Basic study for Human Spatial Cognition Based on Brain Activity during Car Driving

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***Abstract*—The purpose in this research is to contribute to developing of assistive robot and related-apparatus. Recently, there is a pressing need to develop a new system which assists and acts for car driving and wheelchair for the elderly as the population grows older. In terms of developing a new system, it is thought that it is important to examine behaviors as well as spatial recognition. Therefore, experiments have been performed for an examination of human spatial perceptions, especially right and left recognition, during car driving using NIRS. In previous research, it has been documented that there were significant differences at dorsolateral prefrontal cortex at left hemisphere during virtual driving task and actual driving. In this paper, brain activity during car driving was measured and detailed analysis was performed by segmentalizing brain activity during car driving on the basis of subjects' motion. So, we report the relationship between brain activity and movement concerned with perception during driving in this paper.**

Keywords-brain information processing during driving task; spatial cognitive task;determining direction; NIRS.

I. INTRODUCTION

Human movements change relative to his environment. Nevertheless, he/she 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, try to decide the next action in a maze, 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, every task is notional and the particulars about the mechanism that enables humans to perceive space and direction are yet unknown. Also, Brain activities concerned with cognitive tasks during car driving have been examined. For example, there was a report about brain activity when disturbances were given to subjects who manipulated a driving simulator. Also, power spectrums increased in beta and theta bands [4]. However, there is little report on the relationship among right and left perception and driving task.

So, we performed experiments in which perception tasks were required during virtual car driving using Near Infrared Spectroscopy (NIRS) [5]. From experimental results, there were significant differences at dorsolateral prefrontal cortex in left hemisphere via one-sample t-test when subjects watched driving movie and moving their hand in circles as if handling a steering wheel [6].

In addition, we conducted experiments in real-space, which were performed by taking NIRS in the car, and measured the brain activity during actual driving. A purpose in this experiment was to measure and analyze the brain activity during actual driving to compare results between virtual and actual results. As a result, there were significant differences at similar regions [7][8]. In addition, we measured the brain activity of frontal lobe, which is related to behavioral decision-making, during car driving in different experimental design from previous one to verify previous results [9][10].

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It is well known that higher order processing, such as memory, judgment, reasoning, etc. is done in the frontal lobe [11]. We tried to grasp the mechanism of information processing of the brain by analyzing data about human brain activity during car driving. Also, the goal of this study is to find a way to apply this result to new assist system.

So, with the aim of increasing number of subjects and examining more closely the brain activity concerned with spatial perception and direction determination during car driving, we performed additional experiments.

In this time, the brain activity of same lobe with human spatial perception and direction determination was discussed on the basis on changing direction of the gaze and starting to turn the steering wheel. Furthermore, we examined the mechanism of information processing of the brain and human spatial perception during car driving.

II. Experiment

A. Brain activity on virtual driving

1) Brain activity on driving movie is shown

The subjects for this experiment were eight males who 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.

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. We used nine kinds of movies 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 in which they were to turn.

2) Brain activity on handling motion

In this experiment, measuring was performed by NIRS, made by SHIMADZU Co. Ltd with 44ch. Five subjects were healthy males in their 20s, right handed with a good driving history. They were asked to read and sign an informed consent regarding the experiment.

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 make 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 per a circle. The time design was rest (10 seconds at least) – task (20 seconds) – rest (10 seconds) - close rest.

B. Brain activity during actual car driving

1) Brain activity during actual car driving

In general roads, experiments were performed by taking NIRS in the car, and measuring the brain activity when car driven by subjects was went through two different intersections. Six subjects were a healthy male in their 20s, right handed with a good driving history. They were asked to read and sign an informed consent regarding the experiment. In all experiments, measurements were performed by NIRS (Near Infrared Spectroscopy), made by SHIMADZU Co. Ltd [11].

Subjects took a rest during 10 seconds at least with their eye close before driving task and they drove a car during about 600 seconds. Finally, subject closed their eyes for 10 seconds again after task. Then, the brain activity was recorded from the first eyes-closed rest to the last eyes. Subjects were given directions to turn to the right or left at the first T-junction during driving task. They were also taught the place which was on the road sign at the second T-junction. And, they were given the place where they have to go to. So, they had to decide the direction when they looked at the road sign.

A trigger pulse was emitted on stop lines at T-Junctions to use as a measuring stick for the analysis.

Figure. 1. Recorded movie during measurement.
(This picture was view subjects was watched.)

Figure. 2. Sample of first T-Junction
(This T-junction has no sign.)

Figure. 3. Sample of second T-Junction
(This T-junction had a load sign which was shown the direction and place name.)

Also, we recorded movie during the experiment from a car with a video camera aimed toward the direction of movement (Figure. 1). Recorded movies were used to exempt measurement result including disturbances, such as foot passengers and oncoming cars, from analysis. Figureure.2 and figureure.3 shows one sample of T-junction.

2) Verification Experiment

To conduct verification for experimental results in previous experiment, we performed additional experiment which was achieved in a similar way.

In this experiment, experimental course was different from previous one. While previous one was included two T-junctions in which there was road sign at second one and not at first one per a measurement, there were multiple T-junctions. Three were 5 T-junction without road sign and 4 T-junctions with road sing.

Subjects were twelve males who were all right-handed. They drove a car during about 20 minutes after a rest during 10 seconds at least with their eyes close. Subjects were enlightened about turning direction and the place on which road signs was at T-junction during measurement. And, they arbitrarily decided the direction to turn when they confirmed road signs. Also, a trigger pulse was emitted in the same way.

3) Detailed analysis based on driving behavior

In this analysis, movies aimed toward the direction of movement as well as ones aimed subject movement like ocular motion and arm movement were recorded. This is to analyze brain activity using ocular motion in looking at road signs as a trigger. In previous research we performed, stop line at T-junction was used as a trigger. But, brain activity in T-junction involved movement task such as turning steering wheel, changing neck direction, hitting the brake. So, it is thought that brain activity derived from cognitive tasks was overwritten with brain activity due to movement tasks. Therefore, we tried to analyze brain activity on the basis of ocular motions to examine significant differences with cognitive tasks.

III. EXPERIMENTAL RESULTS

A. Brain activity on virtual driving

1) Brain activity on driving movie is shown

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(around #10 area of the dorsolateral prefrontal cortex of the right hemisphere). This might be the variation based on the spatial perceptions

Next, differences were investigated concerning the subject's brain activity. As the first case, it was when the vision was directed after having been told the direction. As the Second, it was when the vision was directed after having been decided the direction under the road sign.

Here, d1 and d2 were defined to analyze measurement data. d1 is the variation of hemoglobin turning of one second 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. These regions were corresponded to around #46 area of the dorsolateral prefrontal cortex of the left hemisphere and around #10 area of the dorsolateral prefrontal cortex of the right hemisphere, respectively.

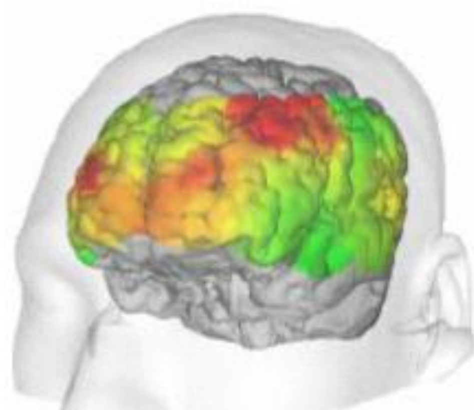

Figure. 4. Brain activity (clockwise)

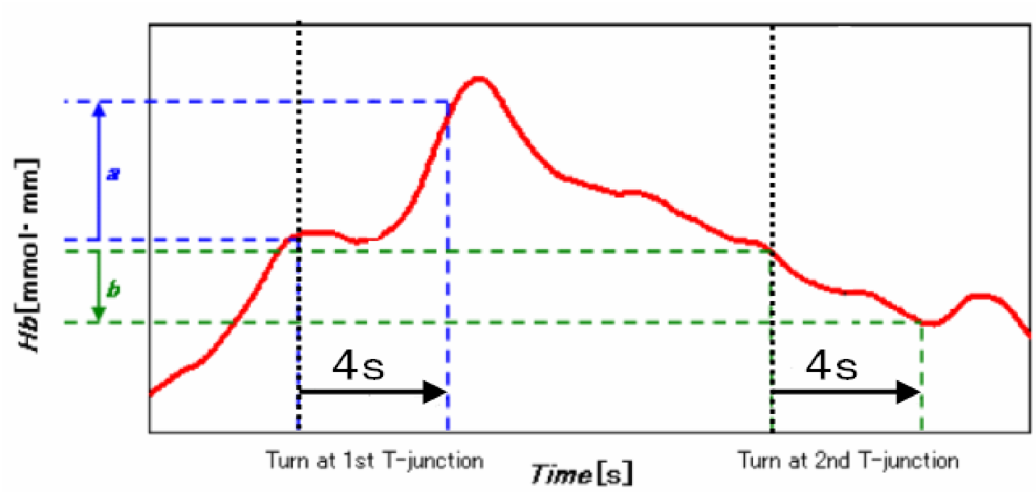

Figure. 5 Analysis method

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 (around #10 area of the dorsolateral prefrontal cortex of the right hemisphere) using paired t test. In only this result, the relationship between pushing a button and d2 cannot be judged.

2) Brain activity on 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 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) (Figure.4). 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.

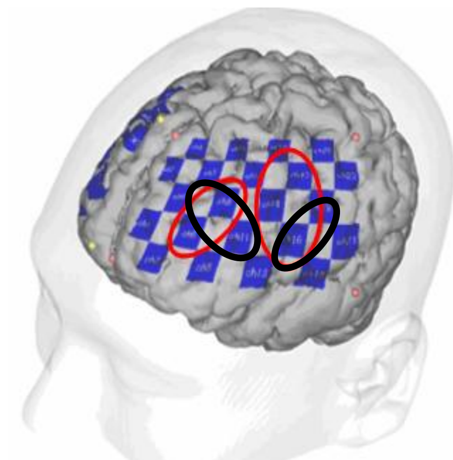

Figure. 6 Significant differences at the turn left

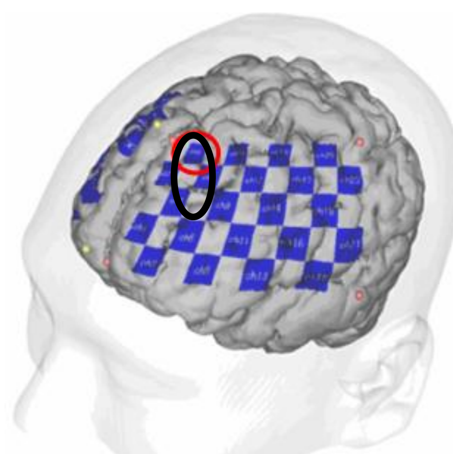

Figure. 7. Significant differences at the turn right

B. Brain activity during actual car driving

1) Brain activity during actual 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 experimental vehicle reached stop line at T-junction. The analysis was performed one-sample t-test using a and b within the significant difference level 5% or less between zero and about four seconds (Figure.5). Here, a is the variation of hemoglobin turning of one second at the first T-junction. And b is variation of hemoglobin at the second one. As the results, there were significant differences around #46 area of the dorsolateral prefrontal cortex and the premotor area of the left hemisphere brain in turning left(Figure. 6:red). Also, there were significant differences #9 of the dorsolateral prefrontal cortex of the left hemisphere brain at the turn right (Figure. 7: red).

2) Verification Experiment

Various tendencies among individuals were observed in comparison with results in B. However, there were tendency that oxy-Hb was increased when car turned left or right at T-junctions and oxy-Hb was decreased during going straight

The analysis method was the same as previous one. Though Gaps were shown regions at which there were significant differences, there were significant differences in common region, too (Figure. 6, 7: black). In the analysis, measurement results including disturbance at T-junctions were excluded as analysis object.

3) Detailed analysis based on driving behavior

The analysis was performed one-sample t-test within the significant difference level 5% or less between brain activity before and after looking at road sign. Each of sample data for analysis was 1 second. Also, analysis was performed with respect to each direction which subject had to go at next T-junction. As a consequence of analysis, there were significant differences at interior front gyrus of flontal lobe of left hemisphere without reference of direction (Figure 8 and Figure 9).

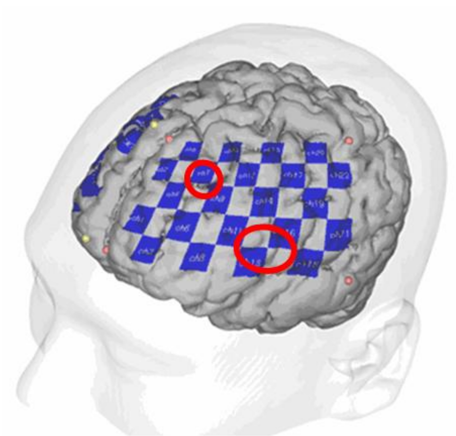

Figure. 8. Significant difference at left direction of road sign

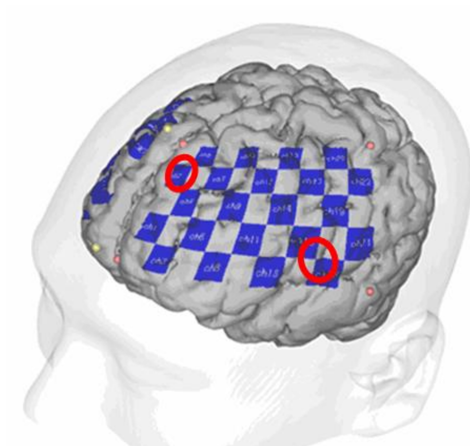

Figure. 9. Significant difference at right direction of road sign

IV. Conclusion and Future Work

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.

Furthermore, it was found that there were significant differences around #44-45 area. It is well known that this region is corresponding to language area. So, it is thought that subjects look at road map to determine direction that they have to go according to word described in road sign.

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 (functional magnetic resonance imaging), EEG (Electroencephalogram), etc.

When compared virtual result to actual ones, there were significant differences around #46 area in both experiments, which were performed in virtual and actual condition, as a common result. It is thought that this result is due to activities of working memory because subjects must to recall memories of movements required for car driving and turning steering wheel. Conversely, there were significant differences around #10 in virtual experiments and around premotor area in actual driving, respectively. In the virtual case, it is thought to result from inhabitation of task without movement. In the actual case, subjects had to perceive space information in real time. So, it is considered that there were significant differences around premotor area because they always ready up to manipulate steering wheel.

As a future plan, we aim to apply these results to assistive human interface. As a matter of course, we plan to performed additional experiments including the verification of these results. And final purpose is to develop a new system for manipulating wheelchair and information presentation system to assist recognition of information including spatial one during car driving.

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