Fundamental Study for Relationship between Cognitive Task and Brain Activity During Car Driving

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Abstract. For a long period, many researches about the human spatial recognition are being carried on. They are needed to make robot and automatic driving system for a car or wheelchair and with functions as high as those of humans: spatial perception, decision-making, and determining direction. The final goal of our measuring brain activity research is to contribute to developing of welfare robots with functions that are responsive like human. In this paper, the hemoglobin density change of human frontal lobe is measured. First, to analyze human spatial perception, experiments using a driving movie were designed. In the experiments NIRS (Near Infrared Reflectance Spectroscopy) was used.

Keywords: Drawing circle line, Frontal lobe, Prefrontal cortex, Premotor area.

1 Introduction

Human movements change the relative relation to his environment. Nevertheless, he recognizes a new location and decides what behavior to take. It is important to analyze 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]. When humans perceive space, for example, in a maze and try to decide the next action, 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 E.A. Maguire et al. measures the brain activations using complex virtual reality town [3]. But each and every task is notional and the particulars about the mechanism that enables humans to perceive space and direction is yet unknown.

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Recently, functional localization of the brain has been gradually clarified through many researches on brain functions. It is well known that in the frontal lobe higher order processing is done such as of memory, judgment, reasoning, etc. However, there is little information on what happens in the frontal lobe when every act of driving taken. We 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, the brain activity of frontal lobe, which related to behavioral decision-making is discussed from the viewpoint of human spatial perception. In particular, a driving movie is shown to the subjects as sensory information. Second, we measured the brain activity of frontal lobe how concern to the handling a wheel motion of drivers connects in action of car driving. Furthermore, The brain activity is to be measured and discuss the mechanism of information processing of the brain by analyzing experimental data on human brain activity during car driving using NIRS.

2 Experiment

2.1 Brain Activity on Driving Movie Is Shown

The subjects for this experiment were eight men 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.

An NIRS (Hitachi Medical Corp ETG-100) with 24 channels (sampling frequency 10 Hz) was used to record the density 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 car with a video camera aimed toward the direction of movement. The movie is included two scenes at a T-junction in which it must be decided either to turn to the right or left. In the second scene, there is a road sign with directions. The movie has nine kinds of movie in about one minute.

Before showing the movie, subjects were given directions to turn 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 they were to turn.

The subject's eyes which were closed and they take a rest during 10 seconds before they were shown the movies and made image after that. Then the brain activity was recorded from the first eyes-closed rest to the last eyes- close rest.

Here we will define Tasks A, B, and C; Tasks A and C were proposed as the same experiment tasks. After the subjects had pushed the button, task B was added as an operation in which the steering wheel was turned in the direction of destination when the subjects were able to judge the task proposed.

For this experiment, a PC (Personal Computer) displayed the movie 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 is recorded the brain activity, the trigger pulse from PC and the pulse from the button that gets pushed at the second T intersection. Fig 1 shows the image of this experiment.

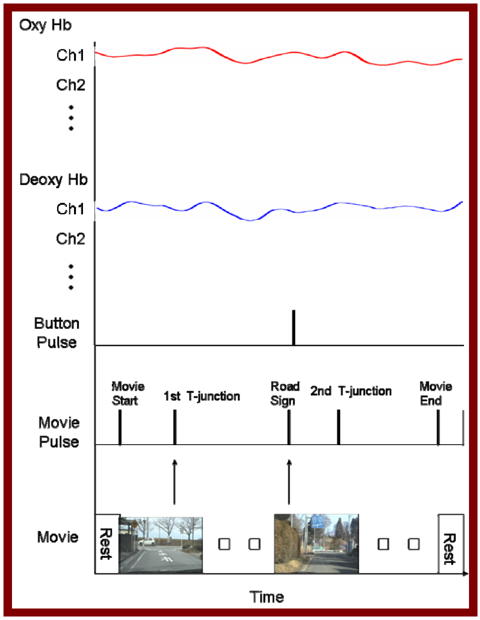

Fig. 1. NIRS records each hemoglobin and pulses

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.

2.2 Brain Activity on Handling Motion

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 using a steering wheel. A PC mouse on the table was used to simulate handling a wheel, and NIRS (near-infrared spectroscopy) to monitor oxygen content change in the subjects' brain. NIRS irradiation was performed to measure brain activities when the subject sitting on a chair making a drawing 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 a circle. The time design was rest(10 seconds) task(20 seconds) - rest(10 seconds).

3 Experimental Result

3.1 Brain Activity on Driving Movie Is Shown

For task A and B, the suggested place the subjects were headed to informed direction, and they let decided which way to turn the road sign. At the T-junction, they were to push the button when they realized the direction. In task A, the task was added after the button indicating the direction to turn was pushed by the subjects. The

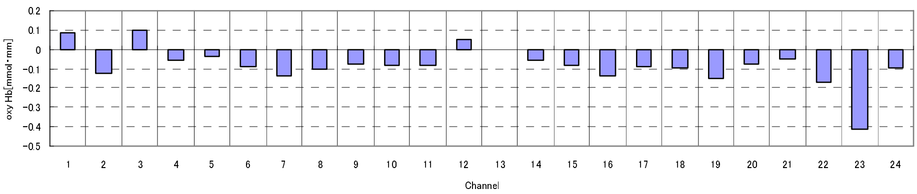

Fig. 2. Result from subject A of task A

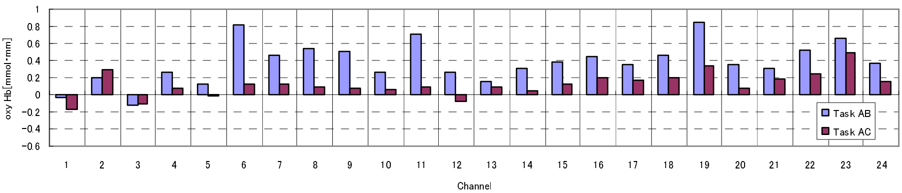

Fig. 3. Compared between turrning the steering wheel and not

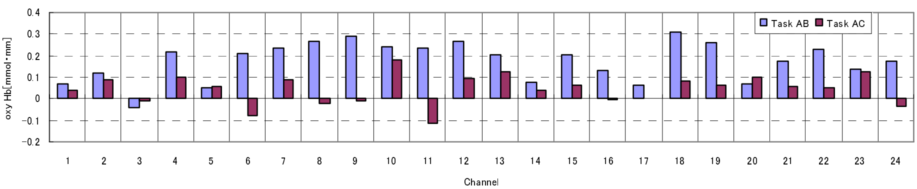

Fig. 4. Compared between turning the steering wheel and not

hemoglobin variation was compared in the results of Tasks A and B, A and C to see the brain activity pertaining to special perception during the same movie.

Structure (1) was used to compare the data. τ_1 was set the time as its length was 1 second before being pushed the button. Similarly, τ_2 was set in a way similar to τ_1. And $x_i\,(t)$ indicates variation of i channel oxy hemoglobin or de-oxy hemoglobin. We then took a average of $x_i(t)$ throughτ_1 andτ_2. 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. Fig 2 shows the sample result for this calculation $c(i)$ in task A with oxy-hemoglobin.

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

A comparison was made between the situations in which the steering wheel was turned and when it was not. Fig 3 is the calculation result of the test subject A with the tasks A and B. And fig 4 is the calculation result of him with the tasks A and C.

For fig 3, it could be found that the incrementation of oxy-hemoglobin was higher when the steering wheel was turned than when it was not. On the other hand; fig 4, it could be found that the tendency in some channel increasing de-oxy hemoglobin. Therefore, it could be found that the total amount of hemoglobin was increased in the frontal lobe.

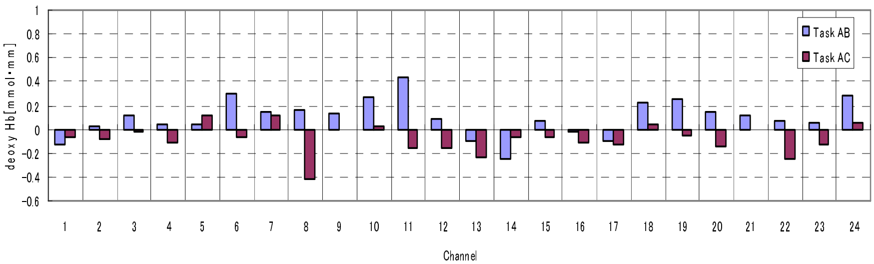

Fig. 5. Compared between turning the steering wheel and not (oxy Hb of average)

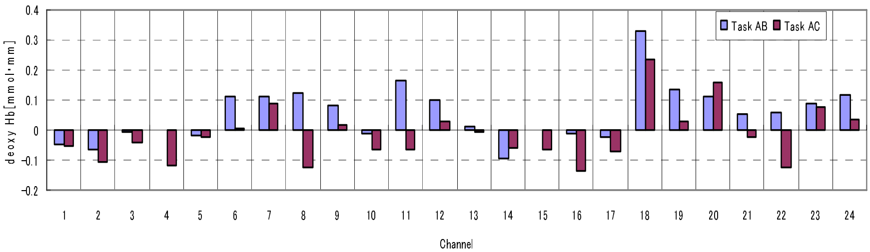

Fig 6. Compared between turning the steering wheel and not (deoxy Hb of average)

The next step was to calculate the average of all subjects. Fig 5 and 6 show the results. Many upward tendencies could be found in fig 5. This might have occurred when they were finding they way from a road sign. In addition, the results indicate a greater increase when the subjects turned the steering wheel. That means Observation of brain activity has been made during movement based on spatial perceptions.

On the whole, the variation in de-oxy hemoglobin (Fig 6) 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. 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.

d_1 and d_2 shown in fig 7 are defined as below. d_1 is the variation of hemoglobin turning at the first T-junction. And d_2 is variation of hemoglobin at the second one. From the measurement result, d_1 and d_2, all of the 269 times of each subject, there were significant differences in oxy hemoglobin 3ch. ($p<0.02$: paired t test) and 20ch. ($p<0.03$) in fig 8 using NIRS.

Subjects pushed a button before turning at the second T-junction, so it influenced brain activities. The possibility of a correlation between d_2 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

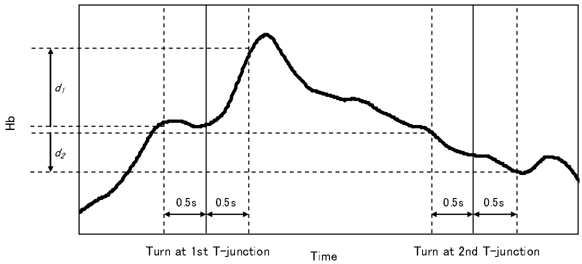

Fig 7. Define variation of hemoglobin d1 and d2

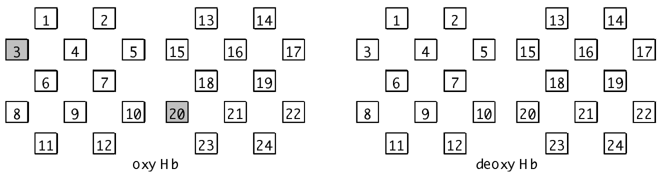

Fig 8. Significant differences at NIRS's oxy-hemoglobin are gray.

paired *t* test. In only this result, the relationship between pushing a button and d_2 cannot be judged.

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 are 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 part of prefrontal cortex a number of significant differences were 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.1) It is well known that in the outside prefrontal cortex higher order processing is done such as of behavior control. It is inferred that the pre-motor area was activated when the subjects moved the hand in the way stated above because the pre-motor area is responsible for behavior control, for transforming visual information, and for generating neural impulses controlling.

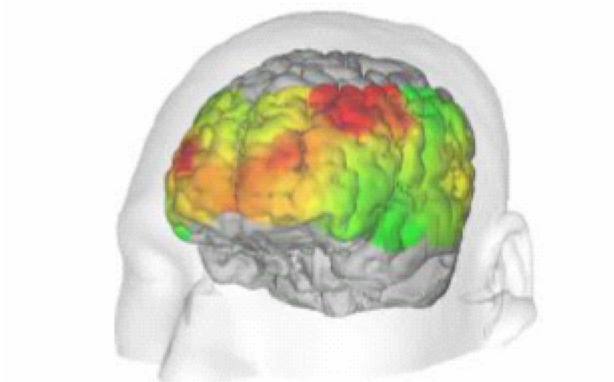

Fig. 9. Brain activity (Clockwise)

4 Conclusion

The hemoglobin density change of the human subjects' frontal lobe is 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 suggest that human behavioral decision-making of different types may cause different brain activities as we saw in the tasks: 1) take a given direction at the first T-junction, 2) take a self-chosen direction on a road sign at the second T-junction and 3) turn 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. Researches into other human brain activities than spatial perception are to be necessary with accumulated data from fMRI, EEG,etc.

Furthermore, experimental results indicate 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.

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