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Recognition of perception and the localization for aperture problem in visual pathway of brain

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***Abstract*— The aperture problem is the one of the experiments to analyze binding mechanism of the space recognition with the human visual pathway. Nishina has already insisted that recognition of visual perception by the aperture problem depends in display time. In this paper, we discuss how other experimental parameters, e.g., radius, distance between circles, and speed of bar depend with recognition rate by measurement analysis of the perception. We simultaneously estimate the reaction latency of the perception by electroencephalograms(EEG) analysis, and we localize the brain activity area by equivalent current dipole(ECD). We then discuss the relationship between the reaction latency of the visual evoked potential(VEP), event related potential(ERP) and the localized equivalent current dipole(ECD) in the visual pathway. By these discussion, we concluded that perception would be localized with the prefrontal lobe.**

I. INTRODUCTION

Aperture problem [1], [2], [4]–[8] is one of the experiments to analyze binding mechanism of the spatial recognition in human early visual sysytem. A circle aperture that the base bar moves in a background is displayed first at the center coordinate of computer display. Two other circles which the flanking bar with the endpoints moves in the background are displayed in both sides of the center circle on the way which the base bar moves from the left lower side as the starting point to toward the upper right corner. The flanking bar, however, moves from the bottom side to the upper vertical orientation. If a subject perceived that the straight line where the base bar and the flanking bar were connected to, then the orientation of the base bar's movement is dragged with the flanking bar's movement, and the subject would perceive that the base bar's direction changed into the same upper vertical orientation as the flanking bar. We call the phenomenon "optic illusion" or "perception". Nishina et al. [2], [3] have already insisted that the recognition of visual perception strongly depends on radius, distance between circles and time scale for displaying the flanking bar (shortly, the display time). We ratified a result of Nishina and argued with dependence for the display time of the perceptual rate [6], [7]. However, we have simultaneously noticed that the perception rate rather decreases at the display time later than 550ms.

In this paper, we use two kinds of analyses namely visual measurement analysis and the electroencephalograms(EEG) analysis and discuss again with dependence of the perceptual rate for the display time and dependence of the perceptual rate for the speed of bar. By two kinds of analyses, we can discuss which part of the brain is related to the perception, and what mechanism causes the perception. In the visual measurement analysis, the perceptual recognition rate is calculated with changing radius, distance between circles, display time, and speed of bar. We particularly discuss the influence of the speed of bar to the perceptual rate. Meanwhile, we argue that subjects tend to fail to recognize the perception on the long display time. We then discuss the dependence of the perceptual rate on the speed of bar by trend analysis. In EEG analysis [9]–[11], we measure the visual evoked potential(VEP) and event related potential(ERP) with the perception in order to localize the brain activity area with changing radius, distance between circles, display time, and speed of bar. Then, the relationship between the latency of VEP and ERP by the perception and the localized equivalent current dipole(ECD) in the visual pathway is discussed. At the last, we conclude which part of the brain relates to VEP and ERP for the perception, and what mechanism causes the perception.

II. APERTURE PROBLEM

Figure 1 shows an experimental subject and the experimental arrangement in aperture problem. In the experiment, a subject is anchored by the frame equipment in position to keep the distance between the subject and the computer display be 100cm. The display is FMV-DP9713 manufactured by Fujitsu Co. Ltd., whose vertical frequency is 85.0Hz, whose horizontal frequency is 68.7KHz, and whose resolution is 1280 x 960pixels.

The draft of aperture problem is shown in Figure 2. We call here a bar in the center circle the base bar, and two kinds of bars in both side circles of the center circle the flanking bar. If a subject perceived that the line joining the base bar and the flanking bar is straight, then the orientation of the base bar's movement is dragged with the flanking bar's movement, and the subject would perceive that the base bar's movement was changed the same upper vertical orientation

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as the flanking bar. We call the phenomenon “optic illusion” or “perception”.

In this paper, we discuss with dependence of the perceptual rate for the experimental parameters by two kinds of analyses, the visual measurement analysis and EEG analysis. In the visual measurement analysis, the perceptual recognition rate is actually calculated to ten subjects in 18 to 22 years old. In EEG analysis, VEP and ERP are measured to one subject in 22 years old.

Figure 3 shows an explanatory drawing for the following sequence of the experimental operation.

(a) A point of attention and a circle are described at the center coordinate of the computer display.
(b) The base bar moves toward the upper right orientation from the the lower left side.
(c) The flanking bar moves toward the upper vertical orientation from the bottom side in both side circles of the center circle. The subject judges the perception.
(d) The center circle only remaines after the flanking bar and two circles are disappeared.
(e) The subject answers the perception, and the perceptual recognition rate is calculated by these answers. Then, VEP and ERP are measured by EEG, and ECD is localized.

Fig. 1. An Experimental Subject and Arrangement

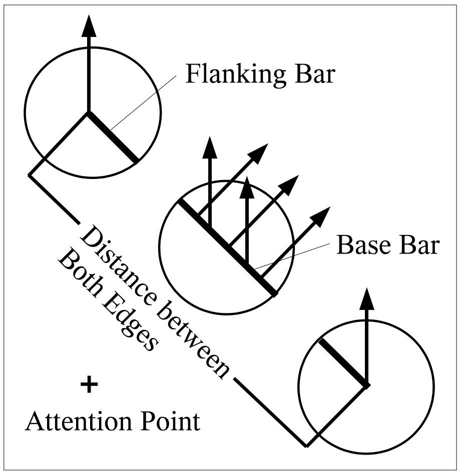

Fig. 2. Aperture Problem

We here conduct the following seven experiments for aperture problem, where R means the radius, SB means the speed of bar, DT means the display time, DC means the distance between circles, and DBM means the distance the bars moved.

Exp.1: Perceptual rate is measured by visual measurement analysis under constant conditions of SB:14.28mm/sec and R:8.7mm, and under conditions that parameters are changing as DC:40.4, 80.8, 121.2, 161.6mm and DT:100, 200, 300, 400, 500, 600msec.

Exp.2: Perceptual rate is measured by visual measurement analysis under constant conditions of SB:14.28mm/sec and DC:121.2mm, and under conditions that parameters are changing as R:8.7, 11.4, 14.3, 17.1mm and DT:100, 200, 300, 400, 500, 600msec.

Exp.3: Perceptual rate is measured by visual measurement analysis under constant conditions of DC:80.8mm and R:8.7mm, and under conditions that parameters are changing as DBM:5.7, 7.1, 14.3mm and DT:100, 200, 300, 400, 500, 600, 800, 1000, 1200msec.

Exp.4: Latency of VEP and ERP is estimated by EEG analysis under constant conditions of SB:14.28mm/sec, R:8.7mm and DT:500msec, and under conditions that DC is changing as DC:28.6, 57.2, 85.7mm.

Exp.5: Latency of VEP and ERP is estimated by EEG analysis under constant conditions of SB:14.28mm/sec, DC:85.7mm and DT:500msec, and under conditions that R is changing as R:8.7, 11.5, 14.3mm.

Exp.6: Latency of VEP and ERP is estimated by EEG analysis under constant conditions of DC:57.1mm, R:11.4mm and DT:500msec, and under conditions that SB is changing as SB:2.9, 5.7mm/sec.

Exp.7: ECD is localized under constant conditions of DC:57.1mm, R:11.4mm, DT:500msec, and SB:14.28mm/sec, and the relationship between the latency of VEP, ERP and the localized ECD is discussed.

The perceptual rate is calculated by the total 150 answers of five repeated experiments of ten subjects under experimental conditions that the orientation of base bar’s movement is fixed at 45 degrees and the orientation of flanking bar’s movement is changing at 0, 45 and 90 degrees. The latency of VEP and ERP is estimated by the total 60 repeated experiments under experimental conditions that the orientation of flanking bar’s movement is changing at 0, 45, and 90 degrees, and the control condition of VEP and ERP is to hide the flanking bar. In the exp.7, ECD is localized by the total 350 experiments under experimental conditions that the orientation of flanking bar’s movement is changing at 0 degree and 90 degrees

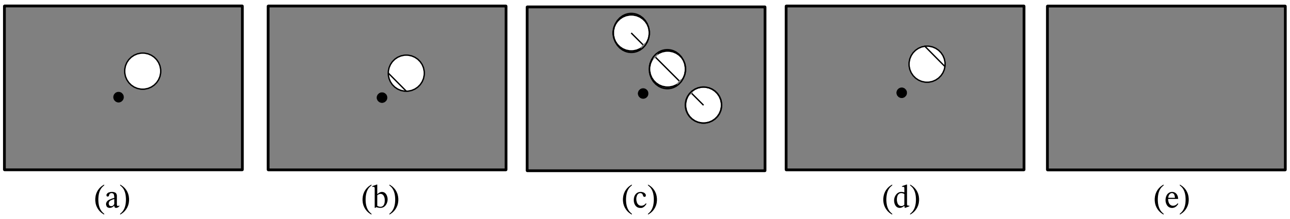

Fig. 3. Sequence of Experimental Operation

III. VISUAL MEASUREMENT ANALYSIS

The perceptual rate of the exp.1 to the exp.3 are shown in Figure 4 to Figure 6, respectively. Figure 4 shows the perceptual rate under constant condition of SB, and under changing conditions of DC and DT. Figure 5 shows the perceptual rate under constant condition of SB, and under changing conditions of R and DT. Figure 6 shows the perceptual rate under changing conditions of SB and DBM.

The perceptual rate in Figure 4 increases with decreasing size of DC. The perceptual rate in Figure 5 increases with increasing size of of R. Both perceptual rates in Figure 4 and Figure 5 increases with increasing DT. By these results, it is obvious that the perceptual rate depends on the combination of the radius and distance between circles, and dispaly time.

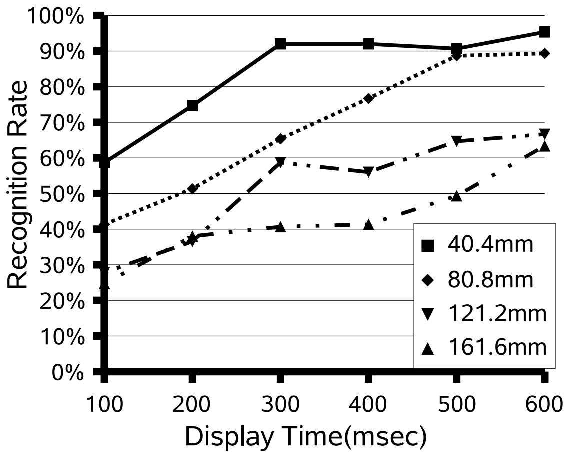

Fig. 4. R.R. under Changing Conditions of DC

On the other hand, we should notice that the perceptual rate is not monotonously decreasing in spite of increasing of SB in Figure 6. In general, we suppose that subject would easily recognize the perception whenever the speed of bar is slow. To verify the strange nonlinearity, we calculated trend of the perceptual rate with changing of SB by trend analysis. Table I shows the trend of perceptual rate with changing of SB under constant condition of DBM:5.7mm. In particular, the F-test value of perceptual rate with changing order of SB is calculated. The F-test values of perceptual rate with the second, the third, and the fourth order of SB are

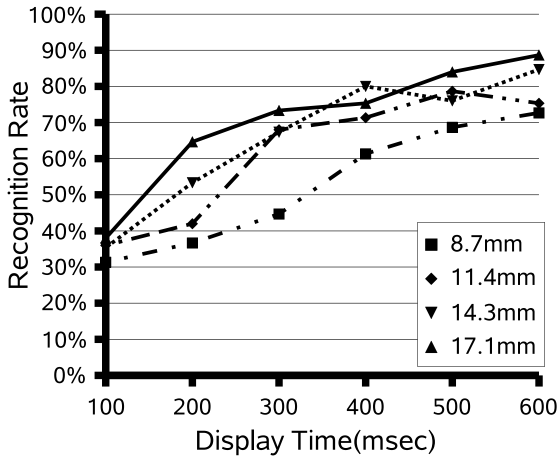

Fig. 5. R.R. under Changing Conditions of R

larger than the critical value, 7.00, at $p = 1\%$ of the degree of freedom(1,72). Therefore, we conclude that a significant trend of perceptual rate with changing the second, the third and the fourth order of SB was verified.

TABLE I

INFLUENCE OF SPEED OF BAR TO PERCEPTURAL RATE

Elements		Square Sum	Free Deg.	Ave. Sq. Val.	F Val.	p Val.
Speed of Bars		158.36	8	19.79	5.61	< 0.01
Order	1	1.93	1	19.27	5.46	n.s.
	2	72.13	1	72.13	20.44	< 0.01
	3	37.46	1	37.46	10.33	< 0.01
	4	39.48	1	39.48	11.19	< 0.01
	5	1.97	1	1.97	0.56	n.s.
Error		254.09	72	3.53		
Total			85			

IV. EEG ANALYSIS

We estimated here the latency of VEP and ERP of subject by EEG analysis, and ECD is simultaneously localized by the exp.4 to the exp.7. As a result, VEP was constantly detected after 340ms of the reaction latency(RL), that is after appearing of the base bar. In the exp.4, when the flanking bar appeared, the amplitude of ERP peaked at RL:900ms. On the other hand, ECD was localized at the right inferior frontal gyrus(RL:1,160ms to 1,170ms) and the left middle

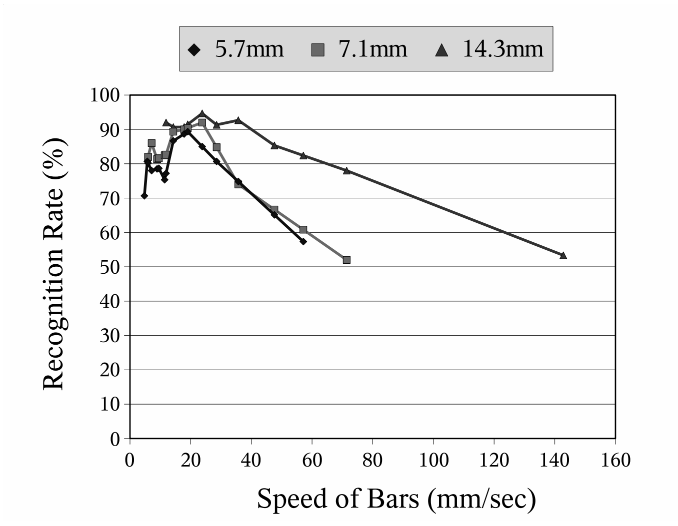

Fig. 6. R.R. under Changing Conditions of SB

frontal gyrus(RL:1,230ms to 1,250ms) when the flanking bar particularly moved in the horizontal orientation(0 degree) and the vertical orientation(90 degrees). Figure 7 shows the localized ECD at the middle frontal gyrus when the flanking bar moved in the horizontal orientation(0 degree) and the vertical orientation(90 degrees). The large amplitude, however, wasn't detected in the orientation of 45 degrees.

Thus, ECD was only localized at the frontal gyrus whenever subject recognized the perception, and the conclusion is acceptable because the frontal gyrus primarily relates to spatial recognition.

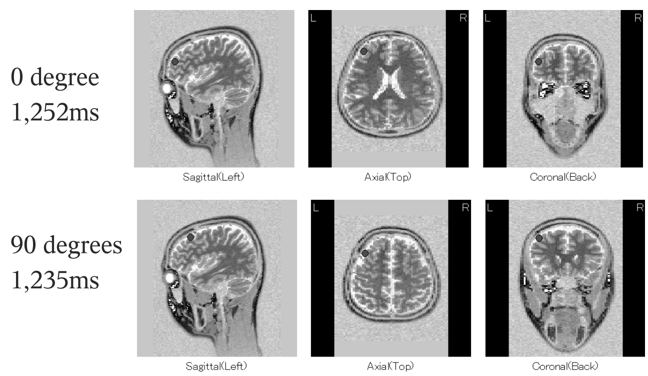

Fig. 7. Localization of ECD in the Fourth Experiment

In the exp.5, the amplitude of ERP peaked at RL:1,300ms when the flanking bar appeared as the exp.4. ECD was then localized at the right superior frontal gyrus(RL:1,640ms to 1,650ms) and the left middle frontal gyrus(RL:2,040ms to 2,050ms) when the flanking bar particularly moved in the horizontal orientation(0 degree) and the vertical orientation(90 degrees). Figure 8 shows the localized ECD at the superior frontal gyrus when the flanking bar moved in the horizontal orientation(0 degree) and the vertical orientation(90 degrees). The large amplitude, however, wasn't detected in the orientation of 45 degrees.

Thus, ECD was only localized at the frontal gyrus whenever subject recognized the perception, and the conclusion is acceptable because the frontal gyrus primarily relates to spatial recognition.

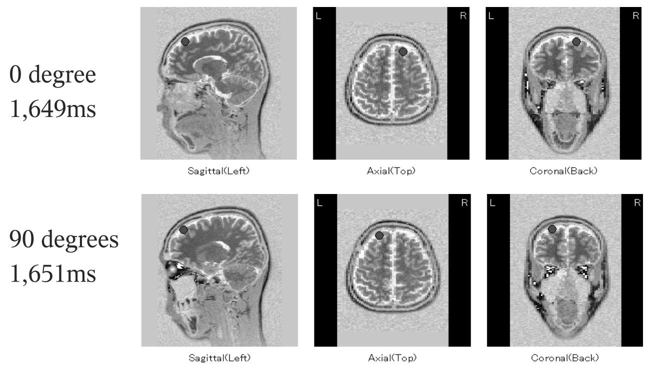

Fig. 8. Localization of ECD in the Fifth Experiment

In the exp.6, VEP and ERP were constantly detected after appearing of the base bar, but the large amplitude wasn't detected in the any orientation including 0 degree and 90 degrees.

In the exp.7, we localized the propagated area of brain related to the flanking bar's movement after RL:340ms under experimental condition that the orientation of flanking bar's movement is fixed at 90 degrees. The amplitude of VEP peaked at reaction latency at 100ms to 400ms, and the amplitude of ERP peaked at two periods of reaction latency, at 500ms to 700ms, and at 1,000ms to 1,300ms. Simultaneously we localized ECD of three peaks. Figure 9 shows VEP and ECD at RL:245ms in V4. Figure 10 shows ERP and ECD at RL:625ms(at RL:285ms after appearing of the flanking bar) in MT.

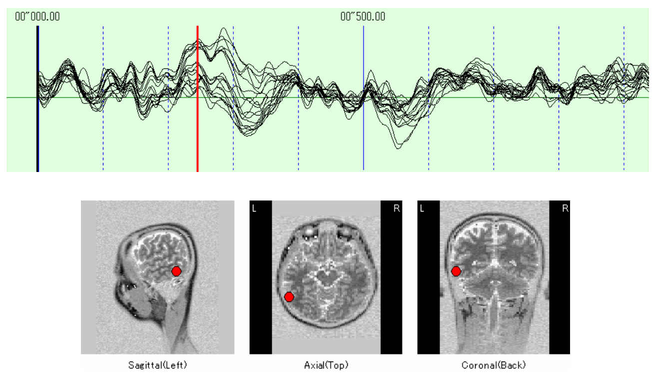

Fig. 9. VEP and ECD in V4

In general, the visual signal activated at ocular propagates from retina to prefrontal cortex via optic hiasm, LGN, and primary visual cortex. In particular, the visual signal of the primary visual cortex propagates two divided pathways

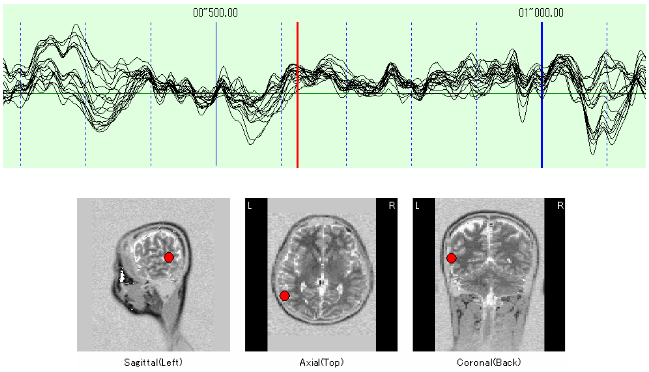

Fig. 10. ERP and ECD in MT

which are the ventral pathway from the primary visual cortex to prefrontal cortex via temporal lobe, and the dorsal pathway from the primary visual cortex to prefrontal cortex via parietal lobe. It's said that the ventral pathway primarily relates to symbolic recognition, and the dorsal pathway primarily relates to spatial recognition. By the knowledge and ECD of the exp.7, the following ventral pathway and the dorsal pathway were described at each reaction latency.

V.Path.: V1 (133ms) → V2 (171ms) → V4 (245ms) → TEO (306ms) → TE (357ms)

D.Path.: V1 (576ms) → V2 (611ms) → MT (625ms) → Occipital Lobe (711ms)

The visual signal of the primary visual cortex propagates through the ventral pathway according to the reaction latency as figured in Figure 11. In the exp.7, the center circle appears at RL:0ms, and the base bar starts to move at RL:340ms. Therefore, we presumed that the localized ECD in Figure 11 derives from appearing of the center circle. The brain activity in the dorsal pathway is also figured in Figure 12. We also presumed that the localized ECD in Figure 12 derives from movement of the base bar because of the bar's start at RL:340ms.

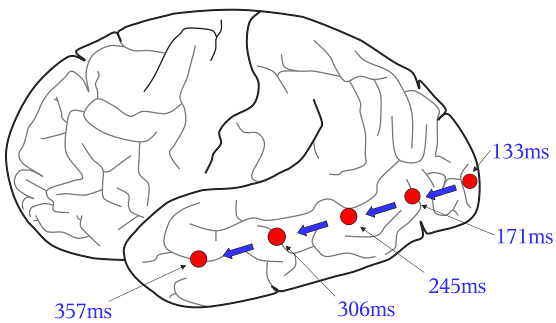

Fig. 11. Localization of ECD in Ventral Pathway

By comparing the latency of VEP, ERP and these localized ECD, we should notice that the brain activity propagated through ventral pathway originated the peak amplitude of VEP at the period of latency of 100ms to 400ms related to appearing of the center circle. Similarly, we should notice that the brain activity propagated through dorsal pathway originated the peak amplitude of ERP at the period of latency of 500ms to 700ms related to appearing of movement of the base bar. Since the ventral pathway primarily relates to symbolic recognition, and the dorsal pathway primarily relates to spatial recognition, these conclusions are absolutely acceptable.

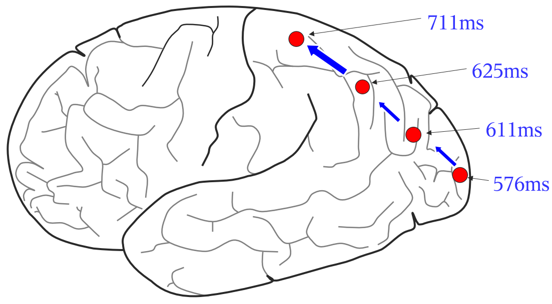

Fig. 12. Localization of ECD in Dorsal Pathway

Now, which part of brain relates to the peak amplitude of ERP at the period of latency of 1,000ms to 1,300ms? What mechanism causes the perception? To analysis the problem, we focused the ECD localization after the flanking bar moved. Consequently, we concluded that ECD was localized at the right superior frontal gyrus(RL:1,165ms to 1,172ms) and the left middle frontal gyrus(RL:1,235ms to 1,252ms) when the flanking bar moved in the horizontal orientation(0 degree) and the vertical orientation(90 degrees). Figure 13 shows the localized ECD by movement of the flanking bar. We should notice that the brain activity propagated through frontal lobe originated the peak amplitude of ERP at the period of latency of 1,000ms to 1,300ms related to appearing of movement of the flanking bar. The conclusion that the perception would be originated at the prefrontal lobe is significant, because the left middle frontal gyrus relates to spatial recognition as temporal memory, and the right inferior frontal gyrus relates to motor recognition as temporal memory.

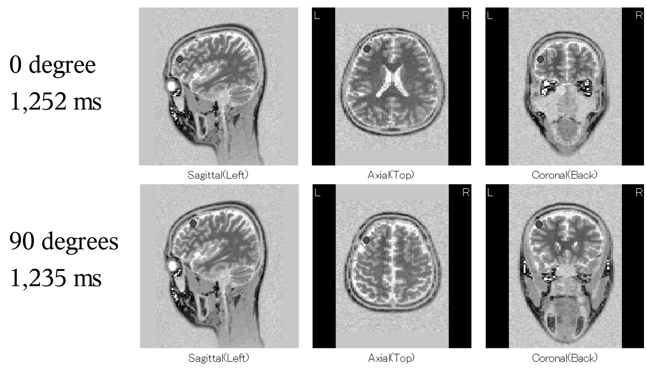

Fig. 13. Localization of ECD by Movement of Flanking Bar

V. CONCLUSION

In this paper, we discussed that perception in aperture problem depended on display time and speed of bar by visual measurement analysis, and we concluded that the perceptual rate particularly depends on the second, the third and the fourth order of speed of bar. We also discussed that the brain activity area of the perception was localized in visual pathway and frontal lobe by the electroencephalograms analysis. At the last, we concluded that perception would be originated at the prefrontal lobe by relationship between the latency of visual evoked potential and equivalent current dipole. However, we should ensure our hypotheses more by various experiments and many subjects in the near future.

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