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Paper:

Spatiotemporal Brain Activity During Hiragana Word Recognition Task

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The 19-channel Event-Related Potentials (ERPs) we recorded during recognition of hiragana (one type of Japanese phonetic characters) were simultaneously and independently presented as a word and a non-word to opposite eyes using a field-sequential stereoscopic 3D display with a liquid-crystal shutter, a word and a non-word were simultaneously and independently presented to the left (right) and the right (left) eyes, respectively. Each word consists of 3 hiragana characters. Three subjects were instructed to press a button when they understood the meaning of the visual stimuli after 3,000 ms poststimulus. Equivalent Current Dipole source Localization (ECDL) with 3 unconstrained ECDs was applied to the ERPs. In the case of right-handed subjects, the ECDs were localized to the Wernicke's area at around 600 ms. In the case of left-handed subject, the ECD was localized to the Wernicke's homologue. After that ECDs were then localized to the prefrontal area, the superior frontal gyrus, and the middle frontal gyrus. At around 800 ms, the ECDs were localized to the Broca's area, then after that ECDs were relocalized to the the Wernicke's area and to the Broca's area.

Keywords: electroencephalogram, brain activity, event related potential, equivalent current dipole source localization, word recognition

1. Introduction

According to researches on the human brain, the primer process of visual stimulus is processed at first on the V1 in the occipital robe. Early on, a right visual field stimulus is processed in the left hemisphere and a left stimulus processed in the right hemisphere. The process then moves to the parietal associative area [1].

Higher order brain processes thereafter have laterality, e.g., 99% of right-handed persons and 70% of left-handed have their language area in the left hemisphere as the Wernicke's area and the Broca's area [2, 3].

Some authors have used the same methodology as the preceding research [4] in presenting kanji words and hiragana words to subjects, then measuring electroencephalograms (EEGs) under these stimuli. Both types of data were then summed and averaged according to the type of stimuli and subjects to get Event Related Potentials (ERPs). Each peak of ERPs were detected and analyzed by the Equivalent Current Dipole source Localization (ECDL) [5] at this latency using a two-dipole model. In both cases of kanji and hiragana recognition, Equivalent Current Dipole (ECD) nodes were localized from early ERP components to the V1, V2, and the Inferior Temporal Gyrus (ITG), after then ECDs were localized to the Wernicke's area and the Broca's area, agreeing with MEG, PET, and fMRI results.

In our study, we used the same methodology as in previous research, determining spatiotemporal brain activity during a hiragana word recognition task using 3-dipole model ECDL and determining the spatiotemporal pathway during the hiragana word recognition task.

2. EEG Measurement Experiments in Mental Translation

2.1. Experimental Apparatuses and Procedures

Three male subjects are from 21 to 22 years old and having normal visual acuity. Two subjects are the right handed and the other is left handed. The subjects put on an electrode cap (ECI, Electrocap International) and watched a 21-inch CRT 30 cm away in front of them. Their heads were fixed on the table on a chin rest. Each word was displayed on the stereoscopic CRT and viewed through field-sequential liquid-crystal glasses. The configuration, consisting of a personal computer, a vertical

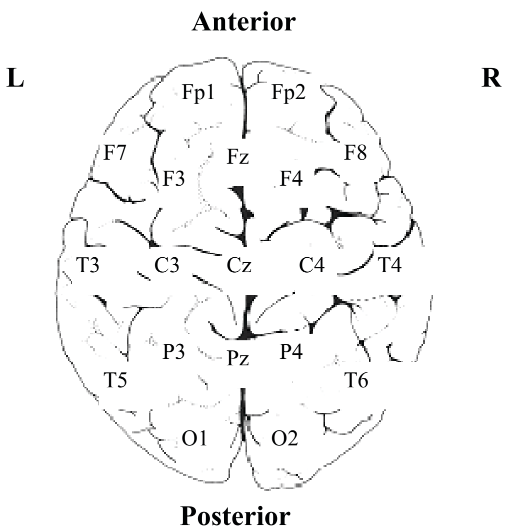

Fig. 1. International 10–20 system electrode arrangement.

synchronizer (Solidray), and the liquid-crystal glasses, enabled infrared signals to be controlled simultaneously. Words/non-words were simultaneously displayed to opposite eyes independently.

Words displayed were stored on disk of PC as a file and presented at random. Cap electrodes followed international 10–20 system (**Fig. 1**), with two electrodes fixed on the upper and lower eyelids to monitor eye movement. Impedance was adjusted from 2 to 5 kΩ. Reference electrodes were put on both earlobes and a ground electrode on the base of the nose. Electroencephalograms (EEGs) were recorded digitally (Synafit EE2500, NEC Corporation). Amplitude was 5 μV/V, the frequency band between 0.15 and 100 Hz, and analog output sampled at 1 kHz and stored on the PC hard disk (**Fig. 2**).

2.2. Stimulus Conditions and Presentation

Two types of words consisting of hiragana characters were presented to subjects simultaneously.

One type was a real word consisting of hiragana and the other a meaningless random non-word. Field-sequential stereoscopic 3D display with a liquid-crystal shutter enabled display simultaneously and independently to opposite eyes; the left (right) eye and right (left) eye, respectively. All words were presented vertically (**Fig. 3**).

2.3. Analysis by Equivalent Current Dipole Source Localization

We measured EEGs of each visual stimulus. To effectively execute the ECDL method, both types of data were summed and averaged according to the characters and subjects to get Event-Related Potentials (ERPs). Summing ERPs by type of stimuli, ECDL was applied to each ERP by each subject. Recording electrodes numbered 19, so a maximum of 3 ECDs was determined using PC-based ECDL analysis software "SynaCenterPro" (NEC Corporation) [5]. The ECDL Goodness Of Fit (GOF) exceeded 99%.

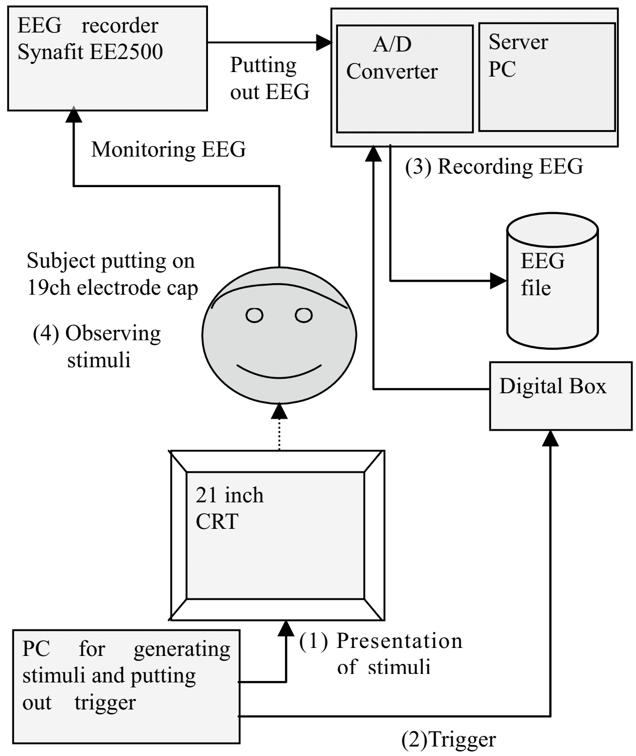

Fig. 2. Experimental apparatus.

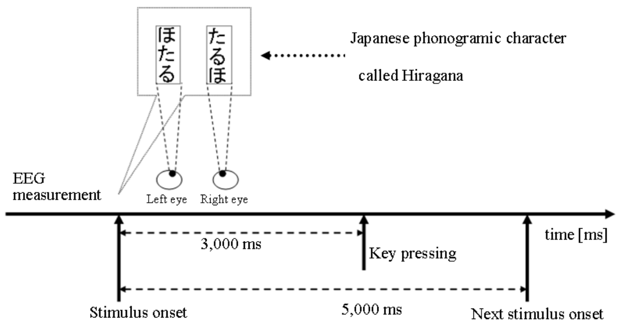

Fig. 3. Experiment timing chart.

3. ECDL Analysis Results

3.1. Result of ECDL Analysis Before Localized to the Broca's Area

As in previous research [4], hiragana is mainly recognized through the left hemisphere. ECDs were localized to the Middle Temporal Gyrus (MTG) called the Wernicke's area at around 600 ms (**Fig. 4**), then ECDs were localized to the Pre-Frontal Area (PFA) (**Figs. 5** and **7**), the Superior Frontal Gyrus (SFG), and the Middle Frontal Gyrus (MFG) (**Fig. 6**). At around 800 ms, ECDs were localized to the Broca's area (**Fig. 8**).

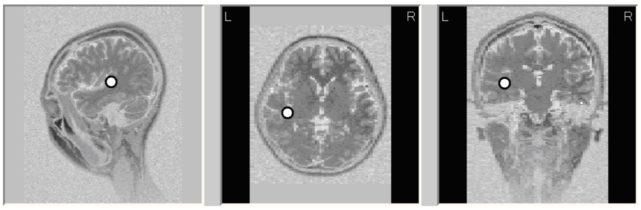

Fig. 4. Example of ECD localized to the Wernicke's area (Brodmann's area 41) at 586 ms (subject NS).

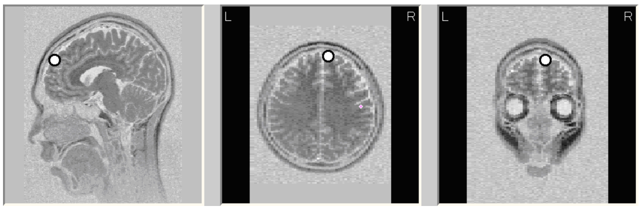

Fig. 5. Example of ECD localized to the PFA (Brodmann's area 10) at 638 ms (subject NS).

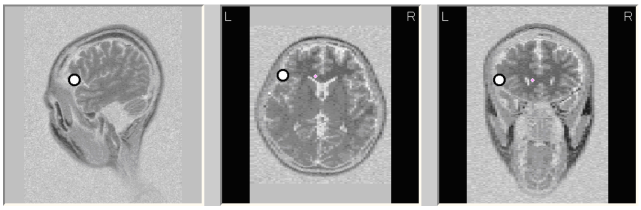

Fig. 6. Example of ECD localized to the left MFG (Brodmann's area 46) at 741 ms (subject NS).

Fig. 7. Example of ECD localized to the PFA (Brodmann's area 10) at 766 ms (subject NS).

Fig. 8. Example of ECD localized to the Broca's area (Brodmann's area 44) at 807 ms (subject NS).

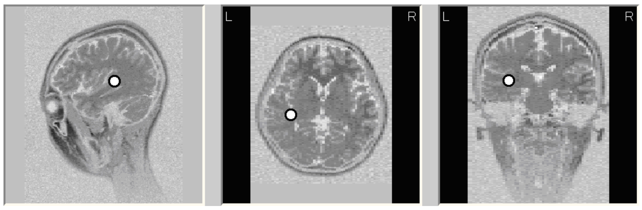

Fig. 9. Example of ECD localized to the Wernicke's area (Brodmann's area 41) at 809 ms (subject NS).

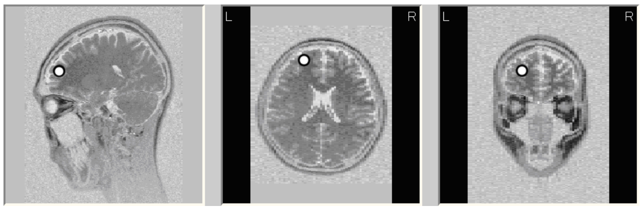

Fig. 10. Example of ECD localized to the PFA (Brodmann's area 10) at 881 ms (subject NS).

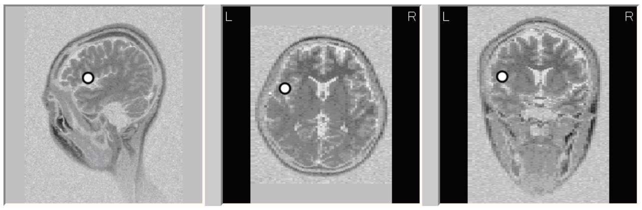

Fig. 11. Example of ECD localized to the left MFG (Brodmann's area 46) at 914 ms (subject NS).

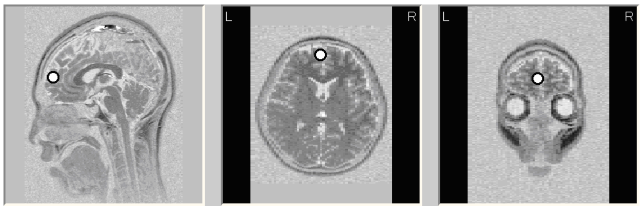

Fig. 12. Example of ECD localized to the PFA (Brodmann's area 10) at 953 ms (subject NS).

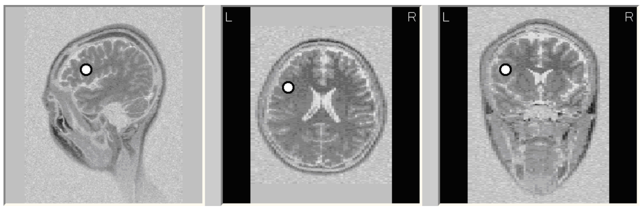

Fig. 13. Example of ECD localized to the Broca's area (Brodmann's area 44) at 977 ms (subject NS).

3.2. Result of ECDL Analysis After Localized to the Broca's Area

In latency after localized to the Broca's area, ECDs were localized again to the Wernicke's area (**Fig. 9**), the PFA (**Figs. 10** and **12**), the left Inferior Frontal Gyrus (IFG), the left MFG (**Fig. 11**), and the Broca's area (**Fig. 13**).

4. Discussion

In the case of hiragana word recognition, ECDs were localized to the language area – the Wernicke's area at around 600 ms, to the PFA, and to the left MFG. At around 800 ms, ECDs were localized to the Broca's area (**Table 1** and **Fig. 14**). After localized to the Broca's area, ECDs were relocalized to the Wernicke's area, the PFA

Table 1. Relationship between localized source and latency before localized to the Broca's area.

Subject	Wernicke	PFA	MFG	PFA	Broca
MY	593	677	712	749	810
NS	586	638	741	766	807
MT	615	634	711	758	822

[ms]

Table 2. Relationship between localized source and latency after localized to the Broca's area.

Subject	Wernicke	PFA	MFG	PFA	Broca
MY	830	861	903	941	973
NS	809	881	914	953	977
MT	825	873	910	953	972

[ms]

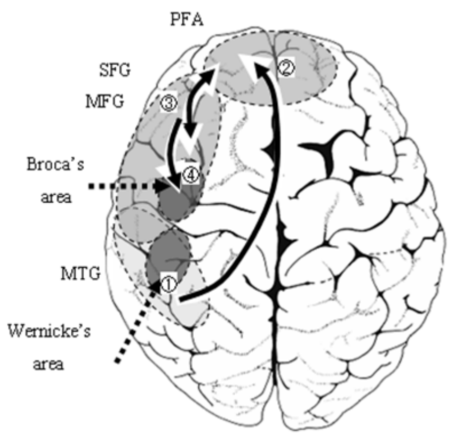

Fig. 14. Spatiotemporal pathways before localized to the Broca's area.

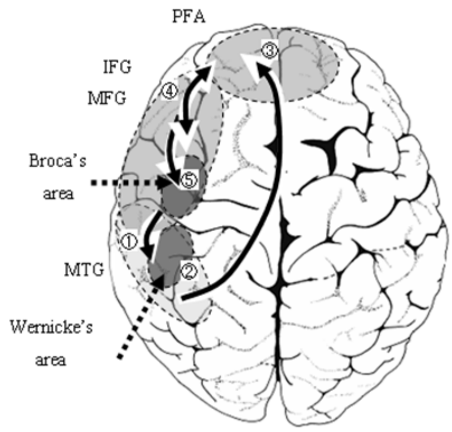

Fig. 15. Spatiotemporal pathways after localized to the Broca's area.

and the left MFG, then to Broca's area at around 970 ms (**Table 2** and **Fig. 15**).

The first spatiotemporal brain activity cycle resembles that for directional kanji recognition using 3-dipole models [6]. These repeated spatiotemporal brain activity cycles are the same in the case of recalling sentences by loci mnemonic system [7]. For recalling sentences task, spatiotemporal brain activities are divided into tasks such as language recognition, memory-related locations, and remembering task corresponding to content.

Stimuli presented here were hiragana characters which are phonogramic words, so spatiotemporal brain activities were divided into pronunciation recognition task and meaning recognition task. This tendency was not observed in the case of kanji word recognition. Kanji characters are ideogramic character, so spatiotemporal brain activities were simple than phonetic word recognition.

5. Conclusions

The results of our study using 3 equivalent current dipoles models showed several tendencies – brain activity during hiragana word recognition is repeated the cycle from the Wernicke's area to the Broca's area. This spatiotemporal brain activity differs in recognition tasks in both areas. These results were from EEG measurement with high time resolution and the ECDL method with high spatial resolution. Our results suggest that phonogramic word recognition in the human brain is much more complex than ideogramic word recognition.

Acknowledgements

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