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Resting state neural networks for visual Chinese word processing in Chinese adults and children

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ABSTRACT

This study examined the resting state neural networks for visual Chinese word processing in Chinese children and adults. Both the functional connectivity (FC) and amplitude of low frequency fluctuation (ALFF) approaches were used to analyze the fMRI data collected when Chinese participants were not engaged in any specific explicit tasks. We correlated time series extracted from the visual word form area (VWFA) with those in other regions in the brain. We also performed ALFF analysis in the resting state FC networks. The FC results revealed that, regarding the functionally connected brain regions, there exist similar intrinsically organized resting state networks for visual Chinese word processing in adults and children, suggesting that such networks may already be functional after 3–4 years of informal exposure to reading plus 3–4 years formal schooling. The ALFF results revealed that children appear to recruit more neural resources than adults in generally reading-irrelevant brain regions. Differences between child and adult ALFF results suggest that children's intrinsic word processing network during the resting state, though similar in functional connectivity, is still undergoing development. Further exposure to visual words and experience with reading are needed for children to develop a mature intrinsic network for word processing. The developmental course of the intrinsically organized word processing network may parallel that of the explicit word processing network.

1. Introduction

In a modern literate society, reading is one of the most important and most frequently encountered tasks we perform on a daily basis. In order to be performed successfully, the ability to visually process words is fundamental to the act of reading. Over the past several decades, neural mechanisms underlying visual word processing have been extensively studied. fMRI research has revealed a vast cortical network, distributed throughout the frontal, temporal, and occipital cortices. This network has been found to be involved in the processing of phonological, syntactic, and semantic information associated with visual words in alphabetic languages and Chinese words (Bokde, Tagamets, Friedman, & Horwitz, 2001; Cohen, Dehaene, Chochon, Lehericy, & Naccache, 2000; Shaywitz et al., 2004; Tan, Laird, Li, & Fox, 2005; Bolger, Perfetti, & Schneider, 2005). One specific area that has attracted considerable attention is the so-called visual word form area (VWFA). The VWFA is located in the middle fusiform gyrus (FG) of the left hemisphere. It has been found to be particularly responsive to the orthographic processing of visual words during reading alphabetic scripts (Cohen et al., 2000; McCandliss, Cohen, & Dehaene, 2003; but see Price & Devlin, 2003).

Research has shown that reading non-alphabetic languages, such as Chinese, also engenders activation in the VWFA. This activation occurs despite the fact that Chinese written words are markedly different from alphabetic words (Chen, Fu, Iversen, Smith, & Matthews, 2002; Liu et al., 2008). For example, unlike words in alphabetic languages, Chinese words are logographs with distinctive configurations of components that are comprised of a number of strokes packed into a square shape according to stroke assembly rules. Generally speaking, unlike phonemes and syllables in alphabetic words, the components of Chinese words do not have obvious letter-sound correspondences. Existing functional neuroimaging studies have suggested that several brain areas are commonly activated

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in both Chinese word and alphabetic word processing. For instance, it has been reported that an area within the middle left FG is involved in the visual processing of Chinese words, the locus of which is highly consistent with the VWFA identified using alphabetic words (Liu et al., 2008; Liu, Tian, Li, Gong, & Lee, 2009; Bolger et al., 2005). The left inferior parietal lobule (IPL) and the left inferior frontal cortex are two areas that have also been found to respond to both Chinese words and alphabetic words (Bolger et al., 2005; Tan, Feng, Fox, & Gao, 2001; Tan et al., 2005; Zhao et al., 2011).

Recently, researchers have begun to explore whether there exists an intrinsically organized neural network for visual word processing even when individuals are not explicitly engaged in reading(Vogel, Miezin, Petersen, & Schlaggar, 2012; Zhao et al., 2011). Zhao et al. (2011) conducted an experiment, applying a low-frequency (0.01–0.08 Hz) functional connectivity (FC) approach used by several existing studies (Hampson et al., 2006; Koyama et al., 2010) to study intrinsic word processing networks during the resting state. It has been suggested that the synchronous low frequency (<0.1 Hz) fluctuations (LFFs) in the blood oxygen level-dependent (BOLD) signal are temporally synchronized between functionally related brain regions during the resting state (Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995; Greicius, Krasnow, Reiss, & Menon, 2003; Lowe, Mock, & Sorenson, 1998; Zhang, Tian, Liu, Li, & Lee, 2009; Zhu, Zhang, Luo, Dilks, & Liu, 2011). This LFF synchronization has been found within the primary motor, auditory, visual cortices, as well as some subcortical regions such as the hippocampus, and thalamus (Biswal et al., 1995; Chen, Zhou, Yang, & Fang, 2010; Smith et al., 2009; Yan et al., 2009; Zhao et al., 2011; Zhu et al., 2011).

In the Zhao et al. (2011) study, Chinese adults were neither made aware of the purpose of the study nor asked to perform any explicit word processing tasks. Results showed that during the resting state, there are significant low-frequency correlations between the left middle FG (i.e., VWFA) and an extensive number of cortical regions that have been implicated in visual word processing and reading, including the right FG, the left angular gyrus, the left supramarginal gyrus, the left IPL, the bilateral superior parietal lobule (SPL), the bilateral middle frontal gyrus (MFG), and the inferior frontal gyrus (IFG) (bilateral at BA 44, left at BA 45). This study demonstrates that during the resting state, there is an intrinsically organized word processing network in adults. One possible explanation for the existence of such a network is that our neural system may be in a constant state of readiness to receive visual word inputs due to the fact that reading is a highly common activity in the everyday lives of adults. Also, the resting state of the visual word processing neural network in adults may be the result of decades of extensive experience with reading and a gained expertise with the processing of visual words.

However, two outstanding issues have yet to be addressed. First, whereas FC analyses using LFF identifies the brain regions functionally involved in the resting state network for visual word processing, Zhao et al. (2011) did not consider the amplitude of the low frequency fluctuations (ALFF) for each brain region within the intrinsic network. The ALFF can be obtained by calculating the regional intensity of spontaneous fluctuations in BOLD signals. As demonstrated by several recent studies (Yang et al., 2007; Zang et al., 2007), the ALFF of the resting-state fMRI signals reflects the cerebral physiological states of brain regions, namely the magnitude of spontaneous brain activities in a resting state functional network. One possibility is that the ALFF may indicate the extent to which a brain region is engaged for a particular resting state network. However, to the best of our knowledge, no study to date has explored the ALFF within the intrinsic word processing network.

Second, Zhao et al. (2011) suggest that the intrinsic network is the product of extensive experience with reading that has been accumulated since childhood. The issue exists, however, that there is no developmental evidence to support this claim. It is entirely unclear whether children also have an intrinsic resting state neural network for word processing. Existing developmental evidence with children performing reading tasks suggests that the VWFA is already seen at about 9–12 years of age and develops gradually throughout childhood (Booth et al., 2001, 2004). Similarities and differences between children's and adults' explicit visual word processing networks have been found. As well, the development of the VWFA has been suggested to be driven by an increase in reading expertise rather than merely by the process of maturation (McCandliss et al., 2003). Based on such existing evidence, differences may exist between children's and adults' resting state neural networks due to differences in experience and reading expertise between the two age groups.

The present study aimed to address these two outstanding issues concerning the development of the visual word processing neural network. Two experiments were conducted using a task-rest paradigm. For the first experiment, adult participants were not informed of the true purpose of the study in order to obtain resting state data. Next, participants performed a visual word discrimination task from which the participants' VWFAs were identified. Using the resting scans, for each adult, the brain regions showing dynamic activities that correlated with those of the VWFA were identified using FC analyses. Measurements were then obtained of the variations of the ALFF within the intrinsic word processing network for adults. We expected to extend the findings of Zhao et al. (2011) by showing, in adults, both the existence of an intrinsic resting state network for visual word processing with the use of the FC analyses, and the associated levels of neural activities within the network with the use of the ALFF analysis.

In the second experiment, the same method and data analysis approach were performed with 10- and 11-year-old child participants, in order to identify the resting state neural network for children, should it exist. The similarities and differences between children's and adults' resting state neural networks were then assessed. In order to do so, the FC and ALFF results for adults were compared with those of children. These comparisons were then used to identify similarities and differences between the child and adult resting state neural networks for visual word processing.

Several possible patterns of results were expected. Regarding the FC results, given the fact that 10- to 11-year-old children would have had 3–4 years of formal schooling and 3–4 years of informal reading experience before entering elementary school, children at these ages may already have a resting state network for visual word processing similar to that of adults. Alternatively, as the ability to read takes a considerable amount of practice and time to acquire, the resting state network for children may be different from that for adults. With regard to the results of the ALFF analysis, the existing fMRI findings concerning children's performance in explicit reading tasks suggest that, when reading, children engage greater neural resources than adults in brain areas that are generally considered to be reading-irrelevant (e.g., Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). Based on these findings, we hypothesized that the ALFF results may differ between children and adults with the former showing greater amplitude of spontaneous brain activities in brain regions that are generally not involved in visual word processing. Alternatively, children's existing reading experience may also be sufficient to eliminate any differences between children and adults in terms of the amplitude of the low frequency fluctuations.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty healthy, right-handed, Chinese adults (age: 20–25; mean age: 22.60; SD: 1.35; 8 males) with normal vision participated in the present fMRI study. Participants were in good health with no history of neurological illness. Participants