Using Functional Near-infrared Spectroscopy to Investigate Frontal Cortical Response to Joint/non-joint Attention in Children

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Abstract— Functional near-infrared spectroscopy (fNIRS) is an optical technique for non-invasively investigating brain functional activity. It measures cerebral hemodynamic parameters that are closely associated with the neural activity. Previous study has demonstrated that individuals with autism are very poor in joint attention skills. In this work, fNIRS was used to access cerebral hemodynamic response to joint and non-joint attention stimuli in children classified as of high and low autistic traits. The stimuli were given by a video that engenders an experience of joint or non-joint attention in observers. 49 channels of oxygenated hemoglobin (HBO) time series were recorded from the frontal cortex when subjects were watching the video. The HBO activation pattern was obtained and the functional connectivity was determined for the two conditions. Results show there are significant differences between children with high and low autistic traits, in both the HBO response and the functional connectivity for each condition. Our data suggest that fNIRS may provide imaging-based objective evaluation on autistic traits.

1. INTRODUCTION

Functional near-infrared spectroscopy (fNIRS) is a promising technique for cost effective and non-invasive brain imaging [1–8]. It uses near-infrared light to measure cortical activity through intact scalp and skull.

Similar to functional magnetic resonance imaging (fMRI), fNIRS measures cerebral hemodynamic parameters closely related to the neuronal activity through neurovascular coupling. fNIRS has high temporal resolution ($\sim$ms), reasonable spatial resolution ($\sim$cm), and is compatible with other commonly used imaging modalities, such as fMRI, EEG and MEG. It is also possible for fNIRS to map the entire cortical surface.

Joint attention is a process whereby two individuals share the focus on the same object, as one is checking and following the attention focus of the other [9]. This cognitive skill emerges very early even in one's infancy, for example, infants can follow the direction of other's gaze in the first year after birth [10]. It is of high social implication, since the only goal of joint attention is to share thoughts, ideas, memories, observations and experiences with another individual.

Previous studies have demonstrated impairment in joint attention is one of the characteristics of autism spectrum disorder (ASD) [11]. fMRI study has shown there is distinct activation pattern in the frontal cortex between joint and non-joint attention stimuli [9]. In this study, we used fNIRS to record HBO signal from the frontal cortex of children classified as of high and low autistic traits during joint and non-joint attention tasks. The HBO response and the functional connectivity in the frontal cortex were determined and compared between children with high and low autistic traits.

2. METHOD

2.1. Participants and Protocol

Seventeen right-handed children (9 boys) participated in this study. They were all recruited from a kindergarten. The average age was 5 ± 0.9 years old (4–6 years old).

Before fNIRS measurement, the social and communication disorders checklist (SCDC) was used to evaluate children's autistic traits. A child with high score in SCDC implies he/she has ASD-like traits. After the SCDC evaluation, Seventeen children were divided into two groups with approximate equal size of group; namely, eight children were classified as of relative high (SCDC > 15), and the other nine as of relative low autistic traits. During the experiment, the child sat in a comfortable chair in a dark room and watched successively 8 video clips for 8 minutes in total. The video clip was made that can engender an experience of joint or non-joint attention in observer [9]. Each video clip consisted of 30 s black screen (control) followed by 30s task (joint or non-joint attention stimuli). The 8 video clips consisted of 4 joint and 4 non-joint attention stimuli, with a random presentation order across subjects.

Prior to the experiment, children and their parents were informed on the measuring procedure and written consents were obtained from the parents. The experiment protocol was approved by the Institutional Review Board of South China Normal University.

2.2. Experimental Setup

Measurements were performed with a commercial continuous-wave fNIRS system (FOIRE-3000, Shimadzu Corporation, Kyoto, Japan) working at three wavelengths, 780 nm, 805 nm and 830 nm. FOIRE-3000 is equipped with sixteen fiber sources and sixteen fiber detectors, building up to 52 detecting channels with a fixed source-detector distance of 3.0 cm. The absorptions of the three wavelengths of near infrared light were measured and then transformed into concentration of HBO based on the modified Beer-Lambert law.

The optical sensors were secured on the scalp by a headgear to ensure good sensor-scalp contact. The measured area and the locations for optical channels are schematically shown in Fig. 1.

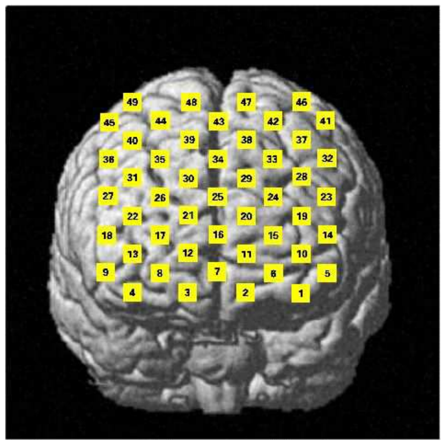

Figure 1: The sketch for positions of the 49 optical channels over the frontal cortex.

2.3. Data Analysis

The 8-min HBO time series data were first filtered with a band-pass (0.004–0.08 Hz) filter to get rid of the very low frequency drift and the systemic components, such as those from cardiac cycles ($\sim$1 Hz), respirations ($\sim$0.2 Hz) and Mayer waves ($\sim$0.1 Hz). After the data were filtered, the block average was performed for the two conditions (joint attention and non-joint attention stimuli), separately.

For the HBO activation pattern, the late 20 s HBO data were averaged in each block, and then averaged across all blocks for the two conditions, separately.

To determine the functional connectivity during the task period, the 30s block averaged HBO data were used for computing the Pearson correlation coefficients between a seed channel and the all other channels.

To visualize the activation pattern, a false color map is made where the color value for each pixel represents the HBO activation value. While for the connectivity map, in the false color map each pixel value is a correlation coefficient between this pixel (channel) and the seed pixel (channel).

3. RESULT

The mean HBO activation map is shown in Fig. 2 for joint and non-joint task, and for children with low and high autistic traits. Distinct activation pattern can be observed: in the condition of joint attention, children with low autistic traits show stronger activation than children with high autistic traits in both hemispheres. However, for the non-joint attention condition, the opposite activation pattern can be observed.

Since both in joint and non-joint attention conditions, right hemisphere (specially the middle frontal gyrus) shows relative strong HBO activation, a seed in the right hemisphere is selected (channel 35 in Fig. 1) to generate connectivity (or correlation) map, as shown in Fig. 3. Children with low autistic traits show stronger intra- and inter-hemispheric connectivity than children with high autistic traits, in both joint and non-joint conditions.

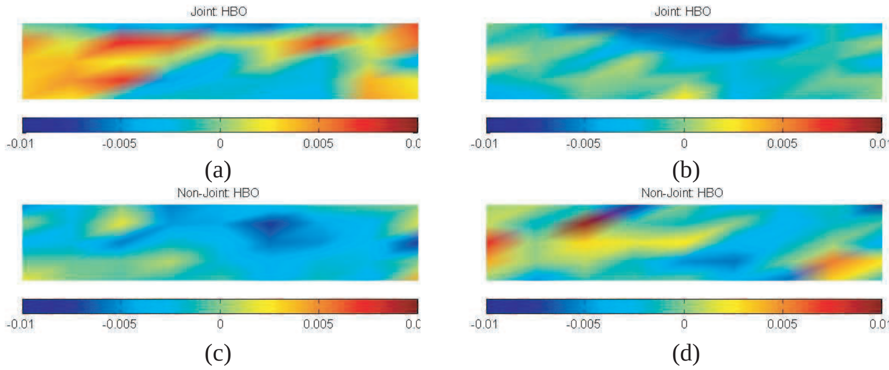

Figure 2: The HBO response for (a), (b) joint and (c), (d) non-joint attention conditions, and for children with (a), (c) low and (b), (d) high autistic traits.

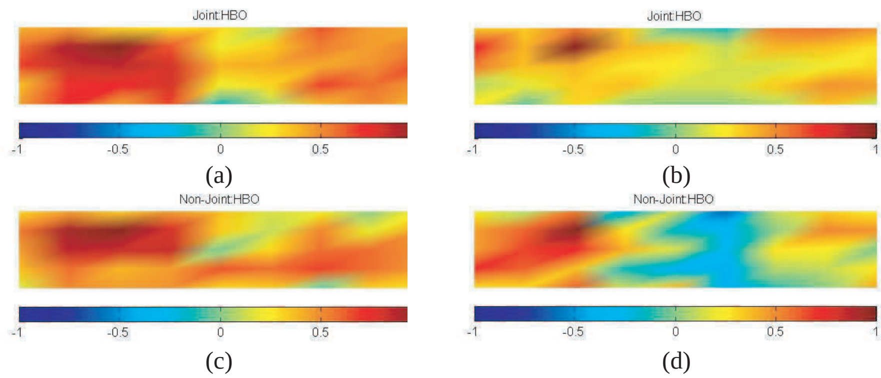

Figure 3: The functional connectivity map in (a), (b) joint and (c), (d) non-joint (bottom row) attention conditions, for children with =(a), (c) low and (b), (d) high autistic traits. In each case, the seed (channel 35) is selected in the right hemisphere, can be visually identified with the largest color value.

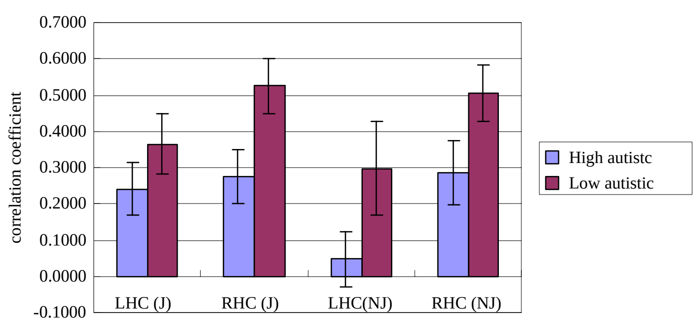

Figure 4: The average connectivity (or correlation coefficients) in the left and the right hemisphere for the two conditions, and two groups of children with low and high autistic traits. The correlations are calculated with respect to the seed (channel 35 located in the right hemisphere). The error bar was calculated across each group for each condition. LHC: left hemisphere correlation, RHC: right hemispheric correlation, J: joint attention, NJ: non-joint attention.

To quantitatively compare the connectivity in the left and the right hemisphere between children with low and high autistic traits, the average correlation coefficients for the left and right hemisphere are calculated for the two conditions, and for the two groups. The result is illustrated in Fig. 4.

The functional connectivity is stronger for children with low than with high autistic traits in both hemispheres, and for both conditions. Statistical analysis shows the difference in the connectivity is more significant ($p < 0.05$) in the right hemisphere for joint attention condition.

4. DISCUSSION

In the past twenty years fNIRS has been rapidly developed and now is becoming an effective tool for investigating functioning brain in a verity of areas ranging from basic neuroscience, psychology to numerous clinical applications.

In this study we used fNIRS to study frontal cortical response to joint and non-joint attention stimuli in children. Previous study with fMRI [9] has demonstrated that both joint and non-joint attention stimuli induce activation in the right middle frontal gyrus. Our HBO activation pattern revealed by fNIRS is in line with this observation. This fMRI study also shows during joint attention task, a large region in the left frontal gyrus is activated, including the left medial, the left superior and the left inferior frontal gyrus. Our data show the HBO activation in the similar region are also observed, but pronouncedly for children with low autistic traits.

Before this work, fNIRS was used to study the frontal response of children to join and non-joint stimuli [12]. However, in their study only a few optical channels were used, with two sources and four detectors, which is hard to make image for cortical response. Their study showed, compared to the resting state, there was a decrease in HBO for both joint and non-joint attention conditions. Our HBO response maps also show there are indeed some region in the frontal cortex where slightly decreased HBO is observed, especially in the anterior prefrontal cortex (Brodmann area 10), as seen in Fig. 2.

Recent studies on autism with fMRI [13] and fNIRS [14] have demonstrated that children with autism show poor synchronization of bilateral cortical (spontaneous) activity. These studies imply that the connectivity in the functional network of children with autism is weaker than children of typical development. Our data reveal the connectivity in the functional network is different between children with high and low autistic traits. Children with high autistic traits have weaker connectivity in the network than children with low autistic traits, which is similar to the comparison between children with autism and children of typical development. Our result may imply that in the view of the spectrum, an individual with high autistic traits is somehow 'closer' to the typical autism than an individual with low autistic traits.

5. CONCLUSION

In summary, we use fNIRS to investigate response in the frontal cortex to joint and non-joint attention stimuli for children. Our data show the HBO activation pattern and the functional connectivity are distinct between children with high and low autistic traits, and between joint and non-joint attention conditions. These results imply fNIRS might be able to provide imaging-based objective evaluation on autistic traits.

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