Temporal Changes of Cerebral Blood Flow for Stroop Color-Word Test: A Near-Infrared Spectroscopy Study

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Abstract

This paper attempts to estimate a level of concentration focusing on temporal changes of cerebral blood flow (CBF) for Stroop color-word test (SCWT) which is sometimes used in psychiatric research to induce prefrontal cerebral blood flow changes reflecting cognitive functions. The CBF is measured by near-infrared spectroscopy (NIRS) instrument and processed by time synchronous averaging (TSA). Then, the distinction of the concentration from the TSA waveforms is also discussed.

Keywords: CBF, NIRS, SCWT, TSA.

1. Introduction

It is preferable to spend keeping a quality of life high, in which we feel various impressions, such as a comfortable feeling, an exciting feeling, an interesting feeling, and so on. Here, we refer to these impressions as human Kansei (HK). Since the HK depends on personal subjectivity, precise measuring of the HK is imposed difficulty. In addition, a mental measurement method is not certain. Recently, researches to estimate the HK have been carried out physiologically and psychologically⁽¹⁻⁵⁾. The physiological approach uses physiological signals detected from electroencephalogram (EEG), magnetoencephalography (MEG), electrodermal activity (EDA), and so forth. As a measurement instrument for complex brain functions of humans, non-invasive techniques for forming images of changing cerebral blood flow (CBF) or cerebral blood volume (CBV) in the cerebral cortex have recently become available. One of the techniques, called near-infrared spectroscopy (NIRS) is a relatively new technology allowing

non-invasive and continuous measurement of cerebral oxygenation levels using near-infrared light. Several NIRS instruments have been developed with the aim to enhance instrumentation and find ways to obtain absolute oxygenation values⁽⁶⁾.

On the other hand, the HK is estimated from results of subjective evaluation in psychological approach. For these solutions, a questionnaire is the most convenient, and new analysis method using visual analog scale (VAS) has been proposed for visual and auditory sensitivities⁽⁷⁾.

This paper focuses on the level of concentration as one of human psychological statements including the HK, and addresses to evaluate using the CBF measured by the NIRS instrument for Stroop color-word test (SCWT). The SCWT is a neuropsychological test extensively used to assess the ability to inhibit cognitive interference occurring when the processing of a specific stimulus feature impedes the simultaneous processing of a second stimulus attribute, well-known as Stroop effect⁽⁸⁾. Temporal changes of the CBF for matching and mismatching conditions of the SCWT are also discussed in this paper.

2. Methods

2.1 Near-infrared spectroscopy

The NIRS is a promising instrument which can be utilized not only for medical treatment but also for learning and education related studies. The principle is to irradiate the head with near-infrared light and to analyze reflection and scattering at the surface of the brain.

The configuration for the NIRS instrument used even allows measurement in the case of a head covered by a large amount of hair. Figure 1 illustrates the optical path of the

Fig. 1. Measurement principle of NIRS⁽⁹⁾.

probe light of a typical NIRS instrument. The human head is roughly composed of a layered structure consisting of scalp including hair, skull, and cerebral cortex in order from the outside in. If a region of scalp among hair roots is irradiated from above by near-infrared light carried by optical laser, some of that light will reach a depth of from 25 to 30 mm. It will then be reflected by cerebral cortex and pass back through the scalp. If the scattered and reflected light returning through the scalp is detected by another optical fiber situated about 30 mm from the point of irradiation, it can be spectroscopically analyzed to measure metabolic molecules in the small region of the cerebral cortex that corresponds to the optical path in Fig. 1⁽⁹⁾.

Neural activity in the cerebral cortex has a strong effect on local blood dynamics, which can be observed through the spectral analysis of hemoglobin (Hb). As shown in Fig. 2, the oxy-Hb and the deoxy-Hb have different absorption spectra in the near-infrared region with an equi-absorption point near 800 nm. Making multi-wavelength and multi-point measurements of transmission spectra around this point gives us a way to map the concentrations of oxy-Hb and deoxy-Hb. It is known that the amount of oxy-Hb reflects changes in the CBF under the condition of hematocrit

Fig. 2. Absorption spectra of oxy-Hb and deoxy-Hb.

Fig. 3. Overview of WOT-100 measurement.

constant⁽¹⁰⁾.

In this study, the NIRS measurements are performed by using WOT-100 (NeU Corporation, Japan) as appeared in Fig. 3. The WOT-100 can measure changes of Hb concentration at 10 channels of prefrontal cortex regions with a sampling period of 200 ms.

2.2 Stroop color-word test

The SCWT assesses the ability to inhibit cognitive interference which occurs when the processing of a specific stimulus feature affects the simultaneous processing of another attribute of the same stimulus. In the most common version of the SCWT, participants are shown a word written in colored characters, and in response, the participant names the color. The cognitive interference is introduced when the word is presented in a color that differs from the color that the word represents semantically. When the character color disagrees with the meaning of the word so-called mismatching condition, the participant will typically respond with a delayed discrimination time and an increased in the number of false reactions compared to when the two attributes are consistent referred to as matching condition. This phenomenon is known as the Stroop effect or the Stroop interference. As the SCWT requires the ability to inhibit a habitual automatic response, it is widely used to assess executive function. While the SCWT is widely used to measure the ability to inhibit cognitive interference and other cognitive functions such as attention, processing speed, cognitive flexibility, and working memory. Thus, it may be possible to use the SCWT to measure multiple cognitive functions.

Figure 4 shows time series examples of 18 SCWT tasks. In this study, participants are required to count the number of tasks in which color of the ink is same as the meanings of

Fig. 4. Example of time series of 18 SCWT tasks.

Kanji character. In Fig. 4, the matching character is of row 2 and column 5 (character “緑” of green color), and all the others are mismatching characters.

2.3 Procedure

Two healthy participants took part in this study. They are 20 years old males, and had no history of major mental illness, neurological illness, and traumatic brain injury. Informed consent was obtained from each participant before participated to this experiment.

In this experiment, each participant sat on a chair facing a computer monitor. The one of the words “red,” “blue,” “yellow,” “green,” “black,” and “pink” written in Kanji character and colored in red, blue, yellow, green, black, and pink is displayed at the monitor, randomly and sequently. For each SCWT, total of 60 tasks, the 10 with matched character color and meanings and the 50 mismatched, are randomly displayed in 3 seconds per character. If the participant cognized the matched case, then the count in his mind was incremented as soon as possible. For each participant, 50 (5 patterns, 10 times) SCWTs are carried out. During the SCWT, participant’s CBF was measured by using WOT-100.

2.4 NIRS data processing

The data are preprocessed by time synchronous averaging (TSA). The NIRS signals from 5 seconds before and 5 seconds after the moment of task displayed were extracted, and averaged in the case of matching or mismatching, respectively. The averaging process gradually eliminates random noise because the random noise is not coherent with the displayed timing. Only the signal that is synchronous and coherent with the timing will persist in the averaged calculation.

3. Results

The TSA results for 50 SCWTs in matching case are shown in Fig. 5. Figure 5 (a) shows an arrangement of each channel of WOT-100, and Fig. 5 (b) depicts the TSA

(a) Channel arrangement of WOT-100 (forehead region).

(b) TSA waveforms of all channels.

Fig. 5. TSA results for 50 SCWTs for matching condition.

waveforms of all 10 channels. In the almost cases, the oxy-Hb concentration values are increased at 0.6 seconds after task presentation.

In order to compare the matching and the mismatching conditions, the TSA waveforms of all 10 channels are further averaged, and the averaged TSA results for each condition are plotted in Fig. 6. For the matching condition, the oxy-Hb concentration increases, whereas those for the mismatching condition are decreased or flat.

The peak appeared at 0.6 seconds later might be considered as neuro-vascular coupling (NVC). The NVC is neural activity occurring in the brain when the blood flowing through the surrounding cerebrovascular vessels increases locally. The CBF may have increased due to the activation of

Fig. 6. Comparison of TSA results for matching and mismatching conditions.

Fig. 7. Comparison of TSA results of 2 participants for matching condition.

nerve activity during visual stimulation⁽¹¹⁾. Further experiments and verifications are required, so that the relationship between the TSA results and the NVC can be more clarified.

Figure 7 shows comparison of the TSA results of 2 participants for matching condition. The TSA waveforms of all channels are also averaged. Both of them increased from 3 seconds before to 0.4 seconds later, continued to decrease until the next character is displayed and increased again.

4. Conclusions

In this paper, we addressed to clarify temporal changes of the CBF for the SCWT using the NIRS device and to evaluate the level of concentration. The NIRS signals were measured for the SCWT by using WOT-100, and processed by the TSA. As a result, the TSA waveforms showed different behavior for matching and mismatching conditions of the SCWT. Furthermore, the relationship between concentration and the CBF was made clear. The amount of oxy-Hb was increased by 0.4 to 0.6 seconds after displaying the colored character in which the color of the character matched with the meaning of the character, and was gradually decreased until the next task was presented. Similar changes were observed for comparison of two participants.

Further studies are necessary to confirm the relationship between the changes of the CBF and the NVC. Moreover, we begin to address autonomous discrimination of the level of concentration by deep learning techniques.

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