Basic Study for Human Brain Activity Based on the Spatial Cognitive Task

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Abstract— **Recently, there is a need to develop a new assist system which acts for car driving and wheelchair for the elderly and disability person as the population grows older. In terms of developing a new system, examining human spatial recognition has important implications. And so, we pay attention to spatial perception, especially left and right ones and differences in brain activity between right and left perception. The final goal of our research measuring brain activity is to contribute to developing of welfare robots with functions that are responsive like human. So, we have performed experiments for investigating human spatial perception by measuring brain blood flow when subjects perform driving tasks. In previous experiment, we measured brain activity when T-junctions were shown to subjects using driving movies. In this time, we performed experiment in which brain activities were measured during actual car driving. We are reporting on these analysis result and comparison result between virtual one and actual one.**

Keywords- spatial cognitive task; NIRS; determing direction during car driving

I. INTRODUCTION

Human can determine his movements and behaviors relative to his environment. In addition, he recognizes a new location and decides what behavior to take. It is important to examine the human spatial perception for developing autonomous robots or automatic driving.

The relation of the theta brain waves to the human spatial perception was discussed in [1][2]. For example, when human perceives space that surrounds him, he tries to decide the next action in a maze and the theta brain waves saliently appear. This means we have a searching behavior to find a goal at an unknown maze. From the side of human navigation, Maguire et al. measured the brain activations using complex virtual reality town [3]. But, each task was notional and the particulars about the mechanism that enables humans to perceive space and determine direction is yet unknown. From researches we performed, there were significant differences at dorsolateral prefrontal cortex in left hemisphere in turning a steering wheel at T-junction [4][5][6].

Brain activities concerned with cognitive tasks during car driving have been documented [7]. For example, there was a report about brain activity when disturbances were given to subjects who manipulated driving simulator. Then power spectra were increased in beta and theta bands. However, there is little report on the relationship between right and left perception and driving task. It is well known that higher order processing is done such as of memory, judgment, reasoning, etc in the frontal lobe [8].

We try to grasp mechanism of information processing of the brain by analyzing data on human brain activity during car driving. The goal of this study is to find a way to apply this result to new assist system with human motions. To achieve the goal, we try to examine the brain activity of frontal lobe, which related to behavioral decision-making, from the viewpoint of human spatial perception. As a first step, we measured the brain activity of frontal lobe relevant to right and left perceptions during car driving. Furthermore, the brain activity is to be measured and discussed about the mechanism of information processing of the brain by analyzing experimental data concerning human brain activity during car driving using NIRS (Near Infrared Spectroscopy).

II. EXPERIMENTS

A. Brain activity on driving movie is shown

The subjects for this experiment were eight males aged 22 to 24. The average age was 22.7 and the age of standard deviation was 0.74. All of the subjects were right handed. They were asked to read and sign an informed consent regarding the experiment.

NIRS (Hitachi Medical Corp ETG-100) with 24 channels (sampling frequency 10 Hz) was used to record the density

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of oxygenated hemoglobin (oxy hemoglobin) and deoxygenated hemoglobin (de oxy hemoglobin) in the frontal cortex area.

Driving movie for the experiment was recorded from a moving car, in which two T-junctions were included. In addition, there was a road sign with directions in the second scene. We used nine kinds of movies in about one minutes. Before showing the movie, subjects were taught directions turning to the right or left at the first T-junction. They were also taught the place which was on the road sign at the second T-junction. They had to decide the direction when they looked at the road sign. They were asked to push a button when they realized the direction in which they were to turn. Subjects took a rest during 10 seconds at least with their eyes close before movies were shown and they viewed the image after that. Finally, subjects took a rest again. The brain activity was recorded from the first eyes-closed rest to the last eyes- close rest.

Here, we defined Tasks A, B, and C; Tasks A and C were proposed as the same experiment tasks and subjects had to push the button. In tasks B, other operation was added. It was the operation that the steering wheel was turned in the direction of destination when subjects realized it.

For this experiment, driving movies were displayed on a HMD (Head Mounted Display). The PC emitted a trigger pulse at the start of the eyes-closed rest and driving movie. Then, NIRS was recorded the brain activity, the trigger pulse from PC and the pulse from the button pushed at the second T-junction.

Subjects were seated in car seat. Then they were fitted with the NIRS probe and the HMD. They were covered with black cloth to shut out the light from outside.

B. *Brain activity on handling motion*

In this experiments, measurements were performed by f-NIRS (Functional Near Infrared Spectroscopy) made by SHIMADZE Co. Ltd with 44ch. Five subjects were a healthy male in their 20s, right handed with a good driving history. The subject was asked to perform simulated car driving, moving their hand in circles as if handling a steering wheel. A PC mouse on the table was used to simulate handling a wheel, and NIRS (near-infrared spectroscopy) was used to monitor oxygen density changes in the subjects' brain.

NIRS irradiation was performed to measure brain activities when the subject sitting on a chair drew a circle line of the right/left hand 1) clockwise, and 2) counterclockwise. The part of measurement was the frontal lobe. The subject was asked to draw on the table a circle 30 cm in diameter five times consecutively, spending four seconds per a circle. The time design was rest (10 seconds at least), task (20 seconds), rest (10 seconds).

C. *Brain activity on car driving*

In general roads, experiments were performed by taking f-NIRS in the car, and measured the brain activity when subjects drove on designed road including intersections.

In this experiment, two kinds of measurements were performed. At first experiment, there were two intersections. And subjects were told to turn the right or left in first intersection. In addition, they were told to read the road map and judge the turning direction in the second intersection. And subjects were enlightened about turning direction before measurement. They were also taught the place on which the road sign was at the second T-junction. And, they were given the place where they have to go. So, they had to decide the direction when they looked at the road sign. Six subjects were a healthy male in their 20s, right handed with a good driving history. Subjects close their eyes for 10 seconds at least, and drove the car for 600 seconds. Three patterns were prepared for the task pattern.

Next, we performed second experiment to conduct verification about above experiment and increase number of subjects. We performed additional experiment which was achieved in a similar way. In this experiment, measuring and analyzing method was performed in same way, but experimental courses were different. Subjects were twelve males who were all right-handed.

III. EXPERIMENTAL RESULT

A. *Brain activity on driving movie is shown*

For task A and C, the subjects were informed direction by suggested movie, and they let decided which way to turn under the road sign. After first T-junction, they were to push the button when they realized the direction at second direction. In task B, they performed other task, turning the steering wheel actually in concert with suggested movie. The hemoglobin variation was compared in the results of Tasks A and B, A and C to see the brain activity pertaining to spatial perception during the same movie.

Equation (1) was used to compare the data. τ1 was set the time as its length was 1 second before being pushed the button. Similarly, τ2 was set in a way similar to τ1. And xi (t) indicates variation of i channel oxy hemoglobin or deoxy hemoglobin. We then took a average of xi(t) through τ1 and τ2. In this situation, i of the defined c (i) was the channel for the brain activity. Because of the sampling frequency was set on 10 Hz, we calculated 10 times per sec.

$$c(i) = \overline{\sum_{\tau_2} x_i(\tau_2)} - \overline{\sum_{\tau_1} x_i(\tau_1)} \quad (1)$$

A comparison was made between the situations in which the steering wheel was turned and when it was not. Figure 1 is the calculation result of oxy-Hb.

The next step was to calculate the average of all subjects. Figure 2 shows the results. This might have occurred when they realized direction from a road sign. In addition, the results indicated a greater increase when the subjects turned the steering wheel. That indicated observation of brain activity has been made during movement based on spatial perceptions.

On the whole, the variation in de-oxy hemoglobin was smaller than in the oxy hemoglobin. However, there was a great increase in Channel 18. This might be the variation based on the spatial perceptions.

Next, differences were investigated concerning the subject's brain activity. The First case was when the vision was directed after having been told the direction.

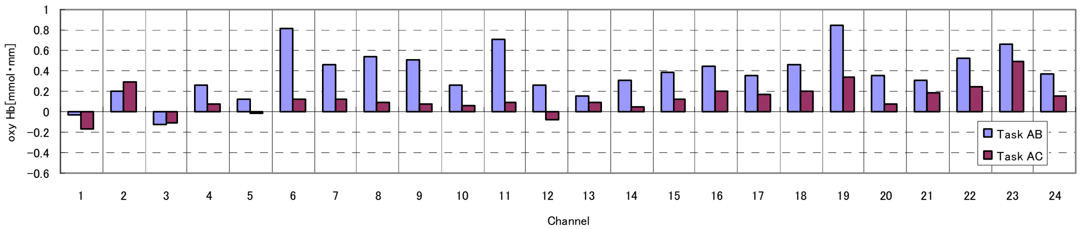

Figure 1. Result from subject A of task A

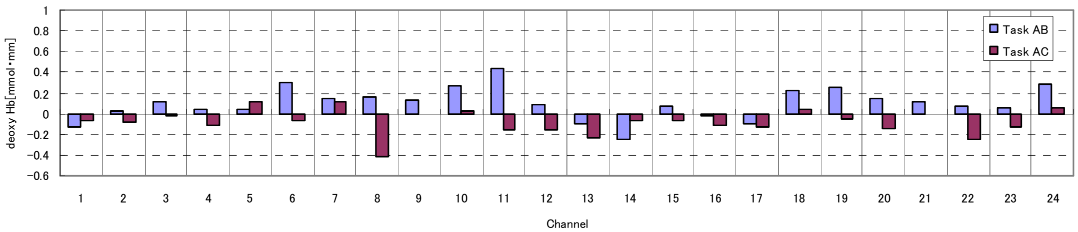

Figure 2. Compared between turrning the steering wheel and not (oxy Hb of subject A)

The Second case was when the vision was directed after having been told the direction gone to the direction which the subjects decided where to go from a road sign. d1 and d2 shown in Fig. 3 are defined as below. d1 is the variation of hemoglobin turning at the first T-junction. And d2 is variation of hemoglobin at the second one. From the measurement result, d1 and d2, all of the 269 times of each subject, there were significant differences in oxy hemoglobin 3ch. ($p < 0.02$: paired t test) and 20ch ($p < 0.03$) using NIRS.

Subjects pushed a button before turning at the second T-junction, so it influenced brain activities. The possibility of a correlation between d2 and the time until the movie was turned at the second T-junction after each subject pushed a button was investigated. Each correlation coefficient of hemoglobin channel was calculated. There was significant difference at only de-oxy hemoglobin 10ch. ($p < 0.07$) using paired t-test. In only this result, the relationship between pushing a button and d2 cannot be judged.

B. Brain activity on and handling motion

During the motion, the increase of oxy hemoglobin density of the brain was found in all subjects. The different regions of the brain were observed to be active, depending on the individual. The subjects were to be observed 1) on starting, and 2) 3-5 seconds after starting moving their 3) right hand 4) left hand 5) clockwise 6) counterclockwise. Although some individual variation existed, the result showed the significant differences and some characteristic patterns.

The obtained patterns were shown as follows. Regardless of 1), 2), 3) and 4) above, the change in the oxy hemoglobin density of the brain was seen within the significant difference level 5% or less in the three individuals out of all five subjects. The part was the adjacent part both of left pre-motor area and of left prefrontal cortex. Especially, in the adjacent parts of prefrontal cortex, a number of significant difference was seen among in four out of five subjects.

Next more emphasis was put on the rotation direction: 5) clockwise or 6) counterclockwise. No large density change was found in the brain with all the subjects employing 6). But the significant difference was seen in four out of five subjects employing 5) (Fig. 4). It is well known that in the outside prefrontal cortex higher order processing is done such as of behavior control. It was inferred that the pre-motor area was activated when the subjects moved the hand in the way stated above because the pre-motor area was responsible for behavior control, for transforming visual information, and for generating neural impulses controlling.

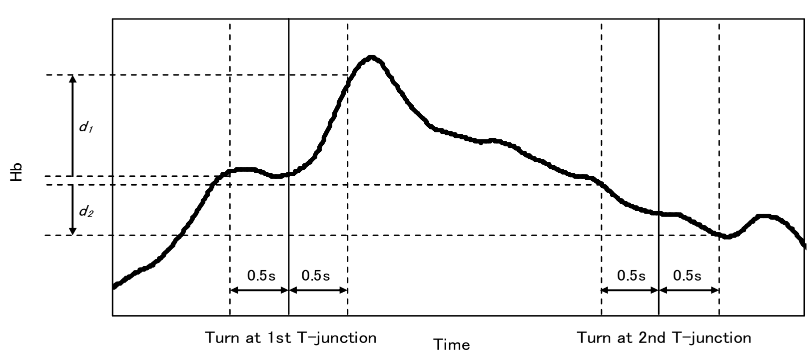

Figure 3. Define variation of hemoglobin d1 and d2

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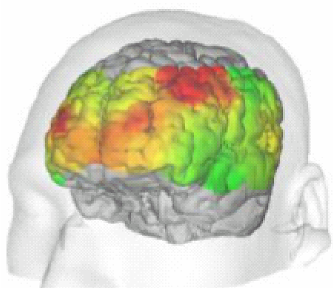

Figure 4. Brain activity (clockwise)

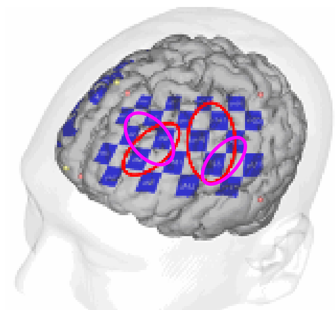

Figure 5. Significant differences at T-junctions in left direction

C. *Brain activity on car driving*

At the first, Hb-oxy was increased in overall frontal lobe after start of operation. This tendency was common among subjects. After that, Hb-oxy was decreased as subjects adjusted to driving the car. This meant that the brain activity changed from collective to local activities.

In this experiment, being considered time as zero when subjects turned a steering wheel. The analysis was performed one-sample t-test within the significant difference level 5% or less between zero and about four seconds after turning.

As the results, there were significant differences around #46 area of the dorsolateral prefrontal cortex and the premotor area of the left hemisphere brain at the turn left (Figure 5: red circles).

Around #46 area was corresponded to working memory. In additional experiment, analysis was conducted using same method, too. In this regard, we analyzed in both orders for confirming to be sequence-independent on the presence or absence of road sign (Figure 5: pink circles).

IV. CONCLUSION

The hemoglobin density change of the human subjects' frontal lobe was partly observed in the experiments we designed, where three kinds of tasks were performed to analyze human brain activity from the view point of spatial perception.

The NIRS measures of hemoglobin variation in the channels suggested that human behavioral decision-making of different types could cause different brain activities as we saw in the tasks: 1) taking a given direction at the first T-junction, 2) taking a self-chosen direction on a road sign at the second T-junction and 3) turning the wheel or not. Some significant differences (paired t test) on NIRS's oxy-hemoglobin and less interrelated results between "pushing a button" and brain activity at the second T-junction are obtained.

Furthermore, experimental results indicated that with the subjects moving their hand in circle, regardless of right or left, 1) the same response was observed in the prefrontal cortex and premotor area, and 2) different patterns of brain activities generated by moving either hand clockwise or counterclockwise.

The regions observed were only those with the 5% and less significance level. Possible extensions could be applied to other regions with the 10% and less significance level for the future study. With a larger number of subjects, brain activity patterns need to be made clear. In addition, it is thought to take particular note of participation concerning working memory when car is driven.

From results of these experiments, there was significant difference around working memory. So, experiments focusing on relationship turning wheel and working memory will be performed. On the other hand, experiments as to actual driving were required a broad range of perception and information processing. Especially, subjects had to determine behaves depending on various information at T-junctions, that is, the color of the traffic light, presence or absence foot passengers and so on. And so, we plan to perform more static experiments. we attention to differences on the basis of turning direction and dominant hand. In addition, we will conduct the experiments in which subjects were narrowed down to left-handedness. Furthermore, researches into other human brain activities than spatial perception are to be necessary with accumulated data from fMRI, EEG, etc.

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