly presented in gray and red backgrounds but did not in blue background. Furthermore, behavioral and functional magnetic resonance imaging results revealed that the modulation of color on conflict adaptation was implemented through changing alertness level. In particular, blue background eliminated conflict adaptation by damping the alertness regulating function of thalamus and the functional connectivity between thalamus and inferior frontal gyrus (IFG). In contrast, in gray and red backgrounds where alertness levels are typically high, the thalamus and the right IFG functioned normally and conflict adaptations were significant. Therefore, the alertness function of thalamus is determinant to conflict adaptation, and thalamus and rIFG are crucial nodes of the neural circuit subserving this ability. Present findings provide new insights into the neural mechanisms of conflict adaptation.

1. Introduction

Conflict adaptation manifests an improved conflict resolution driven by previously experienced conflict (Botvinick et al., 1999; Gratton et al., 1992), which subserves our goal-directed behaviors and therefore is crucial for success in work and everyday life. Specifically, individuals send conflict information detected on previous situation to the top-down control system, which subsequently bias the perceptual processing toward to task-relevant information and away from task-irrelevant information on current situation. A newly prominent model accounting for conflict adaptation, the Hebbian learning model (Verguts and Notebaert, 2009), suggests that the conflict monitoring system triggers an arousal response in a neuromodulatory system, which increases Hebbian learning acting on task-relevant representations and accordingly conflict control would be improved. The neuromodulatory system is mainly located in the subcortical areas (Hobson and Pace-Schott, 2002; Pace-Schott and Hobson, 2002; Pessoa, 2008); however, the activation in these areas is not typically reported in conflict adaptation fMRI (functional magnetic resonance imaging) studies (Verguts and Notebaert, 2009). In fact, knowledge of the mechanisms underlying conflict adaptation is still very limited.

A dominant viewpoint of the Hebbian learning model is that the arousal level modulates conflict adaptation. Usually, to obtain an optimal performance, individuals have to maintain a high arousal/alertness level in experimental conditions. Relationship between alertness and executive control has been detected in the literature (Weinbach and Henik, 2012), with one study suggested that response conflict could induce generalized alertness (Kahneman, 1973). A recent study reported that the alertness level correlated positively with the conflict adaptation effect (Liu et al., 2013). However, as alertness level was not effectively manipulated in previous studies, the critical hypothesis of Hebbian learning model could not be directly examined. Interestingly, color has been suggested to be able to modulate alertness level. As one kind of basic information input, color ubiquitously influences our cognition and behavior (Elliot et al., 2007, 2009; Green et al., 1982). It had been mentioned that red, relative to blue, induces primarily the avoidance motivation, which makes people more vigilant and risk-averse; while, differently from red, blue is often associated with openness, peace, and tranquility (Mehta and Zhu, 2009). Common sense, when individuals perform the task needed to keep more vigilant, they would be in high alertness level. Braun and Silver (1995) examined the effect of color on perceptions of hazard, which may support the hypothesis that the color may exert influence on the alertness level. In their experiment, participants assessed the perceived hazard of signal words printed in specific hazard colors. Results showed that red was linked to the highest level of perceived hazard, followed by orange, black, green and blue. Therefore, once the hypothesis is established, we can

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change the background color of current experiments to examine the influence of color on conflict adaptation.

Gray, blue and red were separately used as the screen background color in current study. Because background color is generally monochrome (i.e., gray, white or black) in previously related studies, the results in gray background can provide a comparison baseline. Blue and red are primary colors when examining the effect of color on cognition and behavior (Jalil et al., 2012). Moreover, they have been found to induce opposite associations: blue is often associated with openness, peace, and tranquility (NAz and Epps, 2004), which may decrease alertness level; in contrast, red is often associated with dangers and mistakes (Elliot et al., 2007), which may induce high alertness. If alertness modulates conflict adaptation, as predicted by the Hebbian learning model, it could be expected to observe distinct influences of blue and red on conflict adaptation.

In the present study, we first used an Attentional Networks Test (ANT) (Fan et al., 2002) to confirm the modulation of background color on alertness level (Experiment 1). The ANT is developed to measure the efficiency of the attentional networks, and it can provide scores for alerting, orienting and executive control (Fan et al., 2005; Petersen and Posner, 2012). In this experiment, we evaluated the alerting score differences across the gray, blue, and red backgrounds through the ANT. Based on Experiment 1, we then employed a letter Flanker task to investigate the color effect on conflict adaptation in Experiment 2. In this task, participants were required to respond to central letter while ignoring flanking letter that may suggest the same response as the target (congruent trial, C) or an opposite response to the target (incongruent trial, I) (Wang et al., 2014). Conflict adaptation is defined as the reduced conflict effect (I − C) following an incongruent trial relative to a congruent trial (Egner, 2007). And then we repeated and extended the investigation about conflict adaptation by combining behavioral and fMRI measurements (Experiment 3). Accordingly, we could obtain the influences of color on alertness and conflict adaptation on both behavioral and fMRI levels, which allows us to analyze whether those brain areas regulating alertness level are modulated by background colors during conflict adaptation, and how these areas interact with cognitive control network (Cole and Schneider, 2007; Power and Petersen, 2013). The event-related fMRI data allows us to address the neural mechanisms of how alertness modulates conflict adaptation. Especially, we will utilize the psychophysiological interaction (PPI) analysis (Friston et al., 1997) to examine the neural network underlying the modulation of color on conflict adaptation.

In general, neuroimaging studies have demonstrated that alertness is associated with the norepinephrine system, including the thalamus, prefrontal cortex and the parietal cortex (Marrocco and Davidson, 1998; Coull et al., 2000 范). The thalamic neurons could mediate the shift between alert and nonalert states (Cano et al., 2006), whilst the anterior and posterior cortical sites and the thalamic area consist of the alerting network (Fan et al., 2005). Meanwhile, conflict adaptation is subserved by a set of prefrontal and parietal regions, involving the anterior cingulate cortex, the prefrontal cortex, and the posterior parietal cortex (Wang et al., 2015; Egner et al., 2011; Kerns et al., 2004). Therefore, in the present study, we expected to observe the color modulated activation of the alertness-related regions, such as the thalamus. And we further hypothesized that the color effect on conflict adaptation is achieved by influencing the interaction between the altering and conflict control systems.

2. Materials and methods

2.1. Experiment 1: Behavioral modulation of color on alertness level

2.1.1. Subject

Forty-two (22 females) volunteers, between the age of 17 and 26 years (20 ± 4.76, mean ± SD), took part in Experiment 1. All participants were right-handed, had normal or corrected-to-normal vision, and normal color perception. Informed consent was acquired from each participant, and the study was approved by Southwest University Human Ethics Committee for the Human Research.

2.1.2. Stimuli and procedure

Participants performed a standard ANT task. Stimuli consisted of five horizontal arrows, with arrowheads pointing leftward or rightward within gray, blue, or red backgrounds. This central target arrowhead was flanked on either side by two arrows in congruent direction, or in incongruent direction, or by lines (neutral condition). The participants were inquired to identify the orientation of the target by pressing different keys. Participants viewed the stimuli from a distance of about 60 cm, and the visual angle of stimulus was 3.08°. The color of the computer screen was manipulated using RGB (red–green–blue) scheme (gray: $R = 128$, $G = 128$, $B = 128$; blue: $R = 0$, $G = 0$, $B = 255$; red: $R = 255$, $G = 0$, $B = 0$).

At the beginning of each trial, a fixation cross was presented for a random duration ranging between 400 and 1600 ms, followed by the appearance of a cue for 100 ms. There were four cue conditions: no cue, center cue, double cue, and spatial cue. In the no-cue condition, only the fixation cross was presented in the center of the screen for 100 ms. In the center-cue condition, an asterisk was presented in the center of the screen for 100 ms. In the last two conditions, the fixation cross was always presented in the center of the screen. In addition, in the double-cue condition, two asterisks were presented simultaneously at two possible target positions for 100 ms; in the spatial-cue condition, an asterisk was presented at the target position for 100 ms. After cue presentation, the fixation cross was again presented for 400 ms followed by the appearance of the target at a visual angle of 0.96° above or below the cross. Target location was always uncertain except on spatial-cue trials. Participants were instructed to focus on the centrally located fixation cross throughout the task.

Participants were instructed to respond as quickly and accurately as possible by pressing a key on the keyboard in correspondence to the target after the appearance of the target. Specifically, half of the participants were instructed to press F with the left index finger if the target oriented left and to press J with the right index finger if the target oriented right. The finger-to-key mapping was reversed in the remainder of the participants. Each participant firstly completed 24 full-feedback practice trials. There were three blocks in this experiment, each of which was randomly set as one of three background colors (gray, blue and red). Each block has 96 ANT trials (4 cue conditions × 2 target locations × 2 target directions × 3 flanker conditions × 2 repetitions).

2.2. Experiment 2: Behavioral modulation of color on conflict adaptation

In this experiment, we asked the participants to complete the letter flanker task under three background screen colors (gray, blue, and red). Because conflict adaptation effect can be analyzed based on the letter flanker task, this experiment allows us to explore the influence of background color on conflict adaptation effect.

2.2.1. Subject

Thirty-six (22 females) right-handed volunteers, between the age of 19 and 26 years (21 ± 1.72, mean ± *SD*), took part in Experiment 2. All participants were right-handed, had normal or corrected-to-normal vision, and normal color perception. Informed consent was acquired from each participant, and the study was approved by Southwest University Human Ethics Committee for the Human Research.

2.2.2. Stimuli and procedure

Stimuli were presented on a computer screen placed at a distance of about 60 cm from participants. The color of the computer screen was manipulated using RGB (red-green-blue) scheme (gray: $R = 128$, $G = 128$, $B = 128$; blue: $R = 0$, $G = 0$, $B = 255$; red: $R = 255$, $G = 0$, $B = 0$). The letter flanker task was employed by using four letters (S,

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