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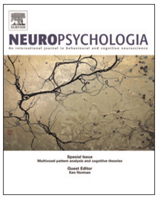

Functional connectivity patterns reflect individual differences in conflict adaptation

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ABSTRACT

Individuals differ in the ability to utilize previous conflict information to optimize current conflict resolution, which is termed the conflict adaptation effect. Previous studies have linked individual differences in conflict adaptation to distinct brain regions. However, the network-based neural mechanisms subserving the individual differences of the conflict adaptation effect have not been studied. The present study employed a psychophysiological interaction (PPI) analysis with a color-naming Stroop task to examine this issue. The main results were as follows: (1) the anterior cingulate cortex (ACC)-seeded PPI revealed the involvement of the salience network (SN) in conflict adaptation, while the posterior parietal cortex (PPC)-seeded PPI revealed the engagement of the central executive network (CEN). (2) Participants with high conflict adaptation effect showed higher intra-CEN connectivity and lower intra-SN connectivity; while those with low conflict adaptation effect showed higher intra-SN connectivity and lower intra-CEN connectivity. (3) The PPC-centered intra-CEN connectivity positively predicted the conflict adaptation effect; while the ACC-centered intra-SN connectivity had a negative correlation with this effect. In conclusion, our data demonstrated that conflict adaptation is likely supported by the CEN and the SN, providing a new perspective on studying individual differences in conflict adaptation on the basis of large-scale networks.

1. Introduction

Individuals differ in their ability to adjust ongoing behaviors to adapt to changes in the environment. In the laboratory, the dynamic adjustment of behavior is often captured by the 'conflict adaptation effect' in tasks with congruent and incongruent conditions. For instance, in the Stroop task (Stroop, 1935), participants are required to respond to the ink color of a printed color name while ignore the word's meaning that may either be congruent with the ink color (congruent trial, C; e.g., RED printed in red) or incongruent with the ink color (incongruent trial, I; e.g., RED printed in blue). Typically, the interference effect (I–C) is reduced after incongruent trials as compared to after congruent trials, which reflects the conflict-induced adjustment (Egner and Hirsch, 2005b; Gratton et al., 1992).

Although it has long been assumed that conflict adaptation is mediated by different brain areas (Botvinick et al., 2001; Egner et al., 2007), recent studies support the view that this effect might result from the dynamic interactions of distributed brain areas. In particular, the conflict monitoring model speculates that the anterior cingulate cortex (ACC) detects the occurrence of conflict and then conveys this information to the dorsolateral prefrontal cortex (DLPFC) to implement an optimal conflict resolution (Kerns et al., 2004; Matsumoto and Tanaka, 2004). However, direct functional integration between the ACC and DLPFC has not been examined yet. Using a variant of the Stroop task, Egner and Hirsch (2005a) observed the functional coupling between the DLPFC and the fusiform face area, demonstrating that cognitive control mechanisms resolve the conflict through cortical amplification of task-relevant information. Furthermore, one of our previous studies suggests that conflict adaptation is implemented by modulating the effective connectivity between parietal and right-frontal regions (Tang et al., 2013). This converging evidence implies that conflict adaptation is achieved through the network-based neural interactions.

Nevertheless, only a few studies to date have attempted to

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identify the neural mechanisms underlying individual differences in conflict adaptation. With the employment of resting-state functional magnetic resonance imaging (fMRI), Wang et al. (2014) observed a significant positive correlation between the conflict adaptation effect and the left dorsolateral prefrontal cortex (DLPFC) regional homogeneity (REHO) values, thus highlighting the crucial role of the DLPFC in conflict adaptation. On the other hand, Egner (2011) reported that individual differences in conflict adaptation might be mediated by the right ventrolateral prefrontal cortex (VLPFC). Still, no study has ever examined the network-based neural mechanisms of individual differences in conflict adaptation. Therefore, the present study aimed to unravel the brain networks subserving individual differences in conflict adaption.

In the present study, we employed an event-related fMRI design with the color-naming Stroop task. First, we examined regional activation during the processing of conflict adaptation in the whole subject group. Then we divided the subjects into two groups (high conflict adaptation effect (hereafter, high-score) group vs. low conflict adaptation effect (hereafter, low-score) group) based on the median value of behavioral scores and compared the between-group differences in functional connectivity patterns. The task-dependent functional connectivity in the present study was performed using the voxel-vise psychophysiological interaction (PPI) analysis (Egner and Hirsch, 2005b). PPI is a regression-based method for measuring functional connectivity that allows the detection of regionally specific responses in one brain area in response to inputs from another brain region (Friston et al., 1997). Since PPI provides a comprehensive characterization of task-dependent connectivity between brain regions, this approach offers novel insights into how separated regions dynamically change their connectivity in support of cognitive control.

We expected to observe the activation of several regions in the prefrontal and parietal lobes, such as the ACC, the DLPFC, the VLPFC, and the posterior parietal cortex (PPC) in response to conflict adaptation, all of which have been demonstrated to play important roles in the conflict adaptation process (Kerns et al., 2004; Mansouri et al., 2009; Soutschek et al., 2013). Furthermore, existing studies suggest that these regions could also be assigned into different control systems: one is to the proactive top-down control system, including the DLPFC (Braver et al., 2007) and the PPC (Yoon et al., 2008), and the other is to the reactive bottom-up control system, involving the ACC (Braver et al., 2009) and the insula (Menon and Uddin, 2010). The tradeoffs between proactive control and reactive control would determine the final performance. Therefore, conflict adaptation performance would result from the relative involvement of proactive control and reactive control. Accordingly, we expected that the high-score group would show higher engagement of the proactive control network and lower involvement of the reactive control network, while the low-score group would show higher engagement of the reactive control network and lower involvement of the proactive control network.

2. Materials and methods

2.1. Subjects

The experimental procedure was approved by the local ethics committee. Thirty-one university students (23 women and 8 men) from Southwest University, China, participated in the experiment for payment. The age of participants ranged from 18 to 24 years (20.77 ± 1.37). All participants were right-handed, native Chinese speakers, and had normal or corrected-to-normal vision, without achromatopsia or color blindness. Signed informed consent was obtained from each subject prior to the experiment.

2.2. Stimuli

Stimuli were standard Stroop color words, consisting of four Chinese characters “Hong” (red), “Huang” (yellow), “Lan” (blue) and “Lv” (green). Each character was presented in one of the four colors (i.e., red (255, 0, 0), yellow (255, 255, 0), green (0, 255, 0), blue (0, 0, 255); 16 stimuli altogether). The display background was always black. Each color corresponded to a response button, the mappings of which were counterbalanced across participants. For example, the participant was instructed to respond with the index finger of their left hand when the color of the word was green, the middle finger of their left hand when the color of the word was red, the index finger of their right hand when the color of the word was yellow, and the middle finger of their right hand when the color of the word was blue.

2.3. fMRI task

Participants performed the color-naming task during one fMRI session. There were a total of 212 trials across four runs. Each trial lasted for 3000 ms, starting with a 1500 ms central fixation cross, followed by a 1500 ms target display, during which participants were required to respond to the colors of the stimuli as fast and accurately as possible. The trials were sequenced in a pseudorandom way in order to result in an equal proportion of each type of stimulus. In addition, there was no direct feature integration (stimulus–stimulus repetition or stimulus–response repetition) (Mayr et al., 2003). Before participants performed the main experiment, they took part in a 40-trial task for practice.

In addition, we used an event-related design with a constant ITI. One may argue that a jittered ITI might be more optimal for an fMRI design, and there are studies using a jittered ITI in the field of conflict control (Egner and Hirsch, 2005a; Liston et al., 2006). The reasons that we did not choose a jittered ITI were as follows: the first one was that the magnitude of the conflict adaptation effect would be affected by increasing ITI (Peter, 2005); the second reason was that a jittered ITI is likely to interact with cognitive control processes in unknown ways (Kerns, 2006; Kerns et al., 2004). Thus, we chose the constant ITI in our design to ensure the purity of conflict adaptation effect.

2.4. fMRI image acquisition

Images were acquired with a Siemens Trio 3.0T scanner in the Laboratory of Cognition and Personality in Southwest University, China. Functional data were acquired in an interlaced way along the AC–PC line with a T2-weighted EPI sequence of 24 axial slices ($TR=1500$ ms, $TE=30$ ms, flip angle$=90°$, acquisition matrix$=64\times64$) of 5 mm thickness with 1 mm inter-slice gap. Within a session, a total of 644 EPI images were acquired. At the end of the experiment, a T1-weighted spin echo data set ($TR=1900$ ms, $TE=2.52$ ms, flip angle$=90°$, acquisition matrix$=256\times256$) was acquired.

2.5. Imaging data analysis

2.5.1. fMRI data preprocessing

All images were analyzed using SPM8 (the Wellcome Trust Centre for Neuroimaging, University College London, UK; http://www.fil.ion.ucl.ac.uk/spm/software/spm8/). The first five volumes of each run were excluded from the analysis to allow for signal stability following onset transients. Functional images were corrected for differences in slice-timing, realigned, and co-registered with the structural images. Then these images were normalized to