Differences in blood flow between auditory and visual stimuli in the Psychomotor Vigilance Task and GO/NOGO Task

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***Abstract*— The Psychomotor Vigilance Task (PVT) and the GO/NOGO task are generally applied to measure the ability of sustained attention. Advances in functional brain imaging equipment, such as functional Magnetic Resonance Imaging (fMRI) and functional Near-Infrared Spectroscopy (fNIRS), have resulted in increased application of brain imaging with these tasks. However, several different stimuli are adopted in these tasks, including both auditory and visual stimuli. Therefore, even when a subject performs these tasks, it can be assumed that the activated brain regions would vary when the different stimuli are given. Furthermore, even when a subject performs the tasks with the same sustained attention, the activated brain regions would vary when the configurations of these tasks are different. In this study, the reaction time and changes in blood flow were measured when a subject performed the PVT and GO/NOGO tasks, and so it is possible to discuss (1) the differences between visual and auditory stimuli and (2) the differences between PVT and GO/NOGO tasks. The results indicated increased blood flow at the left side of the dorsolateral prefrontal cortex in the PVT with visual stimulus compared with the auditory stimulus. In the GO/NOGO task, the blood flow associated with visual stimuli increased at the both sides of the inferior temporal gyrus and the right side of the inferior frontal gyrus compared with auditory stimuli. These observations suggested that the configurations of these tasks, such as the PVT and the GO/NOGO tasks, exert influences on the activated brain regions when a subject performs these tasks.**

I. INTRODUCTION

Tasks in which a subject reacts to a stimulus are very important because the Reaction Time (RT) between stimulus and reaction is altered by the subject's physiology and psychology. For example, the Psychomotor Vigilance Task (PVT) and the GO/NOGO task are applied to measure the ability of sustained attention, and have been used in various types of research, such as studies of circadian rhythms and sleep[1][2]. There has been a recent increase in studies of circadian rhythms and sleep performed using functional brain imaging with these tasks[3][4][5][6]. Although both tasks address the same phenomenon, i.e., sustained attention, the configurations of the PVT and GO/NOGO task are different from each other. Therefore, it is considered that the activated brain regions are different between these two tasks. In these tasks, several different stimuli are adopted, including both auditory and visual stimuli. As the type of stimulus differs between tasks, the activated brain regions may also differ. If the activated brain regions are influenced by the configurations of tasks, attention should be paid to the task configurations used in studies. In the present study, the reaction time and blood flow of subjects performing these tasks were measured and the differences (1) between the PVT and GO/NOGO task and (2) between the auditory and visual stimuli were examined.

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II. PSYCHOMOTOR VIGILANCE TASKS

The PVT is a task used to measure the time taken for a subject to react to irregularly presented stimuli[7][8]. Even when a subject performs the same task at a different time, the reaction time in the PVT would differ due to their physiology and physiology. This characteristic is one of the main reasons why the PVT is used in various types of research, such as studies of circadian rhythms and sleep[2][3].

III. GO/NOGO TASKS

In the GO/NOGO task, two types of stimuli are presented[9], i.e., the "GO" signal to which the subject has to react as soon as it is presented, and the "NOGO" signal to which the subject should not react. Similar to the PVT, the GO/NOGO task is also widely used in various types of research[4][5][6]. Unlike the PVT, however, the GO/NOGO task requires a subject to judge whether the signal is GO or NOGO.

IV. EXPERIMENTAL METHOD

A. Purpose

This experiment was performed to examine the differences in reaction time and blood flow (1) between the PVT and GO/NOGO task and (2) between auditory and visual stimuli.

B. Subjects

Five healthy subjects, all of whom were male, right-handed, and aged between 22 and 23 years old, participated in this experiment.

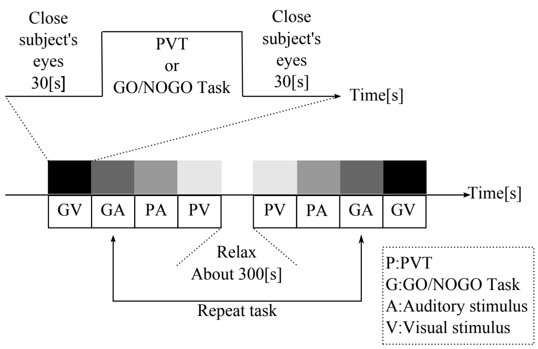

Fig. 1. Design of the experiment

C. Method

Each subject performed the tasks shown in Fig.1. The subject performed four types of task twice: PVT with auditory stimulus, PVT with visual stimulus, GO/NOGO task with auditory stimulus, and GO/NOGO task with visual stimulus. The order of the first four types of task was random for each subject. However, for the second time, the four tasks were performed in the reverse order to the first time to take accumulation of fatigue throughout the whole experiment into consideration. Each task consisted of three blocks. In the first block, the subject rested with his eyes closed for 30 s (Rest Time). In the second block, the subject performed the tasks for 120 s (Task Time). In the third block, the subject rested with his eyes closed again for 30 s. A sine wave of 1000 Hz was used as the auditory stimulus in the PVT. The visual stimulus in the PVT consisted of a cross (”+”) presented in the middle of the computer screen. A sine wave of 1000 Hz was used to indicate the GO signal and a sine wave of 2000 Hz was used to indicate the NOGO signal as the auditory stimuli in the GO/NOGO task. The visual stimuli in the GO/NOGO task consisted of ”+” or ”-” presented in the middle of the computer screen as the GO and NOGO signals, respectively. When the stimulus was presented, subjects were required to push the Enter key on the keyboard as the reaction.

D. Measurements

In this experiment, functional near-infrared spectroscopy (fNIRS)[10] was used to measure changes in blood flow with a 120-channel ETG-7100 optical topography system (Hitachi Medical Co., Tokyo, Japan); this system is much less restrictive than other types of functional brain imaging equipment. The right, left, and frontal lobes were examined in compliance with the international 10-20 EEG system. In this experiment, the changes in levels of oxygenated hemoglobin (oxy-Hb) were investigated, because oxy-Hb level is increased with the occurrence of nervous activity.

V. fNIRS Data Analysis

In this analysis, the changes in blood flow were investigated by a statistical method. The averages of the first and second fNIRS data, which are both time-series data, were computed.

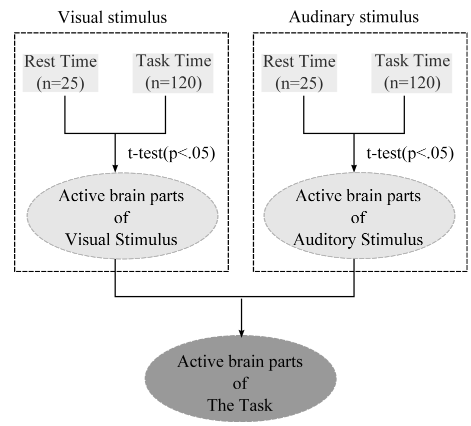

Fig. 2. Flow chart to identify the regions of brain activation

A. Regions of brain activation in the task

To identify the regions of brain activation, the fNIRS data were obtained with the same stimuli and the same tasks as described above; we used the same Task Time (df = 119) with the same Rest Time (df = 24), and the data were compared by heteroscedastic t test ($p<.05$). The regions where cerebral blood flow changed in all subjects during the tasks with both auditory and visual stimuli were regarded as the regions of brain activation of the task (Fig. 2).

B. Comparison of auditory and visual stimuli

The fNIRS data for the regions of brain activation of the task were obtained during the Task Times for both the auditory and visual stimuli and compared by paired t test ($p<.05$). Moreover, the regions of brain activation, where the changes in the cerebral blood flow of all subjects were greater with one of the stimuli compared to the other, were regarded as the brain regions with different degrees of activation by the type of stimulus.

VI. Results (PVT)

A. Reaction Time of the PVT

The RT is the time taken by the subject to react to the stimulus without errors. The RT in the PVT was analyzed as follows. The average RT is the mean of the reaction time. The 10% fastest and slowest RT are the means of the 10% fastest and slowest reaction times of all, respectively. Reactions that occurred later than 0.5 s were regarded as errors. The error rate is the ratio of the number of errors to all responses. Table I shows the results of the RT for the PVT. As shown in Table I, 10% fastest RT of the visual stimulus was slower than that of the auditory stimulus (paired t test, $p<.05$).

TABLE I
RT in the PVT

	Auditory stimulus	Visual stimulus
Average RT[s]	0.259	0.289
10%fastest RT[s]	0.213	0.230
10%slowest RT[s]	0.405	0.448
Error rate[%]	1.58	1.79

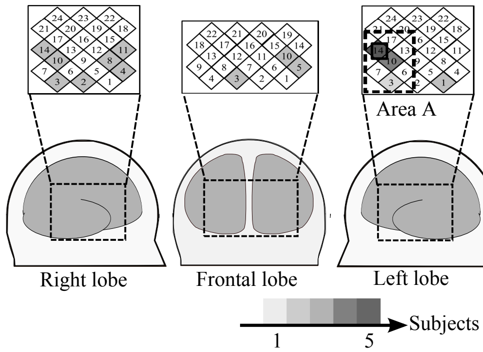

Fig. 3. Blood flow in the PVT

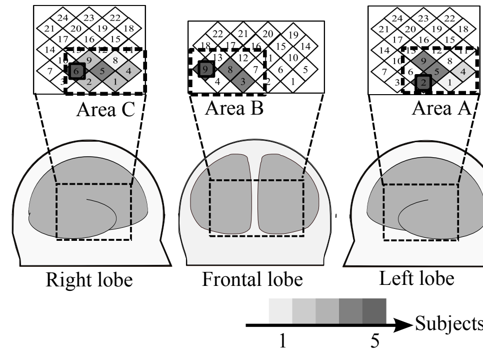

Fig. 4. Blood flow in the GO/NOGO task

B. Blood flow in the PVT

Fig.3 shows the brain activation parts during the PVT. In the 14th-channel of the left lobe, the changes of the blood flows by the visual stimulus were bigger than by the auditory stimulus. The brain parts around this channel, the 14th-channel of the left lobe, are regarded as the Area A. The Area A is the vicinity called the dorsolateral prefrontal cortex. As shown in Fig.3, most of the subjects had the tendency that the blood flows by the visual stimulus of the channels in the Area A were bigger than by the auditory stimulus. From the above, it is considered that the changes of the blood flows at the dorsolateral prefrontal cortex by the visual stimulus are bigger than by the auditory stimulus.

Figure 3 shows the regions of brain activation during the PVT. In the 14th channel of the left lobe, the changes in blood flow associated with the visual stimulus were greater than those for the auditory stimulus. The brain regions around this channel were regarded as Area A, and corresponded to the region called the dorsolateral prefrontal cortex. In most subjects, the blood flow associated with the visual stimulus of the channels in Area A tended to be greater than that with the auditory stimulus (Fig. 3).Thus, the changes in blood flow in the dorsolateral prefrontal cortex associated with the visual stimulus were considered to be greater than those with the auditory stimulus.

VII. RESULTS (GO/NOGO TASKS)

A. Reaction Time in the GO/NOGO task

The RT in the GO/NOGO task was analyzed according to the average RT, 10% fastest RT, 10% slowest RT, and error rate as described for the PVT. Table II shows the results of RT in the GO/NOGO task. The average RT and 10% fastest RT with visual stimulus were slower than those with the auditory stimulus (paired t test, $p<.05$).

TABLE II
RT IN THE GO/NOGO TASK

	Auditory stimulus	Visual stimulus
Average RT[s]	0.297	0.327
10%fastest RT[s]	0.228	0.266
10%slowest RT[s]	0.494	0.471
Error rate[%]	3.90	6.57

B. The blood flows of the GO/NOGO tasks

Figure 4 shows the regions of brain activation in the GO/NOGO task. At the 6th channel of the right lobe, the 2nd channel of the left lobe, and the 9th channel of the frontal lobe, the changes in blood flow with the visual stimulus were larger than those with auditory stimulus. The brain regions around the 2nd channel of the left lobe, 9th channel of the frontal lobe, and the 6th channel of the right lobe are regarded as Area A, Area B, and Area C, respectively. Area A and Area C correspond to the region called the inferior temporal gyrus, and Area B corresponds to the region called the inferior frontal gyrus. As shown in Fig. 4, the changes in blood flow with the visual stimulus tended to be greater than those with the auditory stimulus at the channels corresponding to Area A, Area B, and Area C in most subjects. The above results suggested that the changes in blood flow with visual stimulus at the inferior temporal and frontal gyri were greater than those associated with auditory stimulus.

VIII. DISCUSSION

A. The PVT

The dorsolateral prefrontal cortex, which is associated with sustained attention[11], was more actively influenced by visual stimulus than by auditory stimulus in the present study. However, the 10% fastest RT of the visual stimulus was slower than that of the auditory stimulus. This was considered to be because the visual reaction time resolution is poorer than the auditory reaction time resolution. Although the average RT of the PVT did not show apparent differences between the auditory and visual stimuli, the average RT of the GO/NOGO task showed a difference. The dorsolateral prefrontal cortex is considered to be so active that the reaction time is not influenced by the visual time resolution, and the dorsolateral prefrontal cortex is influenced more significantly by the visual stimulus than by the auditory stimulus.

B. The GO/NOGO tasks

The inferior temporal gyrus is involved in distinguishing the shapes of objects[12], and this region was more active during the tasks with visual stimulus. This region was considered to be involved in distinguishing between the GO and

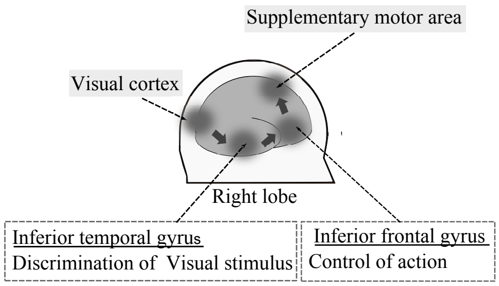

Fig. 5. Information Process of the GO/NOGO tasks

NOGO signals. On the other hand, the inferior frontal gyrus is known to play a role in controlling actions[13]. This region was activated as described in previous studies[14]. In this experiment, the changes in blood flow at the inferior frontal gyrus associated with the visual stimulus were greater than those with the auditory stimulus. Taken together, the above results suggest the information process in the GO/NOGO task shown in Fig. 5. When the visual stimulus is presented to the subject, the visual cortex is activated. Then, the inferior temporal gyrus is activated to distinguish whether the stimulus represents the GO or NOGO signal, which leads to increased changes in blood flow in this area. Thereby, the inferior frontal gyrus is activated and the reaction is controlled so that the average RT of the visual stimulus is slower than that of the auditory stimulus. The same can be applied to the PVT, in which the 10% fastest RT of the visual stimulus was slower than that of the auditory stimulus.

C. *PVT and GO/NOGO tasks*

In this experiment, the regions of brain activation were shown to vary according to whether the task requires judgment on the stimulus; the GO/NOGO task requires judgment, whereas the PVT does not. It was also shown that the degree of blood flow in the regions of brain activation varied according to the type of stimulus. These observations suggested that the task configuration influences the regions of brain activation and the degree of blood flow in these regions. Further studies including changes in the configuration of tasks within the experiment, e.g., presentation of multiple stimuli to the same subjects, are required.

IX. CONCLUSION

In this study, the changes in blood flow in the PVT and GO/NOGO task were measured and the effects of differences in task configuration were examined. In the PVT, the 10% fastest RT of the visual stimulus was slower than that of the auditory stimulus. This was likely because the visual reaction time was slower than the auditory reaction time. The average RT of the PVT was not significantly different between the auditory and visual stimuli, because the dorsolateral prefrontal cortex was more active with visual stimulus compared with auditory stimulus. The information processing in the GO/NOGO task is as follows. When the visual stimulus is presented to the subject, the visual cortex is activated. Then, the inferior temporal gyrus is activated to distinguish whether the stimulus represents the GO or NOGO signal. As the blood flow in the inferior temporal gyrus is greater with visual stimulus than auditory stimulus, the inferior frontal gyrus is activated. Thus, when the reaction of the subject is controlled, the average RT of the visual stimulus is slower than that of the auditory stimulus. It was suggested that the task configuration influences the regions of brain activation and the degree of blood flow changes in these regions. From these results, it was concluded that although both the PVT and GO/NOGO task are stimulation tasks, these tasks should be concerned in selecting tasks in an experiment.

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