Discrimination of mental translation by EEG: An equivalent current dipole source localization approach

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Abstract

To investigate the brain activity during human recognition of characters and symbols with directional meanings, the authors recorded electroencephalograms (EEGs) from four subjects in viewing and mental translating four types of characters (Kanji: Chinese characters being used currently in the Japanese language) and four symbols (arrow) presented on the CRT which means direction for Upward, Downward, Leftward and Rightward. EEGs were averaged for each stimulus type, and event related potentials (ERPs) were obtained. On comparing ERPs of kanji characters with those of arrow symbols with opposite meanings, peak latencies for marked amplitude changes were predominantly similar, but polarities were opposite.

The equivalent current dipole source localization (ECDL) method was applied to these ERPs, and ECDs were estimated by use of the ECDL. The ECD was estimated at a latency of around 110 ms in the MT (V5) area and then around 300 ms in the precentral gyrus. No remarkable differences in this tendency were noted among the eight stimuli. After localization of ECDs to the precentral gyrus, with the kanji characters, ECD was localized to the right middle temporal gyrus regardless of direction. ECD was then estimated in areas related to language, such as the Wernicke's area in the left middle temporal gyrus, the left angular gyrus and the left lingual gyrus. ECD was later localized to the left middle frontal gyrus, the left inferior frontal gyrus and the prefrontal area. ECD was estimated in the precentral gyrus just before the amplitude of ERPs changed remarkably.

With arrow symbols, ECD was localized to the right middle temporal gyrus, and then it was estimated in areas related to the working memory for spatial perception, such as the right inferior or the right middle frontal gyrus. Then, as with kanji characters, ECD was localize to the prefrontal area and the precentral gyrus.

In case of the mental translation, activities were observed on the area around the same latency regardless to the Kanji or the arrow. After on the right frontal robe, which is so-called the working memory, ECDs were localized to the Broca's area which is said to be the language area for speech. Like in our preceding researches, the moment of ECD was almost opposite in each other case of opposite meanings.

This fact is useful for the brain machine interface. We might control a machine by EEGs.

Keywords: Directional Visual Stimulus, Spatiotemporal Human Brain activity, Electroencephalography, Equivalent Current Dipole Source Localization

1 Introduction

From many researches on the human brain, it has been clear that the processing of visual stimulus is done at first on V1 in the occipital robe. In the early stage of it, the process on the right visual field is processed on the left

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hemisphere and the left visual field is processed on the right hemisphere. Then the process goes to the parietal associative area [1].

Higher order process of the brain thereafter has its laterality, for instance, 99% of right-handed and 70% of left-handed have their language area on the left hemisphere as the Wernicke's area and the Broca's area [2, 3]. Besides these areas, language is also processed on the angular gyrus (AnG), the fusiform gyrus (FuG), the inferior frontal gyrus (IFG) and the prefrontal area (PFA). Some of the present authors found that processing areas for Kanji (Chinese characters being used currently in the Japanese language) and Hiragana (one type of Japanese phonetic characters) are different in each [4]. In the case of linearly moving stimulus [5], activities were estimated to the right frontal lobe where it is said to be the working area for the spatial recognition. And recognition of single character of Kanji had been cleared [6]. In the present research, we compared brain activities to Kanji and arrow representing directional meaning, by measuring EEGs and by applying the ECDL method [7, 8] to them.

2 Experiment

2.1 Experimental Apparatus and Method

Subjects are four university students from 20 to 21 years old and have normal visual acuity. All are women and their dominant hand and eye are the right ones. The subjects put on an electrode cap and watched the 21inch CRT 30cm in front of them. Each stimulus was displayed on the CRT. Stimuli had been stored on the disk of a PC as a file and they were presented in random order. Their heads were fixed on a chin rest on the table. 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 movement monitoring. Impedances were adjusted to less than 10 kΩ. Reference electrodes were put on both earlobes and the ground electrode was on the base of the nose. Electroencephalograms (EEGs) were recorded on the digital EEG measuring system (NEC Corporation, Synafit EE2500); the amplitude was 5 uV/V, the frequency band was between 0.15 and 100 Hz. Analog outputs were sampled at a rate of 1kHz and stored on a hard disk in a PC (Fig. 1).

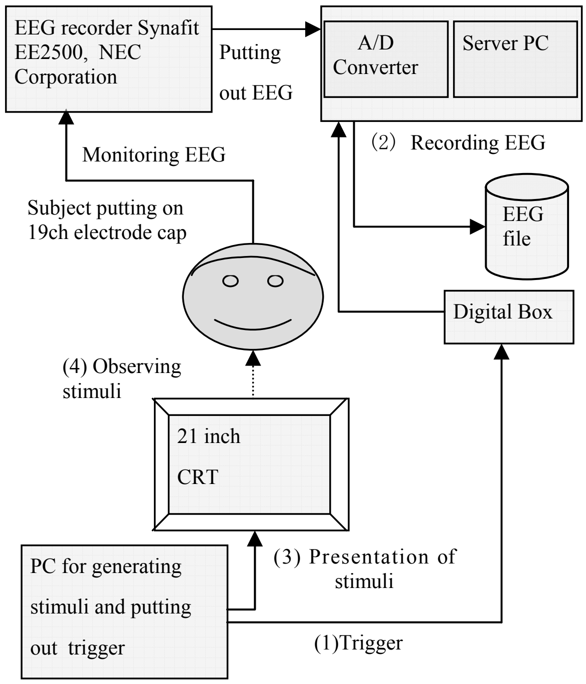

Fig.1. Experimental apparatus

2.2 Stimulus Presentation of experiment

In this experiment, subjects were presented a single character, which has apparent directional meaning, such as "上" (Upward), "下" (Downward), "左" (Leftward), "右" (Rightward), "↑", "↓", "←", and "→". The first period, stimulus was not presented. The second period, stimulus was presented in the center of CRT during 2000 ms, and followed a masking period of 3000 ms. During the last period of 3000 ms, visual stimulus was hidden and subject translated the direction of stimulus mentally. Each stimulus was presented at random, and measurement was repeated thirty times for each stimulus, so the total was 240 times. In these cycles, we measured EEGs during one second and last periods of 2000 ms (Fig. 2).

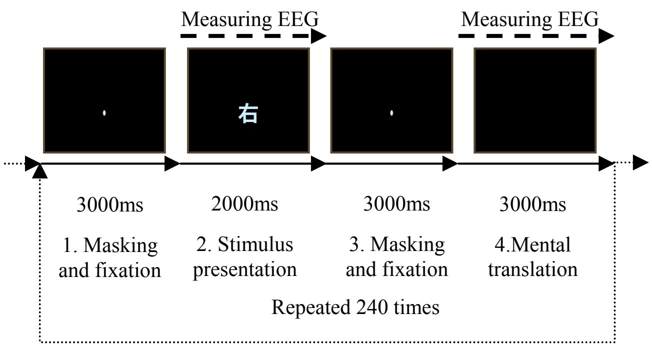

Fig.2. Timing chart of the present experiment

From the experimental instructions, subjects were forced to recognize a direction by character or arrow which was displayed on the center of CRT screen. So we measured brain activities during recognition of direction.

2.3 Analysis by equivalent current dipole source localization

We have measured EEGs of each visual stimulus. In order to effectively execute the ECDL method, both data were summed and averaged according to the type of directions and the subjects in order to get event-related potentials (ERPs). Summing these ERPs of the directional types respectively, then the ECDL method was applied to each ERPs by each subject. Because the number of the recording electrodes was 19, three ECDs at most were estimated by use of the PC-based ECDL analysis software “SynaCenter [8]” (NEC Corporation). The goodness of fit (GOF) of ECDL was over 99.8 %.

3 Experimental Results

3.1 Result of the experiment

We have measured EEGs of the Kanji and the arrow experiments; both data were summed and averaged according to the type of directions and the subjects in order to get ERPs.

We analyzed ECDs of each subject; both data have large potentials at latencies between 200ms and 600 ms (Fig. 3).

We compared with these ERPs by the type of stimulus and by the type of direction. In case of arrows with opposite direction, peak latencies were almost the same but polarities of potentials were inversed. More precisely, the maximal potential of type “↓” was slightly delayed from that of “↑”, and that of “←” was slightly delayed from that of “→”. Comparing ERPs with Kanji of opposite directions, same as the arrows, polarities of potential were inversed. And the latency of maximal potential of type “下” was slightly delayed from that of “上”, and the latency of maximal potential of “左” was slightly delayed from that of “右”.

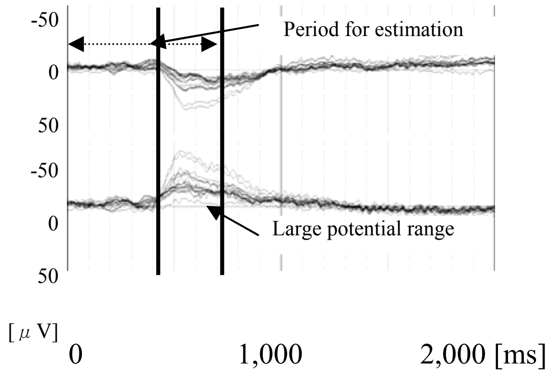

Fig.3. Example of large potential range of ERPs (between two bold lines) and range for estimation (shown by arrows)

When comparing with ERPs of the arrows and Kanji, no large difference was observed until 250 ms at their latencies. The ECDs were localized to the right MT area around 130 ms, to the right postcentral gyrus (PstCG) around 200 ms, and to the precentral gyrus (PrCG) around 270 ms.

In the case of arrow, at latency from 300 ms to the latency when amplitude changes remarkably, though their latencies had some difference, ECDs were localized to the right and the left middle frontal gyrus (MFG) and to the right inferior frontal gyrus (IFG). Regardless the direction of arrow, ECDs were localized to the right middle temporal gyrus (MTG) around 380ms, then ECDs were localized to the superior frontal gyrus (SFG) just before the remarkable change of amplitude (Table 1).

In the case of Kanji, regardless to the direction, ECDs were localized to the left MTG and the Wernicke’s area around 350 ms, then to the left AnG and the left lingual gyrus (LG) after 380 ms. Then ECDs were localized to the left IFG, the left PFA and the left SFG, and the PrCG just around the latency of remarkable change of amplitude (Table 2). This tendency is almost the same for all subjects (Table 3).

In the case of the mental translation, activities were observed on the area around the same latency regardless of the Kanji or the arrow. After on the right frontal robe (the IFG and the MFG), which is so-called the working memory for spatial recognition, ECDs were localized to the Broca’s area which is said to be the language area for speech (Table 4).

Table 1. Example of Relationship between localized source and its latency after PrCG (Subject MM), Stimulus: Arrow

Stim.	right PrCG	Wernicke's area	left ITG	left AnG	left SMG	left PrCG	right MFG	Broca's area	left MFG	right MFG
↑	260	None	356	None	451	472	496	None	583	622
↓	281	None	375	None	445	468	495	None	578	615
←	281	None	383	None	464	461	493	None	599	619
→	267	None	374	None	457	469	507	None	580	619

[ms]

Table 2. Example of Relationship between localized source and its latency after PrCG (Subject MM), Stimulus: Kanji

Stim.	right PrCG	Wernicke's area	left ITG	left AnG	left SMG	left PrCG	right MFG	Broca's area	left MFG	right MFG
上	268	379	None	397	451	464	493	590	650	695
下	268	345	None	426	449	477	514	577	634	692
左	277	370	None	414	449	470	497	580	630	691
右	272	370	None	429	442	464	493	583	635	685

[ms]

Table 3. Example of Relationship between localized source and its latency after PrCG, Stimulus: Kanji ('左: leftward')

Subject	right PrCG	Wernicke's area	left ITG	left AnG	left SMG	left PrCG	right MFG	Broca's area	left MFG	right MFG
MM	277	370	None	414	449	470	497	580	630	691
MY	272	354	None	422	442	464	493	590	650	695
HY	262	359	None	386	435	464	493	583	635	685
SI	263	372	None	417	449	477	514	577	634	692

[ms]

Table 4. Relationship between localized source and its latency (Subject MM), Mental translation

Stim.	left MFG	right IFG	right AnG	left AnG	Broca's area
上	308	451	509	577	610
下	303	468	494	556	608
左	316	455	478	551	611
右	321	459	472	551	622
↑	307	486	490	549	613
↓	296	473	494	527	607
←	313	475	497	531	623
→	311	454	480	537	613

[ms]

4 Discussion

Although before latency of 300ms, ECDs were localized to the left inferior temporal gyrus (ITG) that supposed to be one of the linguistic areas, no remarkable difference was observed on estimated positions and its latencies regardless of the type of stimulus and directions. So we suppose the primary visual processing were done during this period until the PrCG.

After 300 ms, in the case of arrow, most ECDs were rather localized to in the right hemisphere such as the right IFG, MFG and the PFA, than the left hemisphere. On the other hand, in case of Kanji, ECDs were localized to the Wernicke's area (Fig.4), the left AnG, the left FuG and the Broca's area (Fig.5) that supposed to be the linguistic areas. On the contrary, in case of arrow, no ECD was localized to these areas, these processes were done as an image processing, and furthermore the latency of remarkable change of amplitude had some delay, in comparison with Kanji. So even with the same directional stimulus, there is a difference in areas and in route between Kanji (Fig.6) and arrow (Fig.7).

In comparison, the same type stimulus has opposite direction (localized to the right IFG, Fig.8), the direction of localized dipole was opposite during EEGs had opposite polarities (Fig.9). This fact agrees with our preceding experiments [5], so the directional information supposed to be related with a direction of dipole itself.

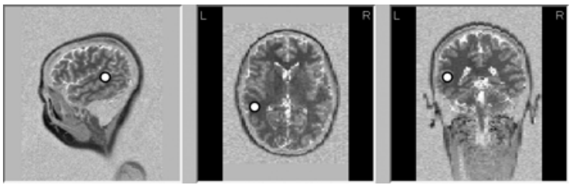

Fig.4 Example of ECD localized to the Wernicke’s area at 378ms (Subject MM), stimulus: downward “下”

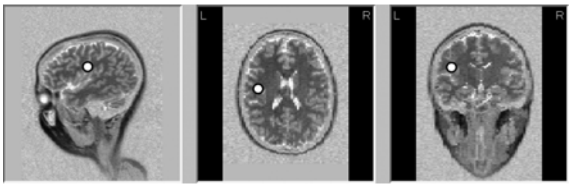

Fig.5 Example of ECD localized to the Broca’s area at 378ms (Subject MM), stimulus: downward “下”

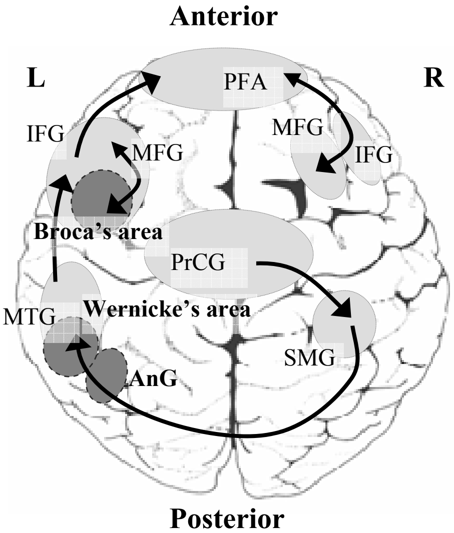

Fig.6 Spatiotemporal transition of estimated ECDs after PrCG (Stimulus: Kanji)

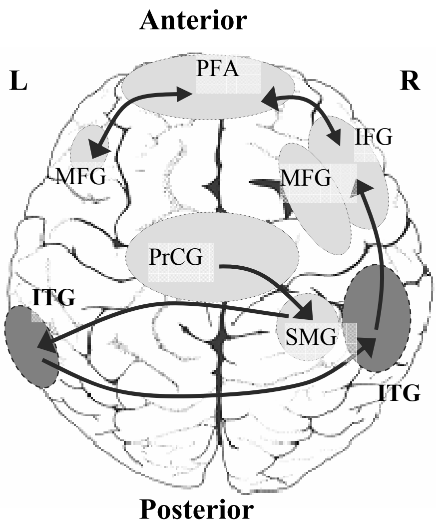

Fig.7 Spatiotemporal transition of estimated ECDs after PrCG (Stimulus: Arrow)

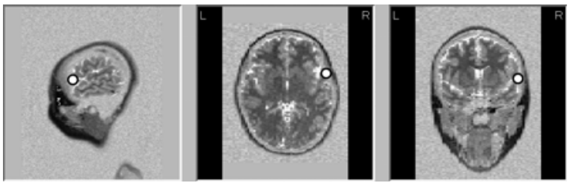

Fig.8 Example of ECD localized to the right IFG at 401ms (Subject MM), stimulus: downward “下”

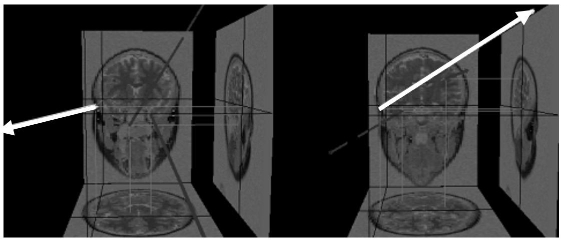

Fig.9 In comparison of the moments of ECDs localized to the right IFG between upward and downward. In the case of ERPs’ polarities were in reverse, ECDs’ moment shown by white arrow were reverse direction (left: upward, right: downward)

In the case of mental translation, tendency of estimated ECDs was different to those in the stimulus recognition. Regardless to direction in stimulus, no ECD was estimated in the Wernicke’s area, which is said to be the hearing language area, however ECDs were localized to the right frontal area which is so-called the working memory and after that ECDs were estimated to the Broca’s area (Fig.10). The moment of ECDs localized to the right frontal area were almost counter in each other case of inverse direction just the same as the preceding research [5] (Fig.11) and in the case of visual stimulus recognition task of the present research. These tendencies are almost the same regardless of presented stimulus and direction at stimulus recognition task.

The investigation of the brain activity during human recognition of visual word and mental translation by use of MEG [9], activities were estimated at the left MTG, at the PFA and at the left MFG. In the present experiment, no visual stimulus was presented to the subjects during mental translation task; therefore ECDs were not localized to the left MTG including the Wernicke’s area. These tendencies that brain activities were estimated at the left MFG and at the PFA are almost the same between visual stimulus and reminded direction.

From these results, it will be possible to estimate directions during mental translation from reminded stimulus by the moment of ECDs on the right PFA and the right frontal cortex, hence by EEGs measured near to the right PFA. Therefore, by output of EEGs from the area, it might possible to control a machine as the brain machine interface. Some of the present authors attempting to make use of outputs of EEG around the right PFA, to discriminate the four type of mental translations.

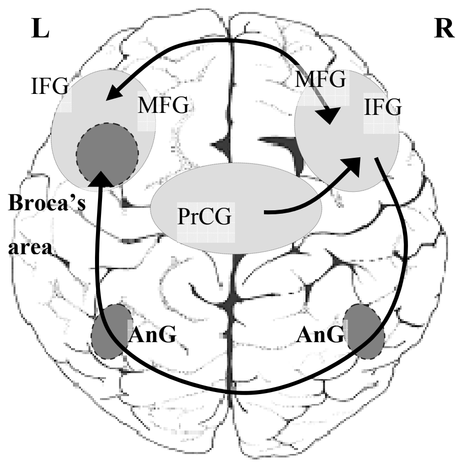

Fig.10 Spatiotemporal transition of estimated ECDs after PrCG (Mental translation)

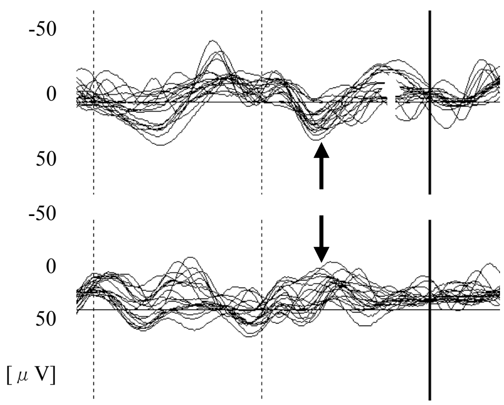

Fig.11. Example of ERPs (arrows denote latencies where signs of potential are opposite in each other and both ECDs were localized to the right IFG), Upper: in the case of stimulus "上", lower: in the case of the stimulus "下" (Mental translation)

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