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# Spatiotemporal EEG Source Localization using ECDs during Smooth Pursuit Eye Movement

**Tomoko YONEMURA*, Hisashi TOYOSHIMA**, Takahiro YAMANOI***, and Shin-ichi OHNISHI*****

**Abstract**

A linear moving white full circle on a CRT display was presented to subjects. Moving patterns were downward, upward, to the right and left. Subjects were requested to trace the stimulus. Meantime, electroencephalograms (EEG) were recorded. The EEG was summed in each movement and the equivalent current dipole localization (ECDL) was done to estimate the source in the brain. As results, the dipoles were localized to the V5 at latency of approximately 143ms, and after to the intraparietal sulcus (IPS, 162ms), to precentral gyrus (PrCG, 224ms) to the frontal eye field (FEF, 236ms) and to the superior colliculus (SC, 248ms). The direction of estimated dipole corresponded with the opposite movements. And the dipole to the superior colliculus was estimated, this organ is supposed to correspond with the eye movement. Also a dorsal pathway and a ventral pathway were found.

**Keywords : visual motion processing, electroencephalograms (EEG), equivalent current dipole localization (ECDL), smooth pursuit eye movement**

## 1. INTRODUCTION

The aim of this study is to provide a detailed spatiotemporal characterization of human brain activities during smooth pursuit eye movements from electroencephalography (EEG) data.

Numerous researches have been carried out for the purpose of deciding which cortical areas are involved in processing of visual motion and eye movement. Previous imaging studies in human adults using MEG, PET and fMRI have shown that the primary visual pathway projects via the lateral geniculate nucleus (LGN) to V1, V2, V5 (middle temporal : MT) and intraparietal sulcus (IPS) [e.g.1–3]. Information in the primary visual cortex is widely believed to be processed in two parallel interconnected pathways, the dorsal (movement) and ventral (object recognition) streams [4]. Moreover, it is known that the frontal eye field (FEF) and the superior colliculus (SC) are responsible for eye move-

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ments [e.g. 5, 6]. Neuroimaging techniques (e.g. fMRI) can have extremely high spatial resolutions but it is rather slow temporally for source localization of brain activity.

In contrast, EEG can have extremely high temporal resolutions for detecting differences in the latency of brain activity, although hardware and measurement costs are significantly lower than those of most other techniques. Early studies on the motion−onset visual evoked potentials (VEPs) reported P1 perk (with a latency of around 130ms) and N2 perk (with a latency of around 180ms) as major components [e.g. 7, 8]. However, EEG cannot to directly display areas of the brain that are active. To overcome this disadvantage, in our previous studies, we estimated current sources during observation of moving targets by use the equivalent current dipole source localization (ECDL) method [9, 10] during smooth pursuit eye movement. We suppose that our brain is consisted as a three layer concentric sphere. And we estimated potentials and directions of electric response from electroencephalogram measured by electrodes (**Fig.1**). ECDL method had been applied to these event related potentials (ERPs). This is an analogy to detect source of earthquake by seismograph. Each peak of ERPs were detected and analyzed by ECDL at that latency by use of two–dipole model [e.g. 11–13]. Our experiment results indicated that dipoles were localized to the V5 at 80–120ms latency, to the IPS at 140–180ms latency, to the precentral gyrus (PrCG) at 210–250ms latency and to the FEF at 210–260ms latency.

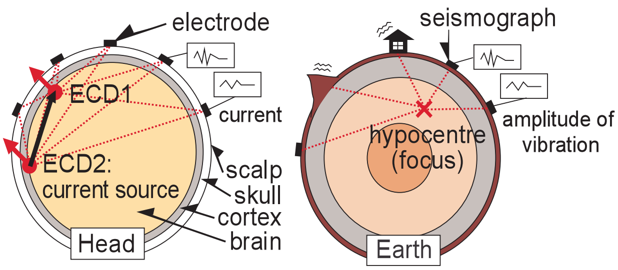


**Fig.1** Principle of ECDL method

In this study, we estimated current sources during observation of moving targets by use ECDL method at the latency from 0ms to 300ms using the three–dipole model [e.g. 14] which is more accurate than a two–dipole method. The authors had attempted to assure that the ECDL method is able to provide a detailed spatiotemporal characterization during smooth pursuit eye movement. Moreover, we will discuss whether it is different in current sources and pathway depending on the direction of target motion.

## 2. METHOD

### 2.1. Subject

Two healthy adult females (20–21 years old) participated in this experiment. All the subjects were right–handed according to the Edinburgh Inventory [15]. Some of the subjects were paid volunteers and received JPY 850 (about USD 8) per hour.

### 2.2. Stimuli and apparatus

A linear moving white full circle (R=50 pixel, 19mm), speeds : 0.8 pixel / msec (“continuous” mode), on a CRT display was presented each subject. Moving patterns were four directions, i.e. upward, downward, to the left (leftward) and to the right (rightward). Positions of electrodes on the cap were according to the international 10–20 system and other two electrodes were fixed on the upper and lower eyelids for eye blink monitoring. Impedances were adjusted to less than 50 kΩ. Reference electrodes were put on both earlobes and the ground electrode was on the base of the nose. EEG measurement systems are consisted of cap for recording EEGs, a digital electroencephalograph (Synafit EE2500, NEC, Japan), and a PC−based ECDL system software (SynaCenterPro, NEC, Japan). The goodness of fit (GOF) of ECDL was more than 99 %.

### 2.3. Procedures

Above four movements were presented at random on a CRT display to the subjects. The subjects were requested to trace the stimulus with binocularity (each 30 trials). VEPs by the stimuli were recorded by electrodes on the head of subjects (**Fig.2**).

In the masking period during 3000ms, a fixation point was presented. In the cognition period, stimulus was presented in the center of CRT display during 3000ms, and EEGs were measured in this period (**Fig.3**). The experiments were done in a dark room.

### 2.4. Analysis of Electroencephalogram Data

EEGs were summed in each movement and subject to obtain VRPs. We investigated differential EEGs between continuous mode and control mode. Then, response positions in the brain were detected by the ECDL around these peak latencies of the EEG before P300 and results of the ECDs are imposed on fMRI images of the subject the subject herself.

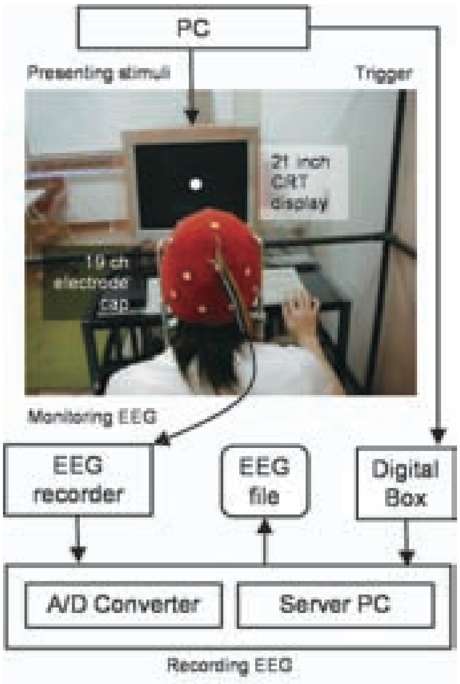


**Fig.2** Experimental apparatus for stimulus presentation and EEG measurement and experimental situation

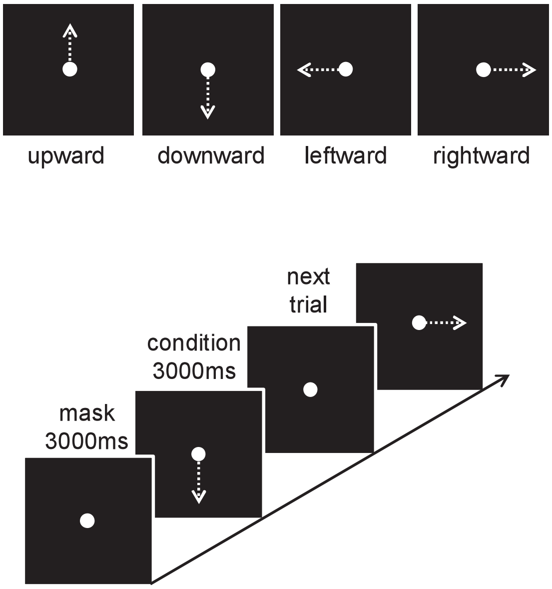


**Fig.3** Experimental procedure

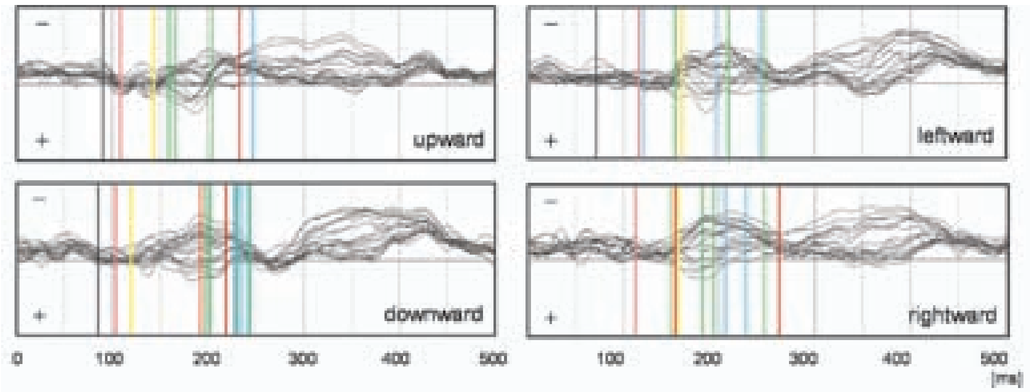


**Fig.4** Example of VEPs (Subject HY). Vertical lines denote significant estimated ECDs.

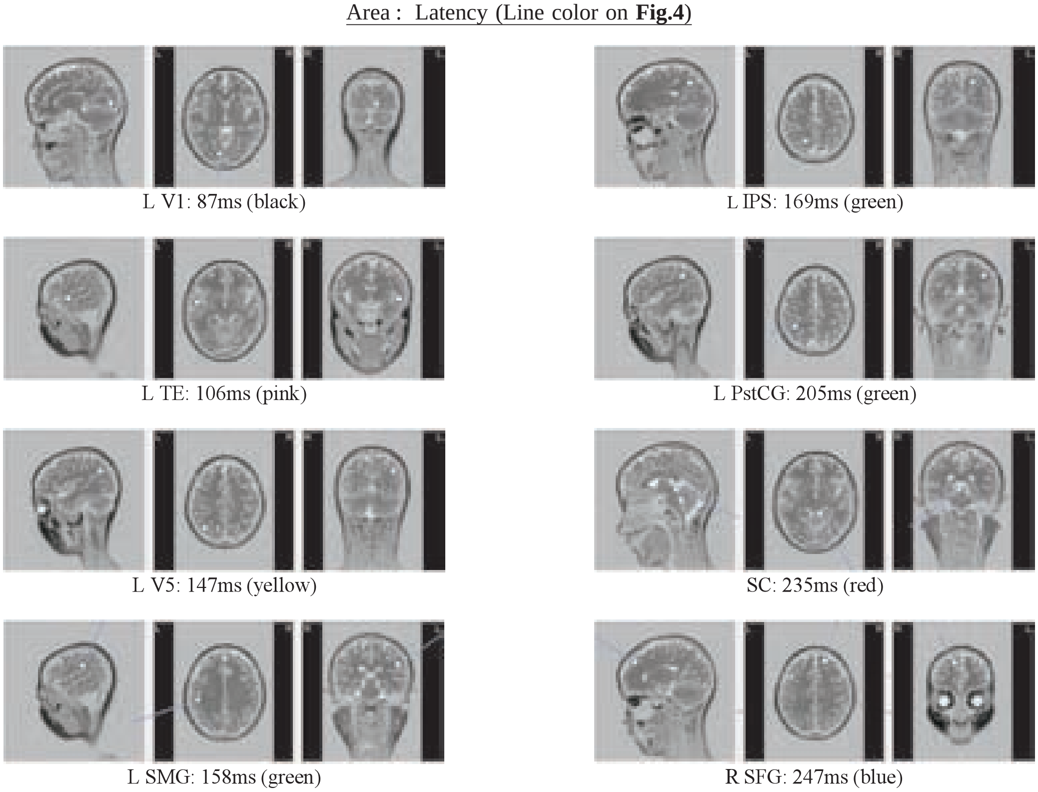


**Fig. 5** Examples of Estimated ECDs superimposed to fMRI of subject HY in the upward condition.

## 3. RESULTS AND DISCUSSION

An example of VEPs of the subject HY is shown in **Fig. 4**. We estimated ECDs to significant areas regarding to some latencies, the **Fig. 5** shows some results of localized ECDs. Statistics are shown in **Table 1** for latencies at which ECDs were estimated to significant areas. A ventral pathway and a dorsal pathway were found during eye movement (**Fig. 6**).

The ECDs were localized to the TE at approximate latency of 118ms, and after on the precentral gyrus (PrCG, 127ms), and on the prefrontal area (PFA, 160ms). In contrast, the dipoles were localized to the V5 at latency of approximately 143ms, and after to the intraparietal sulcus (IPS, 162ms), to PrCG (224ms) and to the frontal eye field (FEF, 236ms). These are on a ventral pathway. Statistics of latencies according to the four moving directions at estimated ECDs to significant brain area are shown in Table 1. And also estimated ECDs to significant area in four directional moving types are shown in Table 2 by the subject HY and SI.

Moreover, the dipole on the superior colliculus (SC) was estimated at latency of approximately 193 ms and 248ms, the SC is supposed to be the area that correspond with the eye movement. These results agree with the results on MEG, PET or fMRI [e.g.1–6].

**Table 1** Statistics of latencies at estimated ECDs [ms, N=2, four moving directions, † : 1st & † † : 2nd times]

| area | V1−V2 | V4−TE | PrCG † | PFA † | V5 | IPS | MFG | PstCG † | SC † |
|---|---|---|---|---|---|---|---|---|---|
| median [ms] | 87 | 118 | 127 | 160 | 143 | 162 | 185 | 190 | 193 |
| mean [ms] | 92 | 127 | 127 | 160 | 137 | 169 | 184 | 192 | 181 |
| SD [ms] | 15.38 | 27.67 | 0.00 | 30.50 | 18.08 | 20.52 | 17.12 | 14.77 | 20.61 |
| number of data | 7 | 8 | 1 | 2 | 8 | 4 | 4 | 6 | 3 |
| area | IFG † | SMG | PrCG † † | SFG | PFA † † | FEF | IFG † † | PstCG † † | SC † † |
| median [ms] | 204 | 217 | 224 | 229 | 230 | 236 | 245 | 246 | 248 |
| mean [ms] | 204 | 217 | 219 | 206 | 227 | 221 | 248 | 251 | 247 |
| SD [ms] | 8.50 | 42.89 | 20.94 | 42.55 | 13.85 | 21.21 | 8.38 | 14.82 | 21.52 |
| number of data | 2 | 5 | 4 | 7 | 5 | 3 | 3 | 6 | 4 |

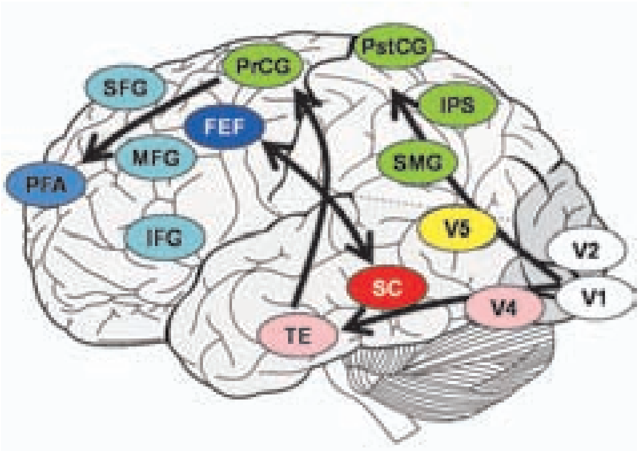


**Fig.6** The areas ECDs were estimated and dorsal and ventral pathways.

Our estimated results were almost identical with that of our previous research by use of two–dipole model [e.g. 11–14]. ECDs were localized to the V1, the V2, the V5, and the IPS that supposed as areas of the primary visual motion processing before latency of 200ms. After 200ms, ECDs were rather localized to the PrCG, the FEF and the SC that supposed as areas of the higher−order processing and eye movement for tracking target.

In addition, we were able to estimate new sources in brain areas that were lost in our previous analyses. ECDs were localized to the V4, the temporal area (TE), the, supramarginal gyrus (SMG) and the postcentral gyrus (PstCG). The V4 and the TE in ventral pathway for visual processing is involved in object perception and recognition. The SMG and the PstCG constitute a multi–modal associative area that receives visual and somato–sensory inputs as the part of dorsal pathway. Furthermore, results indicated that dipoles were localized to the middle frontal gyrus (MFG), inferior frontal gyrus (IFG), superior frontal gyrus (SFG), and PFA that supposed as areas of the primary motor function, or our ability to consciously move our muscles. The ECDL method using the three–dipole model provided a detailed spatio–temporal characterization during smooth pursuit eye movement.

When comparing with ECDs by moving patterns, no large difference was observed. However, in some areas such as the V1, the V4, the V5, and PstCG, it seemed that ECDs were localized to opposite hemisphere at same time (**Table 2**). This fact suggests that the activity in these areas depend on direction information.

**Table 2** Relationship between localized source and its latency [area, ms].

subject HY

| upward | | downward | | leftward | | rightward | |
|---|---|---|---|---|---|---|---|
| L V1 | 87 | R V1−2 | 85 | R V2 | 73 | | |
| L TE | 106 | L TE | 101 | | | L TE | 113 |
| | | | | R V4 | 122 | | |
| | | L V5 | 129 | R SFG | 127 | | |
| L V5 | 147 | | | | | R IPS | 149 |
| | | | | R IPS | 155 | SC | 152 |
| L SMG | 158 | | | L V5 | 156 | R V5 | 153 |
| L IPS | 169 | | | | | | |
| | | | | | | L PstCG | 178 |
| | | | | | | | |
| | | SC | 193 | | | L SMG | 193 |
| | | L PstCG | 198 | L IFG | 195 | | |
| L PstCG | 205 | R IPS | 202 | | | R MFG | 205 |
| | | | | R PstCG | 214 | | |
| | | SC | 219 | | | | |
| | | R SFG | 229 | | | | |
| | | L PstCG | 230 | | | | |
| | | R PFA | 230 | | | PFA | 230 |
| SC | 235 | R FEF | 236 | | | | |
| R PstCG | 245 | L PrCG | 244 | R IFG | 239 | | |
| R SFG | 247 | L IFG | 245 | L PstCG | 244 | R PstCG | 247 |
| | | | | | | SC | 261 |

subject SI

| upward | | downward | | leftward | | rightward | |
|---|---|---|---|---|---|---|---|
| L V2 | 78 | | | | | | |
| R V5 | 96 | | | | | L V2 | 95 |
| R V4 | 106 | L V2 | 113 | L V2 | 116 | | |
| R PrCG | 127 | R V4 | 124 | | | | |
| R PFA | 129 | | | | | R V5 | 129 |
| | | R V5 | 146 | L V5 | 140 | | |
| R SFG | 155 | | | | | | |
| R MFG | 161 | | | | | | |
| | | | | L V4 | 171 | | |
| | | L MFG | 175 | R PstCG | 174 | R V4 | 176 |
| R PstCG | 186 | L PstCG | 182 | R PFA | 190 | | |
| | | | | R FEF | 191 | | |
| | | SC | 196 | R MFG | 195 | | |
| | | | | R PFA | 205 | | |
| | | | | R IFG | 212 | | |
| | | | | R SMG | 217 | | |
| | | R PFA | 223 | R SFG | 218 | R PrCG | 223 |
| | | R PrCG | 224 | | | R SMG | 227 |
| | | R SFG | 230 | | | | |
| | | | | | | L SFG | 236 |
| | | | | | | R FEF | 236 |
| R PFA | 248 | | | | | | |
| R PstCG | 261 | | | L IFG | 256 | | |
| SC | 274 | | | | | R PstCG | 277 |
| R SMG | 288 | | | | | | |

## 4. CONCLUSION

The authors elucidate that the ECDL method could be provides a detailed spatiotemporal activities in the brain. For example, although it is a relatively short time period, activities in the primary vision were found (V1−V2). And the dorsal pathway and the ventral pathway were found even during smooth pursuit eye movement. As future works, it is necessary to investigate with estimated ECDs for more subjects and to be clarified differences of estimated ECDs caused by moving patterns.

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