Estimation of brain activity for perception of aperture problem

Isao Hayashi
Kansai University
Takatsuki, Osaka, Japan
ihaya@kcn.res.kutc.kansai-u.ac.jp

Hisashi Toyoshima
Hokkai Gakuen University
Sapporo, Hokkaido, Japan
toyosima@isrc.co.jp

Takahiro Yamanoi
Hokkai Gakuen University
Sapporo, Hokkaido, Japan
yamanoi@eli.hokkai-s-u.ac.jp

***Abstract*—Aperture problem is a psychological experiment for analyzing binding mechanism of the spatial recognition in an early stage of visual pathway. In this paper, we measure perceptual rate in the aperture experiments, and discuss the dependency between the perception and various parameters in the experiments. We also record Electroencephalograms(EEG) of subjects who are recognizing the perception. By the electroencephalograms(EEG) analysis, we measure reaction latency of visual evoked potential (VEP) and event related potential(ERP) related to visual pathway, and estimate the localized equivalent current dipole(ECD) in the visual pathway.**

I. Introduction

Aperture problem [1]–[7] is a psychological experiment to analyze binding mechanism of the spatial recognition. A circular aperture that a base bar moves in the background first is displayed at a central coordinate position of a computer display. While the base bar moves to the top right corner orientation from the the lower left side as the starting point, two other circles that a flanking bar moves in the background appear at both ends of the center circle. The flanking bar, however, moves to the upper orientation from the lower side. If a subject perceived that the line joining the base bar and the flanking bar is straight, his/her recognition for orientation of the base bar's movement would be dragged with the flanking bar's movement. The subject would so perceive that the base bar's movement was changed the same upper vertical orientation as the flanking bar. We call the phenomenon "perception". How will we perceive influence from neighboring other apertures and we depend on an experimental parameters for moving lines? Nishina et al. [2] have already discussed that the perception strongly depends on radius, distance between circles and time scale for displaying the flanking bar (shortly, the display time) by binding mechanism. In human early visual pathway, a binding mechanism performs an important function.

In this paper, we affirms Nishina's results and discussed the dependence of the perceptual rate on the display time [5], [6]. However, we have simultaneously noticed that the perception rate rather decreases at the display time later than 550ms. We discussed so the dependence of the perceptual rate on the display time by the visual measurement analysis, and in addition we here estimate the localized equivalent current dipole(ECD) in the visual pathway by the electroencephalograms(EEG) analysis [8]. By two kinds of analyses, we can discuss which localization of the brain relates to the perception, and what mechanism causes the perception in the aperture problem. 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) of the perception in order to estimate the localization of the brain activity area with changing radius, distance between circles, display time, and speed of bar. Then, we discuss the relationship between the latency of VEP and ERP by the perception and the localized equivalent current dipole(ECD) in the visual pathway. At the last, we presume which part of the brain relates to VEP and ERP for the perception, and what mechanism causes the perception.

II. Aperture Problem

The summary of the aperture experiment is shown in Figure 1. Here, we call a bar in the center circle a base bar. Two kinds of bars in the circles to be located in both side of the center circle are called franking bar. The computer display is FMV-DP9713 made in Fujitsu corporation. The vertical frequency of the display is 85.0Hz, and horizontal frequency is 68.7KHz, and the resolution is 1280 x 960pixels.

The subject is fixed with a stand to keep the distance between the subject and the computer display be 100cm. 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 in the vertical orientation same as the flanking bar.

In this paper, we discuss the dependency of the perceptual rate on the experimental parameters, by the visual measurement analysis and the EEG analysis. In the visual measurement analysis, we detect he perceptual recognition rate by ten subjects of 18 to 22 years old. In the EEG analysis, VEP and ERP are measured by one subject of 22 years old.

Figure 2 shows the explanatory drawing explaining the following sequences of the experimental procedure.

(a) The point of fixation and the central circle are drawn on the central coordinate of the computer display.

(b) A basic bar moves to the top right corner orientation from the lower left.

(c) A flanking bar moves from a lower corner to the upper orientation in circles of both ends of the center circle.

(d) The central circle only stays after two circles of both ends and the flanking bar disappeared.

(e) The subject recognizes a perception and answers the judgment on this perception. The perceptual recognition rate is calculated by these answers. Then, VEP and ERP are measured by EEG, and ECD is localized.

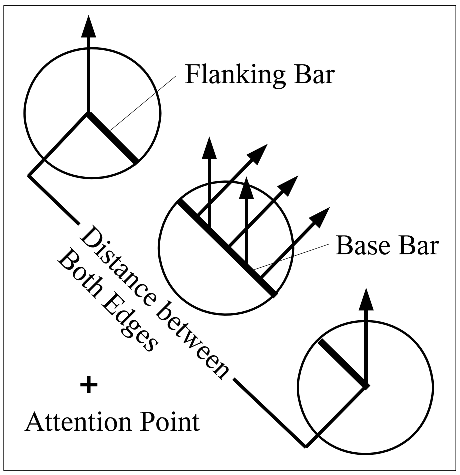

Fig. 1. Aperture Problem

We 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: When the speed of bar is SB:14.28mm/sec and the radius of circles is R:8.7mm, the perceptual rate is calculated by the visual measurement analysis in the condition that changed the distance between circles as DC:40.4, 80.8, 121.2, 161.6mm and the display time as DT:100, 200, 300, 400, 500, 600msec.

Exp.2: When the speed of bar is SB:14.28mm/sec and the distance between circles is DC:121.2mm, the perceptual rate is calculated by the visual measurement analysis in the condition that changed the radius of the circles as R:8.7, 11.4, 14.3, 17.1mm and the display time as DT:100, 200, 300, 400, 500, 600msec.

Exp.3: When the distance between circles is DC:80.8mm and the radius of circles is R:8.7mm, the perceptual rate is calculated by the visual measurement analysis in the condition that changed the distance the bars moved as DBM:5.7, 7.1 and the display time as DT:100, 200, 300, 400, 500, 600, 800, 1000, 1200msec.

Exp.4: When the speed of bar is SB:14.28mm/sec, the radius of circles is R:8.7mm and the display time is DT:500msec, the latency of VEP and ERP is estimated by the EEG analysis in the condition that changed the distance between circles as DC:28.6, 57.2, 85.7mm.

Exp.5: When the speed of bar is SB:14.28mm/sec, the distance between circles is DC:85.7mm and the display time is DT:500msec, the latency of VEP and ERP is estimated by the EEG analysis in the condition that changed the radius of circles as R:8.7, 11.5, 14.3mm.

Exp.6: When the distance between circles is DC:57.1mm, the radius of cirlces is R:11.4mm and the display time is DT:500msec, the latency of VEP and ERP is estimated by the EEG analysis in the condition that changed the speed of bar as SB:2.9, 5.7mm/sec.

Exp.7: When the distance between circles is DC:57.1mm, the radius of cirlces is R:11.4mm, the display time is DT:500msec, and the speed of bar is SB:14.28mm/sec, ECD is localized and the relationship between the latency of VEP, ERP and the localized ECD is discussed.

As a moving orientation of the bars in the experiment condition, the orientation of base bar's movement is fixed at 45 degrees and the orientation of flanking bar's movement is only changed at 0, 45 and 90 degrees. The perception rate is calculated in total 150 answers by five times of repetition experiments of ten subjects. To estimate the latency of VEP and ERP, we repeated 60 times of experiments of the flanking bar's movement. In the exp.7, ECD is localized by total 350 experiments in the condition that changed the orientation of flanking bar's movement as at 0 degree and 90 degrees.

III. Visual Measurement Analysis

The perceptual rate of the exp.1 to the exp.3 are shown in Figure 3 to Figure 5, respectively. Figure 3 shows the perceptual rate in the condition that fixed SB, and changed DC and DT. Figure 4 shows the perceptual rate in the condition fixed SB, and changed R and DT. Figure 5 shows the perceptual rate in the condition changed SB and DBM.

The perceptual rate in Figure 3 increases when the size of DC decreases. The perceptual rate in Figure 4 increases when the size of R increases. Both perceptual rates in Figure 3 and Figure 4 increase when the display time DT increases. By these results, it is obvious that the perceptual rate depends on the combination of the radius and distance between circles, and dispaly time.

On the other hand, we should notice that the perceptual rate is not monotonously decreasing in spite of increasing of SB in Figure 5. In general, subjects would easily recognize the perception whenever the speed of bar is slow. However, the result of the Figure 5 does not show the generality, and the

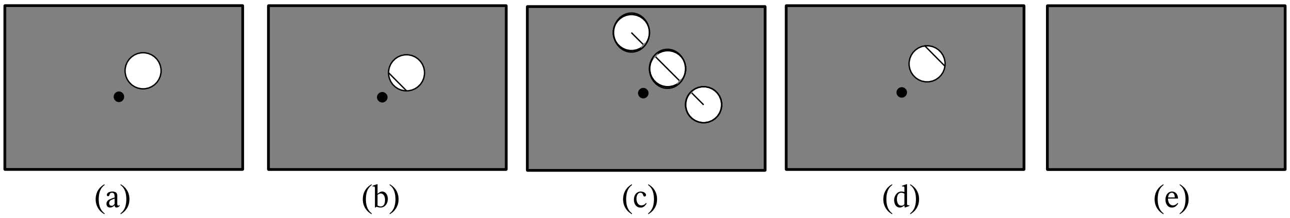

Fig. 2. Sequence of Experimental Operation

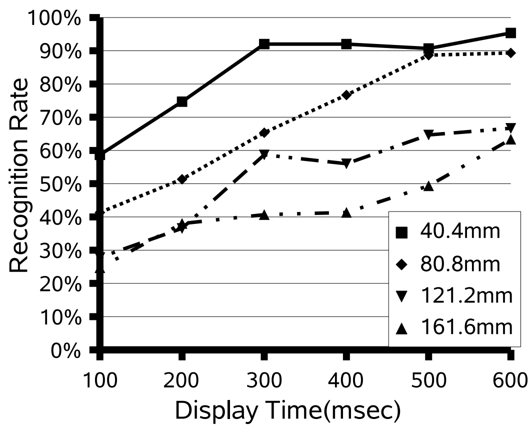

Fig. 3. R.R. under Changing DC

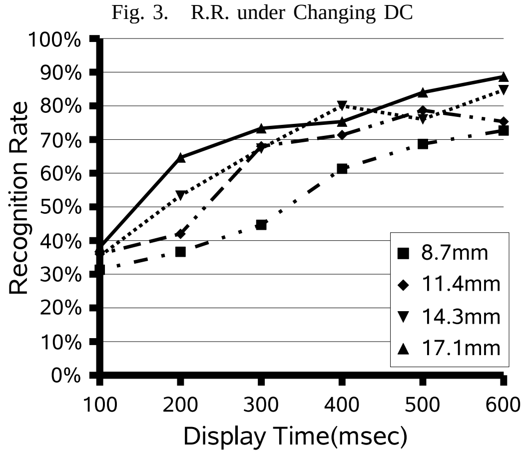

Fig. 4. R.R. under Changing R

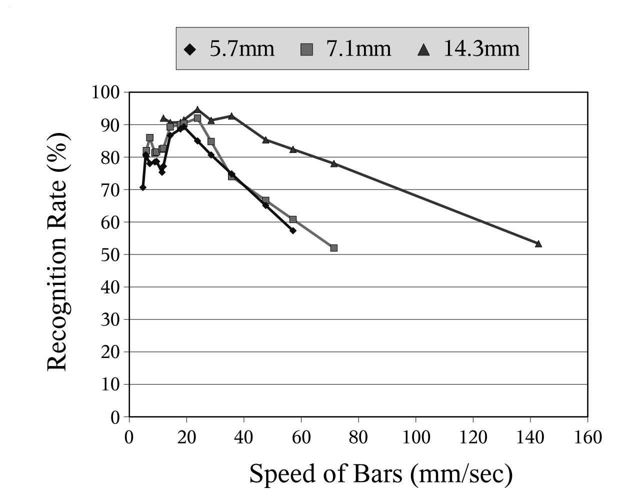

Fig. 5. R.R. under Changing SB

TABLE I
INFLUENCE OF SPEED OF BAR TO PERCEPTUAL 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			

perceptual rate is not linear. To verify the nonlinearity, we calculated trend of the perceptual rate by the trend analysis in the condition that changed the speed of bar SB. Table I shows the trend of perceptual rate in the condition that changed SB and fixed the distance the bars moved as DBM:5.7mm. The F-test values of the perceptual rate with the second, the third, and the fourth order of SB are larger than the critical value, 7.00, at $p = 1\%$ of the free degree(1,72). Therefore, we conclude that a significant trend of perceptual rate in the condition that changed the second, the third and the fourth order of SB was verified.

IV. EEG ANALYSIS

We estimated here the latency of VEP and ERP of subject by the EEG analysis, and ECD is simultaneously localized by the exp.4 to the exp.7. A change of the amplitude of VEP with the change of the visual stimulation was detected in all conditions. In particular, VEP was constantly detected after 340ms of the reaction latency(RL), when the base bar appears. In the exp.4, when the flanking bar appeared in the screen, the amplitude of ERP reached the peak at 900ms. In particular, ECD was localized at the right inferior frontal gyrus(RL:1,160ms to 1,170ms) and the left middle frontal gyrus(RL:1,230ms to 1,250ms) when the flanking bar moved in the horizontal orientation(0 degree) and the vertical orientation(90 degrees).

Figure 6 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). However, any change of amplitude was not detected at 45 degrees. By these results, when the flanking bar moves in either the horizontal orientation or the vertical orientation, we concluded that more active VEP was detected at the frontal gyrus primarily relates to the spatial recognition.

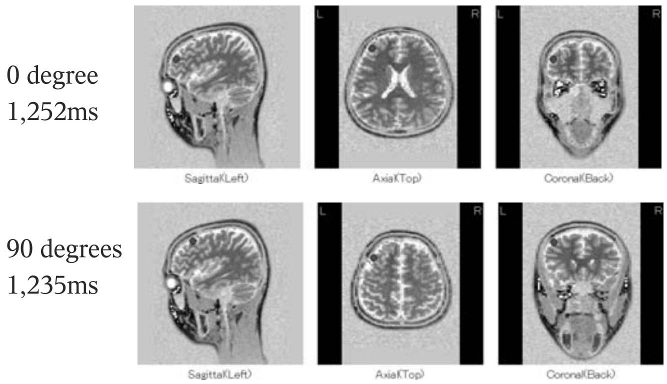

Fig. 6. Localization of ECD in the Fourth Experiment

In the exp.5, the amplitude of ERP reached the peak at RL:1,300ms when the flanking bar appeared. 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) or the vertical orientation(90 degrees). Figure 7 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). However, any change of amplitude was not detected at 45 degrees.

By these results, we concluded that more active VEP was detected at the frontal gyrus primarily relates to spatial recognition.

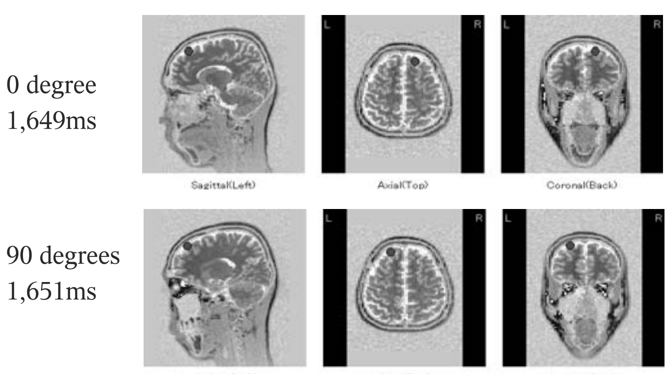

Fig. 7. Localization of ECD in the Fifth Experiment

In the exp.6, VEP and ERP were constantly detected after appearing of the base bar, but any large change of amplitude was not detected at all orientation including 0 degree and 90 degrees.

In the exp.7, we estimated the propagated localization related to the flanking bar's movement after RL:340ms in the condition that fixed the orientation of the flanking bar's movement as at 90 degrees. The amplitude of VEP reached the peak at reaction latency at 100ms to 400ms, and the amplitude of ERP reached the peak at two periods of reaction latency, i.e., at 500ms to 700ms, and at 1,000ms to 1,300ms. Figure 8 shows VEP and ECD at RL:245ms in V4. Figure 9 shows ERP and ECD at RL:625ms(at RL:285ms after appearing of the flanking bar) in MT.

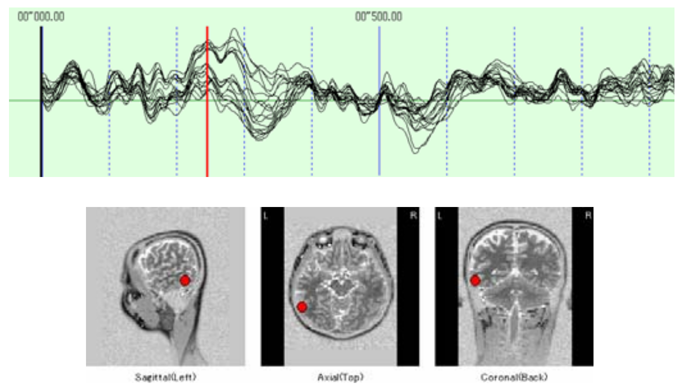

Fig. 8. VEP and ECD in V4

In general, the visual stimulation input by retina propagates to the prefrontal cortex through the optic hiasm, LGN, and the primary visual cortex. In particular, the propagated signal at the primary visual cortex is divided in two pathways which are the ventral pathway from the primary visual cortex to the prefrontal cortex through the temporal lobe, and the dorsal pathway from the primary visual cortex to the prefrontal cortex through the parietal lobe. In general, the ventral pathway relates to symbolic recognition, and the dorsal pathway relates to spatial recognition. By ECD of the exp.7, the following ventral pathway and the dorsal pathway were estimated with reaction latencies.

Ventral Pathway: V1(133ms) → V2(171ms) → V4(245ms) → TEO(306ms) → TE(357ms)

Dorsal Pathway: V1(576ms) → V2(611ms) → MT(625ms) → Occipital Lobe(711ms)

The signal propagated to the temporal lobe from the primary visual cortex with each reaction latency as figured in Figure 10. The center circle appears at RL:0ms, and the base bar starts to move at RL:340ms in the exp.7. Therefore, we concluded that the localized ECD in Figure 10 derives from appearing of the center circle. The propagation in the dorsal pathway is also figured in Figure 11. We concluded that the localized ECD in Figure 11 relates to the movement of the base bar,

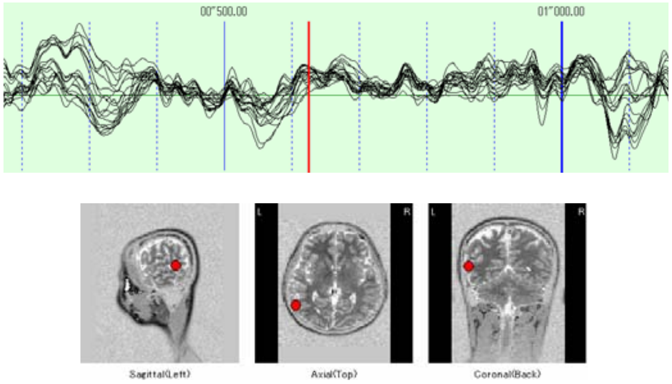

Fig. 9. ERP and ECD in MT

because the base bar starts at RL:340ms.

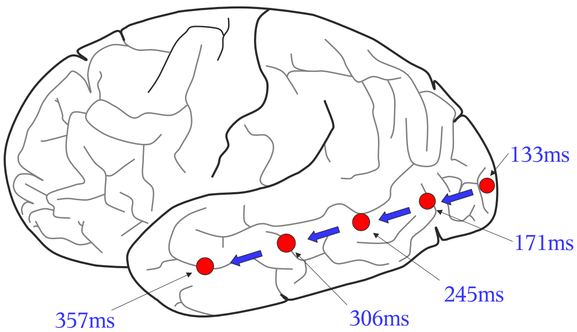

Fig. 10. Localization of ECD in Ventral Pathway

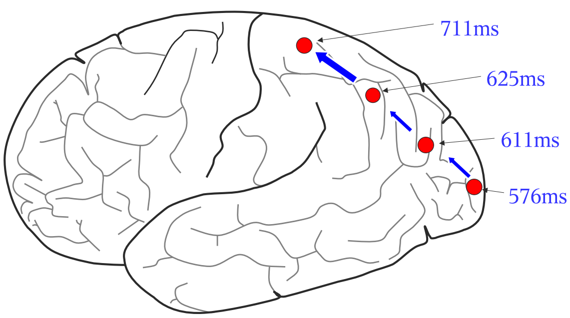

Fig. 11. Localization of ECD in Dorsal Pathway

By comparing the latency of VEP, ERP and the localized ECD, we should notice that the active signal propagated to the temporal lobe through the ventral pathway at the period of latency of 100ms to 400ms from the primary visual cortex, and the active signal related to the appearing of the center circle. Similarly, we should notice that the signal propagated to the parietal lobe through the dorsal pathway at the period of latency of 500ms to 700ms and the signal related to the movement of the base bar. Since the ventral pathway primarily relates to symbolic recognition, and the dorsal pathway primarily relates to spatial recognition, these presumption would be acceptable.

Now, which part of brain relates to the peak of amplitude of ERP at the period of latency of 1,000ms to 1,300ms? To clear the problem, we presumed the localization of ECD after the flanking bar moved. The localizations of ECD were estimated 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 12 shows the localized ECD by movement of the flanking bar. We should notice that active signal propagated to the frontal lobe at the period of latency of 1,000ms to 1,300ms related to the movement of the flanking bar. Therefore, we concluded that the perception would be originated at the prefrontal lobe, 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.

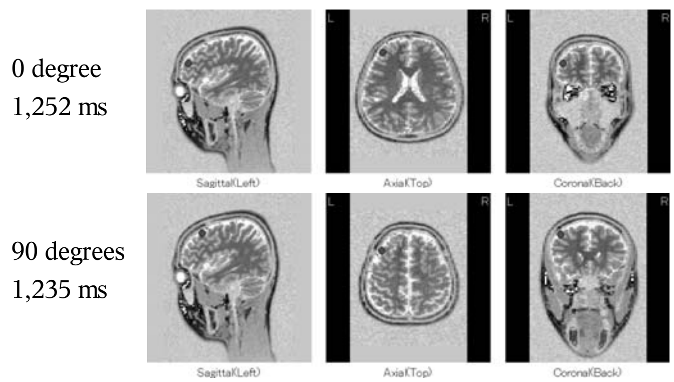

Fig. 12. Localization of ECD by Movement of Flanking Bar

V. Conclusion

We discussed here that the perception of aperture problem depended on the display time and the speed of bar by the visual measurement analysis. 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 active signal about the perception was localized in the visual pathway and the frontal lobe by the electroencephalograms analysis. We concluded that the perception would be originated at the prefrontal lobe by both the latency of the visual evoked potential and the equivalent current dipole. However, It is necessary to make the precision of the hypothesis better by a lot of experiments using more subjects in the near future.

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