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Measurements of right / left hemisphere activation using functional near-infrared spectroscopy during incongruent Stroop test

Tomoyuki Hiroyasu, Michihiro Fukuhara, Hisatake Yokouchi, Mitsunori Miki and Masato Yoshimi

Abstract— **The human brain automatically processes information at multiple sites when recognizing various types of information at the same time, such as color, shape, etc. Cognitive conflict may occur when conflicting information is recognized at the same time. Functional near-infrared spectroscopy (fNIRS) is often used to examine the brain activity associated with this phenomenon. To examine activation of the visual system, we measured brain activity in the right / left hemispheres during cognitive conflict in the Stroop test. Consistent with the results reported previously by Ehlis, the brain activity in the near inferior-frontal gyrus of the left hemisphere was increased during the incongruent task. The brain activity also increased in the near inferior-frontal gyrus of the right hemisphere during the incongruent task. These results indicated that fNIRS can be used to detect brain activity in the inferior-frontal gyrus of the right / left hemispheres during the Stroop test.**

I. Introduction

The human brain can recognize various types of information at the same time. When multiple types of incoming information reach the brain, the information is processed at multiple sites automatically [1], [2]. This information processing mechanism has been the subject of considerable research regarding the visual system. Non-invasive methods, such as functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS), are used to measure the activity of the human brain.

We focused on the Stroop test to examine the brain activity associated with awareness of sensation in the visual system. This test involves both verbal and color information, and cognitive conflict occurs in the brain when the two types of information do not correspond [3], [4]. We used fNIRS, a brain imaging methodology using near-infrared light, to examine the brain activity [5], [6], [7]. This method has several advantages, including low cost and high flexibility for measurement of brain activities. Therefore, Many researches using this method is increased in late years [8], [9]. fNIRS can detect the brain activity during psychological test at the same time. We can estimate not only psychological approach but also the brain activity during Cognitive assessment with Stroop test. Previous studies using the Stroop test with fNIRS have been reported, but they dealt only with the left hemisphere [10]. Here, we used this method to obtain measurements in multiple areas at the same time.

In this study, we measured the brain activity in the right/left hemispheres during cognitive conflict in the Stroop test involving both verbal and color information with fNIRS, and discuss activation of the visual system.

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Tomoyuki Hiroyasu is with Department of Life and Medical Sciences, Doshisha University, Japan tomo@is.doshisha.ac.jp

Michihiro Fukuhara is with Department of Engineering, Doshisha University, Japan mhukuhara@mikilab.doshisha.ac.jp

Hisatake Yokouchi is with Department of Life and Medical Sciences, Doshisha University, Japan yoko@mis.doshisha.ac.jp

Mitsunori Miki is with Department of Science and Engineering , Doshisha University, Japan mmiki@mail.doshisha.ac.jp

Masato Yoshimi is with Department of Science and Engineering , Doshisha University, Japan myoshimi@mail.doshisha.ac.jp

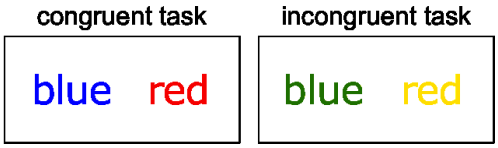

Fig. 1. Stroop test

II. Stroop test

The Stroop test is a task in which subjects read aloud the names of colors shown in colored text [3]. This test is major psychological test estimated the cognition function. When the color of the letters does not match the color named, cognitive conflict occurs and the action time increases (Fig.1). The meaning of the word, and not the color of the word itself, increases the latency of the response.

III. Experiment

A. Objective

Previous studies using the Stroop test and fNIRS indicated that the incongruent task (e.g., the word “blue” written in green text) invoked specific activation in the near inferior-frontal gyrus [10].However, the brain activity was detected in multiple areas based on the results of fMRI and PET measurements [11], [12], [13]. These results suggested that fNIRS may be able to yield similar results. Other methods, such as fMRI and PET, tend to constrain the experimental environment in terms of cost and flexibility.

Therefore, the use of fNIRS may be beneficial. Here, we measured the brain activity in the right / left hemispheres at simultaneously during the Stroop test with fNIRS.

B. Environment

In this study, oxy-Hb and deoxy-Hb were measured using an ETG-7100 Optical Topography System (Hitachi Medical Co., Japan). We used a 24-channel array of optical electrodes to measure the brain activity in the right/left hemispheres(Fig.2). This array consisted of an alternating arrangement of light emitters (red areas) and photo-detectors (blue areas) with measurement channels located between them. The array covered the right/left sides of the head at

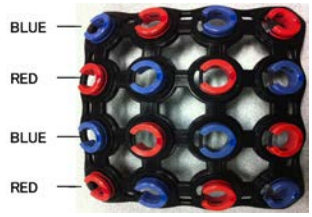

Fig. 2. The 24-channel array of optical electrode

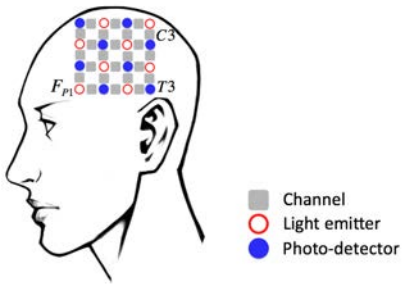

Fig. 3. Probe positions

positions T3, C3, Fp1/T4, C4, and Fp2 according to the international 10/20 system of electrode placement [14]. Fig.3 shows the probe positions (light emitters are shown as red circles, photo-detectors are shown as blue filled circles, and Channels are shown as gray areas).

C. Subjects

Nine healthy male subjects ranging in age from 21 to 22 years old participated in this experiment. The subjects had adequate sleep (more 6 hours) and the experiments were conducted between 13:00 and 15:00.

D. Protocol

The experiment was conducted as follows.

1) The subjects are given account for an experimental outline.
2) The experiment was performed as outlined in Fig.4.
   - Rest Control
     The subjects repeated the vowel sounds “a, i, u, e, o” (the normal order in Japanese).
   - Congruent Task
     Words were presented in the color consistent with their name. Subjects answered the color name.
   - Incongruent Task
     Words were presented in a color inconsistent with their name. The words were combined among “blue, red, yellow, and green”. The word pairs of color and meanings were displayed randomly.

   In both tasks, the experimenter switched the word each time the subject answered.
3) The subjects repeated operation-2 three times without a break.

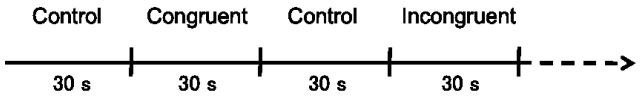

Fig. 4. Sequence of the experiment

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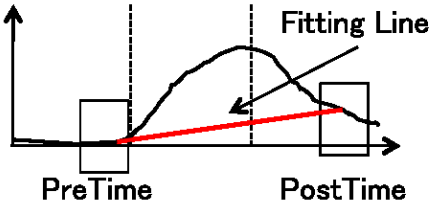

Fig. 5. Baseline

The order of congruent and incongruent tasks was randomized. All segmentation periods (congruent, incongruent, and control) were 30 s in length.

E. Analysis and statistics

In this study, we examined the number of correct responses/times required for responses in congruent and incongruent tasks and the changes in oxy-Hb levels as an approximate index of brain activity. The oxy-Hb data were processed as follows.

First, data were smoothed by the moving average method (sample size: 10 s). Second, the task condition (congruent and incongruent task) was processed by a “baseline” with 10 s preceding each task (PreTime) and 10 s after a 20-s “control” segment (PostTime) in each block. This method can correct the baseline by the least squares method with PreTime and PostTime dat(Fig.5). Using this method, the changes in oxy-Hb can be converted to changes based on the baseline to clarify the response. Third, the segment of each condition was averaged after the above processing. This method can increase the S/N ratio. After the above processing, the segments of each condition were integrated, and these data are discussed.

To determine the repeatability of previous results suggesting that oxy-Hb can be used as an indicator of specific activation for the incongruent task in inferior-frontal areas of the left hemisphere, we separated area based on previous research [10]. We examined the three areas at the bottom shown in Fig. 6 because this area includes those involved in higher brain functions, such as Broca’s area and Wernicke’s area (Fig.6). The electrodes of Area1 are placed on inferior frontal gyrus. This part is positioned at Broca’s area. The electrodes of Area2 are placed on middle temporal gyrus and superior temporal gyrus. Superior temporal gyrus is positioned at Wernicke’s area. The electrodes of Area3 are placed on precentral gyrus.

The right hemisphere was examined in the same manner as the left area. The paired t test was used for comparison between the results for each condition, and NIRS data were analyzed by ANOVA.

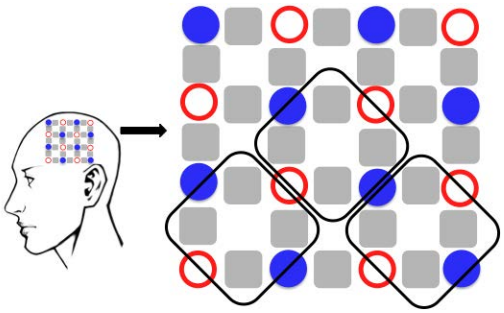

Fig. 6. Areas examined

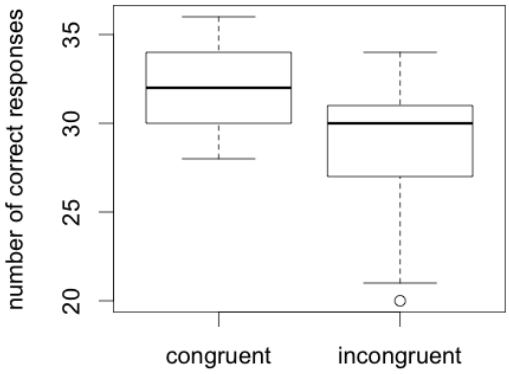

Fig. 7. Number of correct responses/Times required for responses for each condition

IV. Result

A. Stroop Effect

Fig.7 shows box plots expressing the number of correct responses/times required for responses in the congruent and incongruent tasks. The number of correct responses/time required for responses was decreased in the incongruent task compared to the congruent task ($t = 4.39, p < 0.001$).

B. fNIRS data

The various areas were designated as shown in Fig.8.

The data mentioned in chapter III-E are presented as means $\pm$ SD(Fig.9, Fig.10, Fig.11, Fig.12).

In the left hemisphere, there were no significant differences among areas in the congruent task ($F = 0.53, p > 0.1$; ANOVA). However, there were clear differences among areas in the incongruent task ($F = 6.30, p > 0.1$). The differences between the areas were examined by paired t test, and the results are shown in TABLE.I. These results indicated that Area1 showed specific activation in the left hemisphere.

The results of ANOVA also showed that there were no differences among areas in the right hemisphere in the congruent task ($F = 0.44, p > 0.1$). However, there were differences among areas in the right hemisphere in the incongruent task ($F = 3.87, p > 0.05$). Similar to the left hemisphere, we examined the differences between areas using the paired t test and the results are shown in TABLE.II.

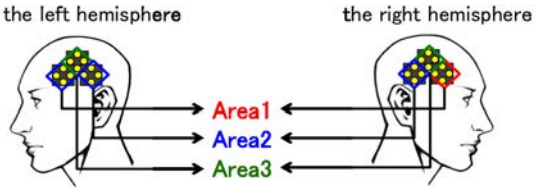

Fig. 8. Names of areas

TABLE I

Result of left hemisphere with t-test

Pair	p-value	t-value
Area1-Area2	0.06	2.21
Area1-Area3	0.04	2.35
Area2-Area3	0.68	-0.42

TABLE II

Result of right hemisphere with t-test

Pair	p-value	t-value
Area1-Area2	0.12	1.71
Area1-Area3	0.09	1.91
Area2-Area3	0.77	-0.28

These results indicated that Area1 showed specific activation in the right hemisphere.

V. Discussion

The results shown in Fig. 7 indicate that the number of correct responses/time required for responses for the incongruent task was smaller than for the congruent task. This result indicated that the Stroop test induced cognitive conflict.

In the left hemisphere, Area1 showed specific activation during the incongruent task. This result agreed with the findings of previous studies. Area1 is located close to the inferior-frontal area. We showed that Broca's area becomes activated during cognitive conflict [15], [16].

At the same time, Area1 in the right hemisphere showed specific activation during the incongruent task. This observation indicated that this area becomes activated during cognitive conflict. The functional localization of the right hemisphere has not been characterized in detail. It was reported that this area shows a significant response to visual stimuli [17]. Based on this result, we speculated that fNIRS detected brain activity related to the visual system in the right hemisphere.

VI. Conclusion

In this study, we measured brain activity in the right / left hemispheres during Stroop test by fNIRS.

The number of correct responses/time required for responses was smaller in the incongruent task than in the congruent task. The result of fNIRS indicated that the brain activity in the inferior-frontal areas of the right / left hemispheres is increased during the incongruent task. There were no differences between the areas in the congruent task.

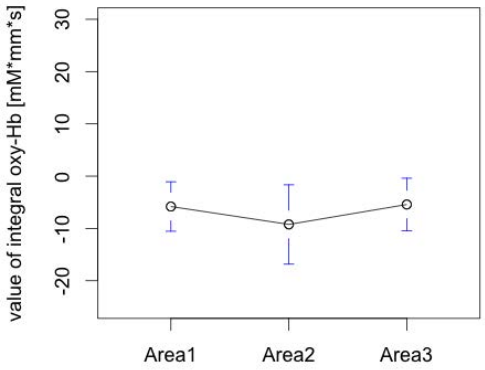

Fig. 9. Brain activity in the left hemisphere in the congruent task

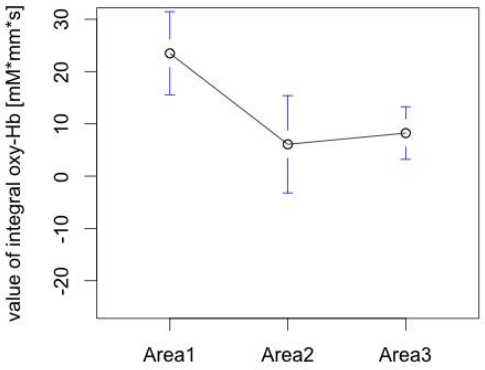

Fig. 10. Brain activity in the left hemisphere in the incongruent task

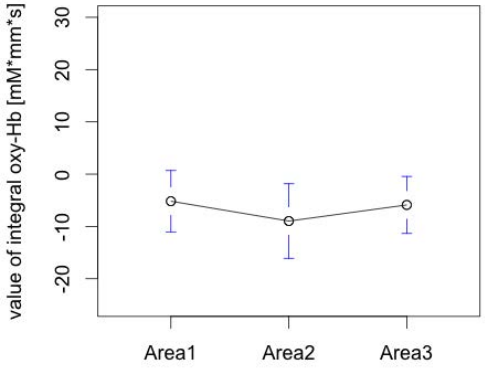

Fig. 11. Brain activity in the right hemisphere in the congruent task

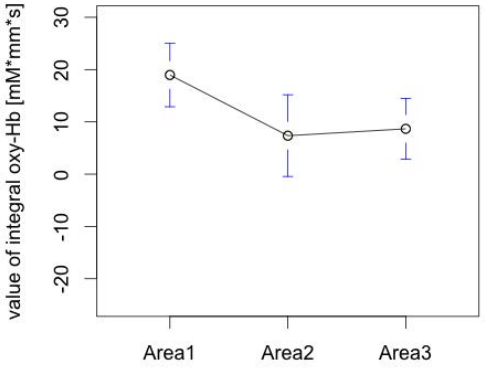

Fig. 12. Brain activity in the right hemisphere in the incongruent task

Thus, the present study indicated that fNIRS can be used to examine brain activity in inferior-frontal areas of the right / left hemispheres during Stroop test.

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