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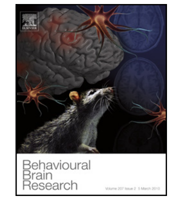

Research report

The relevance of fractional amplitude of low-frequency fluctuation to interference effect

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HIGHLIGHTS

- To examine the relationship between fALFF and behavioral interference effect.
- MSIT was used to measure the behavioral interference effect.
- fALFF was used as an indicator of intrinsic brain activity.
- fALFF in OPFC and right IFG were negatively related to the interference effect.

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ABSTRACT

Growing evidence has indicated a potential connection between resting-state functional magnetic resonance imaging (RS-fMRI) signal and cognitive performance. However, the relationship between intrinsic neural activity and behavioral interference effect on cognitive control has been poorly understood. In the present study, seventy-eight healthy subjects underwent RS-fMRI and performed Multi-Source Interference Task (MSIT). The fractional amplitude of low-frequency fluctuation (fALFF) was measured as an indicator of intrinsic brain activity. The difference in reaction times between interference and control conditions in MSIT was evaluated as interference effect. Then we examined the associations between fALFF and interference effect using partial correlation analysis controlling for age, gender and mean framewise displacement. The results demonstrated that fALFF values in orbital prefrontal cortex (OPFC) and right inferior frontal cortex (IFC) were negatively correlated with the interference effect in MSIT. The findings manifest that OPFC and right IFC may influence the processing efficiency of cognitive conflict and play a crucial role in cognitive control.

1. Introduction

In the era of information explosion, people are exposed to vast amount of relevant and irrelevant information. To enhance efficiency, it is crucial for people to effectively distinguish useful information from the rest. For example, if one desires to use the web to access the most efficacious information on one's research, special attention is demanded to disregard irrelevant information (such as latest breaking current news) from inconsequential websites and fully concentrate on the most relevant websites. Generally speaking, the ability to effectively eliminate interference from extraneous information and predominantly focus on the appropriate information could be extremely helpful in our daily life. To better explore the psychological processes for such phenomenon, interference resolution tasks on cognitive control are widely applied [1].

Among these interference resolution tasks, Multi-Source Interference Task (MSIT), which combined the Stroop, Simon and flanker effects, has been extensively studied. The initial studies on MSIT have showed that MSIT could robustly induce the activation in the cingulo-frontal-parietal network in both group and individual analyses [2,3]. The cingulo-frontal-parietal network (CFP network) encompasses dorsal anterior cingulate cortex (dACC), dorsolateral prefrontal cortex (dlPFC) and superior sections of parietal cortex. The activation of dACC ascribes to such relevant processes as the identification of the target, novelty or error, response choice, task difficulty, stimulus/response conflict and the regulation of ongoing behavioral adjustment [2–5]. The dlPFC and superior sections of parietal cortex are responsible for initiating and modulating

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the cognitive control [3,6,7]. The MSIT-based functional imaging studies have been widely used to investigate the activation of dACC or CFP network in a wide range of population, including both clinical (such as schizophrenia, obsessive–compulsive disorder (OCD), attention-deficit/hyperactivity disorder, cannabis users, depression, etc.) [8–16] and nonclinical samples (such as children, adolescents, youth, old participants, female twins, etc.) [17–20]. Moreover, some studies have examined the connections between MSIT-evoked activation and resting-state. For example, Fitzgerald et al. found that pediatric OCD displayed hyperactivation of dACC, which showed different patterns of functional connectivity during MSIT-related condition and during resting state condition [12]. Davey et al. found that resting functional connectivity of the subgenual anterior cingulate cortex showed connection with different regions in response to MSIT in depression and healthy control groups [16]. In the latest study, when the researchers measured teenage brain activities during MSIT and during a resting-state, they observed that the brain network of teenage cognitive control was characterized by a dynamic and reciprocity between the cognitive control network and default-mode network [20]. These results reflect that the resting state is correlated with MSIT-evoked activation and may characterize the behavioral relevancy of spontaneous neural activity. To further characterize the inter-individual differences in MSIT, it is necessary to recognize how these differences associate with alternations in the brain's intrinsic activity.

Resting-state functional magnetic resonance imaging (RS-fMRI) is an important tool for investigating and characterizing the spontaneous neural activity in the absent of any specific cognitive tasks [21]. Relative to the resting state, task-evoked elevations of the brain energy expenditure are little (less than 5%), suggesting that the brain energy expenditure is less influenced by task execution but more by intrinsic activity [22,23]. Correspondingly, the resting state approach is quite suitable for understanding the essential feature of brain function [22,23].The spontaneous low-frequency (0.01–0.08 Hz) oscillations (LFO) have been corroborated to reveal the intrinsic neuronal activity. The fractional amplitude of low-frequency fluctuation (fALFF) is a normalized measure of amplitude of low-frequency fluctuation (ALFF) [24] and is one of the important indexes in reflecting the LFO fluctuations of RS-fMRI signals. As a robust and reliable method in RS-fMRI, fALFF measure could effectively suppress the physiological artifact [24,25]. Some recent studies have exhibited that the inter-subject differences of fALFF have identified tight linkages with individual variance in personality traits and multiple cognitive tasks [26–31]. The four of the Big Five personality traits (extraversion, neuroticism, openness and conscientiousness) were shown to correlate with the fALFF in different cerebral areas [26]. Wei et al. further found that the associations between fALFF and extraversion or neuroticism dimensions relied on distinct frequency bands [27]. fALFF was shown to be associated with task-relevant brain activity and with behavior performance during an Eriksen flanker task [28]. Meanwhile, fALFF in the supplementary motor area (SMA) and pre-SMA was reported to be negatively linked to not only age, but also the stop signal reaction time (SSRT) in the stop signal task [29]. More recently, van Dam et al. demonstrated that various memory measures, including general, domain-specific and demand-specific memory abilities, were related to fALFF in the extensive and distinct brain networks [30]. The positive correlation between fALFF and word-reading skill was found in the left precentral gyrus and superior temporal plane, whose regions served a role in phonological processing of language [31]. All the investigated correlations reveal that fALFF, as a data-driven method, is appropriate to exploratory analysis and the correlation analyses between fALFF and behavior could be valuable gauges to examine the potential neural characteristics for cognitive control.

However, to our best knowledge, no study has explored the relationship between behavioral results of interference effect on MSIT and spontaneous brain activity. Therefore, the current study aims to explore how interference effect of MSIT is supported by intrinsic neural activity without performing any cognitive task. We focused on the relationship between fALFF and interference effect of MSIT and investigated the neural basis of individual differences in interference effect by measuring fALFF of RS-fMRI signals. The interference effects were estimated by subjects' behavior performance in MSIT. Based on the previous imaging study on MSIT, we predicted that the regions related to cognitive control would show significant fALFF-interference effect correlations.

2. Methods

2.1. Participants

Seventy-eight college students (45 male, 20.9 ± 1.32 years, range: 18–25 years old) completed both MSIT and resting-state scans. All participants were right-handed, and had normal or corrected-to-normal vision. None had any current or past psychiatric or neurological disease. Each participant provided written informed consent and received monetary compensation for their time and effort. The study was approved by the Institutional Review Board of Dalian University of Technology.

2.2. Behavioral test

Adapting the MSIT from Bush et al. [2], each stimulus was consisted of a set of three characters (the digits "1", "2", or "3", or a letter "*X*") and presented in the center of the screen for 1750 ms. Among the three characters, one digit was always different from the other two digits or letters, and the participants were instructed to recognize such digit. A numeric keypad, which featured the digit "1", "2", "3" from left to right, was used as the response apparatus. The participants were asked to respond the target digits and press the corresponding numeric key by using the index, middle and ring fingers of their right hand.

During the experiment, the stimuli with two kinds of control/interference conditions appeared in a pseudorandom sequence. In the control condition, the digit was the target item and the letter "*X*" was the distractor. The size of target digit was a slightly larger than that of the distractor. The position of the presenting target digit was compatible with its position on the butter-press (e.g., "XX3", target is "3", and the button be pressed at the 3rd position). In contrast, during the interference condition (integrated with Stroop, Simon and flanker effects), both the target and distractor were digits. The size of the target was sometimes larger and sometimes smaller than that of the distractor. The presenting target digit did not match its position on the response key (e.g., "311", target is "3", but the correct key should be pressed at the 3rd position).

The MSIT was conducted individually using E-Prime software on a laptop computer in a quiet room of the lab. After instructions and practice, participants would complete three blocks of MSIT, 192 trials per block (96 control trails and 96 interference trials), for a total 576 trials. In between the blocks, the participants could take a short break. Both response accuracy and speed were equally stressed. Both reaction time (RT) and accuracy were collected for all subjects using E-Prime software. The RTs for incorrect or null responses were discarded from further analysis. According to the initial studies on MSIT [2,3], the interference effect is the difference score between RTs in the interference condition and RTs in the control condition (RTs interference—RTs control).