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# Classification subject effects using changes in cerebral blood flow on the Stroop test

Tomoyuki Hiroyasu, Michihiro Fukuhara, Hisatake Yokouchi and Mitsunori Miki

*Abstract*— **Functional near-infrared spectroscopy (fNIRS) is often used as a diagnostic method for mental illness, because the average patterns of changes in cerebral blood flow vary between such patients and healthy subjects. In addition, indoor environments and psychology alter the average patterns of changes in cerebral blood flow. These observations suggest that it may be possible to classify healthy subjects into different groups according to certain characteristics. The accuracy of fNIRS should be improved once it becomes possible to automatically determine the key factors affecting fNIRS data. The present study was performed first to determine whether there are differences in fNIRS data when the test subjects are classified into groups based on the scores related to task performances and questionnaires, and to determine whether there are differences in score when the test subjects are classified into groups based on fNIRS data. Differences were observed in fNIRS data between groups when the subjects were classified based on incorrect answers on the questionnaire and their degree of fatigue. In addition, there were differences in score between groups when the subjects were classified according to fNIRS data. These results suggested that subjects can be classified into groups automatically based on scores related to both task performance and fNIRS data.**

## I. INTRODUCTION

There have been a number of studies using fNIRS as a quantitative indicator of the degree of emotion and affection. fNIRS is an emerging medical imaging modality using near-infrared light [1]. fNIRS is often used in diagnosis of mental illness because the average patterns of changes in cerebral blood flow vary between such patients and healthy subjects [2]. In addition, indoor environments and psychology alter the average patterns of changes in cerebral blood flow. This implies that it may also be possible to classify healthy subjects into groups according to certain characteristics or factors.

The application of fNIRS to brain-computer interfaces (BCI) has been considered in various ways [3][4]. However, it is difficult to determine clearly which factors affect fNIRS data. This is because the length of the light path is unclear, and the degree to which skin blood flow contributes to fNIRS signals varies between individuals. Another problem is that biological signals may show different results depending on not only the influence of fNIRS, but also the health and mental status of the subject during the experiment. Thus, it is not practical to clarify the reproducibility of transit patterns of blood flow determined by fNIRS.

The reactions of blood flow may vary even in healthy subjects. It has been reported that the signals of fNIRS differ between healthy subjects classified into groups according to various factors, such as subjective fatigue and sleepiness [5]. This suggests that classification into groups makes it possible to discuss the changes in cerebral blood flow, taking the influences of various factors in account. It should be possible to improve the accuracy of fNIRS once it becomes possible to automatically determine the key factors affecting these data. Thus, it is necessary to consider what values of various factors influence upon fNIRS data in advance.

To examine the factors and parameters that may be useful for group classification, Stroop tests were performed and the relations between fNIRS data and the scores obtained in task performances and questionnaires were investigated.

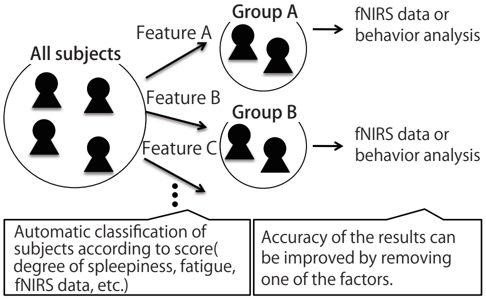

Fig. 1. The concept of classification of subjects

## II. CLASSIFYING SUBJECTS BASED ON THEIR PERSONALITY

As mentioned in the previous section, it is uncertain whether the transit patterns of blood flow indicated by fNIRS are reproducible. As brain activity can be affected by the surrounding environment, such as temperature, luminosity,, etc., and psychogenic factors, such as stress, fatigue, sleepiness,, etc., it is considered that the cerebral blood flow may also be affected by these factors. Therefore, even in healthy subjects, it is necessary to consider which physical and psychogenic factors affect the results. Thus, automatic determination of the key factors that influence fNIRS data will lead to improvements in the accuracy of fNIRS data (Fig. 1).

Here, the values of various factors influencing fNIRS data are discussed. First, we examined differences in fNIRS data

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in groups of subjects classified according to the scores of task performance and questionnaire results. Second, we examined whether there are differences in scores between groups of subjects classified based on fNIRS data.

These results were expected to reveal factors related to both difference in fNIRS data and differences in scores. The possibility of automated classification based on these factors is also discussed.

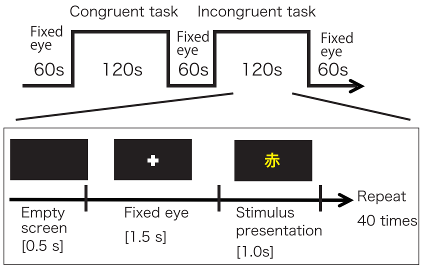

Fig. 2. Experimental schedule

## III. EXPERIMENT

### A. Environment and subjects of the experiment

The fNIRS equipment used in this experiment was an ETG-7100 Optical Topography System (Hitachi Medical Co., City, Japan). This device can be used to measure changes in concentration of oxygenated hemoglobin (oxyHb) and deoxygenated hemoglobin (deoxyHb). A measurement channel was placed in the inferior frontal gyrus, referring to the guidance provided in the international 10/20 system of electrode placement [6]. It has been reported that increased blood flow is detected in this area in subjects processing congruent tasks in the Stroop test [7][8]. The sampling frequency of fNIRS was 10 *Hz*.

The fNIRS data obtained was analyzed as follows. First, moving average processing was performed for fNIRS data (sampling period: 10 *s*). Then, baseline processing was performed (PreTime: 10 *s*, RelaxationTime: 30 *s*, PostTime: 10 *s*).

The study population consisted of 12 right-handed men, all aged between 21 and 23 years old, with Japanese as their first language.

The laboratory was maintained at a constant temperature of $21.1^\circ$ C ± $0.6^\circ$ C and humidity of 36.4% ± 6.7%.

### B. Procedure of the experiment

The experiment was conducted as follows.

1) The subjects are accounted for the experiment.
2) The subjects practice the tasks to perform in the experiment and wear fNIRS devices.
3) The subjects participate in the experiment (Stroop tests).

   In the Stroop tests, the subjects are assigned to a task involving reading colored words and are required to tell the experimenter what color is used for the words [9]. In some tasks, the meaning of the colored words and the color used for the words are the same; for example, the word “yellow” is written in yellow. In other tasks, the meaning of the colored words and the color used for the word are different; for example, the word “yellow” is written in green. The former tasks, in which the meaning of the colored words and the color used are the same, are called congruent tasks. The latter tasks, in which the meaning of the colored words and the color used are different, are called incongruent tasks. In an incongruent task, subjects tend to take a longer time to answer, because the meaning of the colored words does not match the color used. This test is often used to investigate cognitive functions. We chose this test for this experiment because the results are known to vary between individuals.

   In this experiment, subjects were assigned to congruent tasks first. They took time for “fixed eyes,” which is explained below, and then were assigned to incongruent tasks (Fig.2) [10]. The details of each task were as follows.

   - Fixed eye (60 *s*)
     Between congruent tasks and incongruent tasks, the subjects sat still on a chair with their eyes fixed on the center of the screen.
   - Congruent and incongruent tasks by pushing buttons (120 *s*)
     Tasks were performed according to the flow shown in Fig. 2. The flow of each task was as follows. After a blank screen is displayed (0.5 *s*), a cross shape is displayed on the center of the screen (1.5 *s*), followed by the display of a colored word (1.0 *s*). Looking at the colored word, the subject pressed the button corresponding to the color displayed. After carrying out these tasks 40 times, the subjects took some time for the “fixed eyes” again. The colors used in this experiment were blue, red, yellow, and green. In congruent tasks, four patterns of colored words were displayed randomly, in which the meaning of the colored words and the color used for the words were the same. In incongruent tasks, four patterns of colored words were displayed randomly, in which the meaning of the colored words did not match that used for the words.
4) Questionnaire
   At the end of the experiment, subjects filled out questionnaires regarding to the degree of subjective fatigue and sleepiness [5]. Each questionnaire was evaluation using a scale from 1 to 7, with the subjects selecting one level.

### C. Review method

The followings are the two main reviews on this study.

- Review of the changes in the concentrations of oxyHb in each group classified by the scores
  The scores were counted from the results of the questionnaires and task performance, and the subjects were classified into groups based on these scores. Then, the differences in changes in oxyHb concentration were

examined between the groups. The scores used for classifying the groups were: (1) presence or absence of incorrect answers, (2) degree of subjective fatigue, and (3) degree of subjective sleepiness. For both (2) the degree of subjective fatigue and (3) sleepiness, the groups were classified according to the mean value of all subjects ' scores as the threshold.

- Review of the relevance of the scores in each group classified based on the changes in the concentrations of oxyHb
  The subjects were divided into two groups of six each according to the mean change in oxyHb concentration during the incongruent task. The subjects who were highly reactive against the incongruent tasks were classified into one group, while the remaining subjects were classified into the other group. For this classification, two types of mean value were applied—the average of the results obtained for the entire period from the start to the end of each task, and the average of the results obtained for only the first 30 s after the start of each task. Various factors may influence the results as the time slot for each task was 120 *s*, which is relatively long. Thus, the mean value for the first 30 *s* was applied, with reference to previous studies in which fNIRS was used with Stroop tests [7].

subjects data was chose significant differences in reaction time of congruent and incongruent task (t-test, $p < .05$). fNIRS data in incongruent task and the score was used.

We studied using the changes in oxyHb. oxyHb is incresed in connection with neural activity in the brain[11]. In this study, we regarded as the brain activity of oxyHb.

## IV. RESULTS

### A. *Changes in oxyHb when classified according to score*

The extents of changes in oxyHb during congruent tasks are shown in 3, Fig.4, and Fig.5; Fig. 3 shows the results when the subjects were grouped according to presence/absence of incorrect answers; Fig. 4 shows the results when the subjects were grouped according to the degree of subjective fatigue; Fig. 5 shows the results when the subjects were grouped according to the degree of subjective sleepiness.

As shown in Fig. 3, the subjects who answered incorrectly had stronger oxyHb reactions than those who answered correctly.

As shown in Fig.4, the subjects who felt fatigued showed peaks in the reactions of oxyHb at the beginning of the task, but then the extent of changes gradually decreased compared to the subjects who were less fatigued. The subjects who were less fatigued showed peaks in the reactions of oxyHb late in the task period, and the extent of changes did not decrease during the task.

As shown in Fig. 5, there were no distinct differences between the two groups when the subjects were classified according to the degree of subjective sleepiness, although the subjects who felt drowsy tended to show smaller changes in oxyHb.

### B. *Scores when classified according to changes in oxyHb*

Figure 6 shows the three types of score, i.e., the number of incorrect answers, subjective fatigue, and subjective sleepiness, when the subjects were grouped according to the mean changes in oxyHb concentrations during the incongruent tasks. There were no significant differences in the scores between the groups in Fig. 6. Four of 6 subjects answered incorrectly in the highly reactive group.

Figure 7 shows the three types of score as in Fig. 6, but here the subjects were grouped according to the mean values of the results obtained for only the first 30 *s* after starting the congruent task. There was a significant difference in the degree of subjective fatigue in Fig. 7. Three of six subjects answered incorrectly in the highly reactive group.

## V. DISCUSSION

The first point examined in this study was whether there are significant differences in the changes in fNIRS data when the groups are classified according to their scores. The groups classified according to the presence or absence of incorrect answers showed a significant difference in changes in oxyHb (Fig. 3). It is assumed that oxyHb level is affected by impatience in making incorrect answers. There was also a difference in the changes in oxyHb between groups classified according to subjective fatigue (Fig. 4). Compared to the subjects who were less fatigued, those subjects who felt fatigued showed reaction peaks at the beginning of the tasks, but then the extent of changes decreased gradually. A previous study indicated that changes in oxyHb become smaller as the subjects become aware of a high degree of fatigue [5]. The same trend was seen in the present study over the entire task period. Even more remarkably, there was a difference in oxyHb changes at the beginning of the tasks.

On the other hand, there seemed to be no significant differences between groups classified according to subjective sleepiness. A previous study regarding the degree of subjective sleepiness and fatigue indicated that sleepier subjects showed larger oxyHb reactions. This can be explained by (1) the differences in cognitive tasks performed by subjects in the experiment and (2) differences in methods used for classifying subjects into groups. In future, it will be necessary to consider the influences of these factors. The results of the present study indicated that there are patterns of change that are peculiar to each group, although it will be necessary to take into consideration the methods used to classify subjects into groups in future studies. These observations suggest that classification into groups by scores will allow the extraction of factors that influence fNIRS data.

The second point examined in this study was whether there are significant differences in scores between groups classified according to the mean value of changes in oxyHb. When the groups were classified according to the mean value of changes in oxyHb obtained for the entire tasks period, there were no significant differences in the scores (Fig. 6). Although the numbers of errors did not vary between groups, it is remarkable that 4 of 6 subjects answered incorrectly in the highly reactive group. These results indicated a connection between fNIRS data and the presence of incorrect answers. There was a significant difference in the degree of subjective fatigue when the subjects were grouped according to the mean changes in oxyHb obtained for only the first 30 s after starting the tasks. Assuming that the changes in oxyHb are affected by making incorrect answers, the impact on the subjects should be smaller when the average oxyHb measured in only the first 30 s of the task compared to the average oxyHb measured over the entire task period. For this reason, the influence due to incorrect answers was decreased, and the effects of subjective fatigue were instead identified. With regard to subjective sleepiness, there were no distinct differences in the results for each group classified according to the mean value for the first 30 s and those classified by the mean value for the entire task period. There were also no differences between the subjective sleepiness groups in oxyHb classified according to score, and therefore sleepiness was taken to have had little effect on the subjects in this experiment.

As discussed above, some factors affect both the scores and fNIRS data. Therefore, it may be possible to automatically classify subjects into groups using these factors. However, many issues remain to be addressed regarding how fNIRS data should be processed during classification, and what types of scores should be used.

## VI. CONCLUSION

In this study, Stroop tests were carried out and the subjects were classified into groups according to fNIRS data and task performance scores. Difference between groups were identified when the subjects were grouped according to the presence or absence of incorrect answers and subjective fatigue. In addition, the scores showed significant differences when the subjects were grouped according to fNIRS data.

These results indicated that various factors influence both the scores and fNIRS data, and it may be possible to automatically classify subjects into groups using these factors.

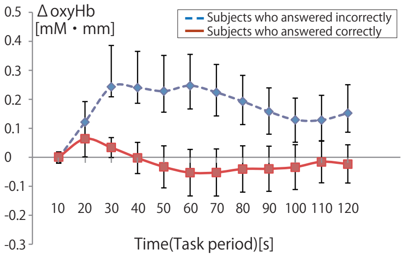

Fig. 3. The changes in oxyHb when subjects are grouped by the presence of incorrect answers.

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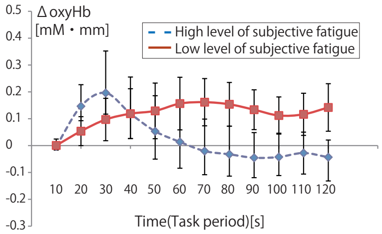

Fig. 4. The changes in oxyHb when subjects are grouped by the subjective fatigue

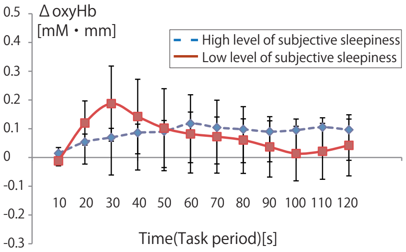

Fig. 5. The changes in oxyHb when subjects are grouped by the subjective sleepiness

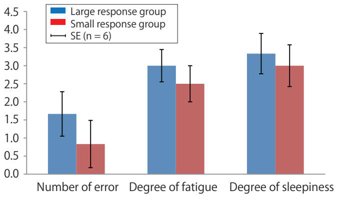

Fig. 6. The scores classified by the changes in oxyHb(the mean value of the results for the entire period of tasks)

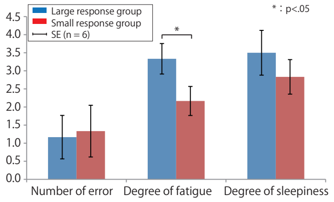

Fig. 7. The scores classified by the changes in oxyHb(the mean value of the results for the first 30 seconds after the beginning of tasks)

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