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An Investigation into Kanji Character Discrimination Process from EEG Signals

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Abstract**—** The frontal area in the brain is known to be involved in behavioral judgement. Because a Kanji character can be discriminated visually and linguistically from other characters, in Kanji character discrimination, we hypothesized that frontal event-related potential (ERP) waveforms reflect two discrimination processes in separate time periods: one based on visual analysis and the other based on lexcical access. To examine this hypothesis, we recorded ERPs while performing a Kanji lexical decision task. In this task, either a known Kanji character, an unknown Kanji character or a symbol was presented and the subject had to report if the presented character was a known Kanji character for the subject or not. The same response was required for unknown Kanji trials and symbol trials. As a pre-processing of signals, we examined the performance of a method using independent component analysis for artifact rejection and found it was effective. Therefore we used it. In the ERP results, there were two time periods in which the frontal ERP wavefoms were significantly different betweeen the unknown Kanji trials and the symbol trials: around 170ms and around 300ms after stimulus onset. This result supported our hypothesis. In addition, the result suggests that Kanji character lexical access may be fully completed by around 260ms after stimulus onset.

Keywords**—** Character discrimination, Event-related Potential, Independent Component Analysis, Kanji, Lexical access.

I. INTRODUCTION

THE frontal area in the brain is known to be involved in behaviroal judgement [1]. Several studies investigated how fast human decides a behavioral judgement when requiring a demanding visual processing [2], [3]. The authors used event-related potential, which has an advantage in its time resolution for investigating cognitive brain functions, and studied judgement process in the frontal area. For example, in such a study [2], the subjects reported if a natural image presented contains animals or not by responding or not responding respectively. The images were new to the subjects and not repeatedly presented. For each animal image, the subjects didn't know the kind, number, size, and location of the animals a priori. Although such a demanding task, the frontal ERP waveforms showed clear amplitude differences from around 150ms after stimulus onset when a presented image contained animals and when it didn't, reflecting the judgment process in the brain. Such an animal detection may be a special case, because that function may be acquired during evolution for biological advantages to survive. However, it is shown that artificial objects such as cars are similary quickly processed [3], [4], which suggests a possibility that such a rapid visual processing is common for visual discrimination.

In this paper, we examined if it is true when language information is involved, because it is suggested that, in language processing, different mechanisms are involved in addition to visual analysis. In word recognition, it is generally assumed that words are processed in the two stages: visual analysis, and semantic and phonological retrieval [5]. Firstly the form of a presented word is visually recognized, and then the meaning and sound of the word are retrieved. The latter stage is also called lexical access. It is suggested that lexical access for words occurs 200-250ms after stimulus onset [6], [7].

Kanji (also called Chinese characters) is a Japanese logogram system. Kanji characters have at least three different characteristics from European alphabets. First, those visual forms are relatively complex (ex. see Fig.1). Second, a single Kanji character has one or more sounds to be pronounced and often has a meaning by itself. Third, there are many Kanji characters (about 2,000 Kanji characters are commonly used in Japanese). An ERP study suggests that a single Kanji character is processed like a word [14], probably due to these characteristics.

Therefore, in Kanji character discrimination, we hypothesized that frontal ERP waveforms reflect two discrimination processes in separate time periods: one based on visual analysis and the other based on lexical access. To examine this hypothesis, we recorded and analyzed subjects' ERP waveforms while performing a kanji lexical decision task. In this task, either a known Kanji character, an unknown Kanji character or a symbol was presented. The subject had to report if the presented character was a known Kanji character for the subject or not. If either an unknown Kanji character or a symbol was presented, the same response was required. Because of the following reasons, we compared the unknown Kanji trials with the symbol trials. (1) Because unknown Kanji characters are Kanji characters but symbols are not, they have different visual features in those forms (ex. see Fig.1). Also (2) it can be considered that the Kanji character lexical access is involved when judging unknown Kanji character, however, it is not involved when judging symbols. Because the required response was the same in those trials, if there are differences in the frontal ERP waveforms, the differences can be considered as differences in discrimination processes in the frontal area. Therefore, by comparing the frontal ERP waveforms in the unknown Kanji trials and symbol trials, we examined the hypothesis.

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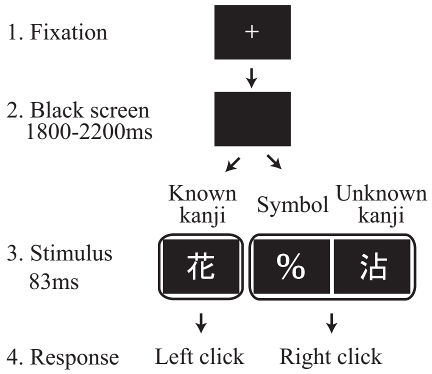

Fig. 1 Experimental task

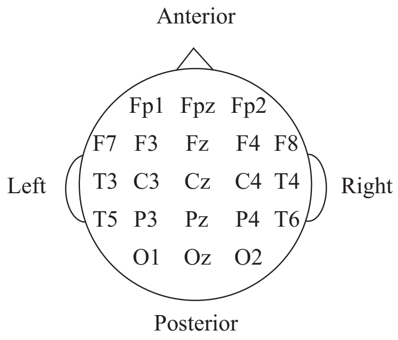

Fig. 2 Electrode placement

Especially, it can be considered that when judging an unknown Kanji character, Kanji character lexical access should be fully completed to find out that no information is stored in the brain. Therefore the discrimination process based on Kanji character lexical access may appear from around 250ms after stimulus onset, because lexical access is suggested to occur around 200-250ms after stimulus onset [6], [7].

Before analyzing ERPs, it is common to remove artifacts from EEGs [8], [9], [10], [11], [12]. Because a method using independent component analysis (ICA) is suggested to be effective [8], [9], we examined this before analyzing ERPs.

II. METHODS

A. Kanji Lexical Decision Task

The experimental task is depicted in Fig.1. In this task, the subjects were asked to judge if the presented character is a known Kanji character (a Kanji character they know) or not. Three types of characters were used: known Kanji characters, unknown Kanji characters, and symbols. We will describe the details about the character types later. In this task, a character was presented on a PC monitor. (1) The subject clicked the left mouse button to start a trial. (2) Then a black screen was presented for a random delay (1.8-2.2s) and (3) a character either a known Kanji, an unknown Kanji, or a symbol image was presented briefly (83ms). (4) The subject had to report if the presented image was a known Kanji or not by clicking the left mouse button or clicking the right mouse button respectively. This brief presentation of an image is to prevent exploratory eye movements [2], because an eye movement is an artifact for ERP recording. The trial image order was pseudo-randomized. The images were presented in a 17 inch PC monitor located at 100cm away from the subject. Six subjects (23-25 years old) participated in this experiment.

B. Experimental Stimuli

To select Kanji characters, we used a Kanji database which stores the known rates and complexity of Kanji characters examined by a linguistic study [13]. The study reported the proportion of the subjects who surely know that a Kanji character exists as the known rate of the Kanji character. Also, the complexity of a Kanji character was reported as the average scores that the subjects rated the subjective complexities in a scale of 1 to 7 (1: simple, 7: highly complex).

We used three types of characters. (1) Known Kanji characters: Kanji characters which have 100% known rates in the database. We used these Kanji characters as the most common characters almost all Japanese know. (2) Unknown Kanji characters: Kanji characters that the subjects didn't know. In the recording session, we used rare Kanji characters which have less than 40% known rates. We didn't confirm if the subjects know each rare Kanji or not beforehand, because we didn't want to present characters twice to avoid the influences of learning on ERP waveforms. After the recording session, we confirmed that the subject didn't know almost all rare Kanji characters presented in the recording session. (3) Symbols: symbols which are very commonly used. We selected the symbols from the character set defined by JIS (Japanese Industorial Standards). To controll the complexities of Kanji characters in a range, all Kanji charecters were selected from those which have moderate complexities in a range (3.0-4.0).

The number of trials for each character type was 100. Each character was presented only once. The size of the images was $7.9^\circ \times 7.9^\circ$. In each image, a character was shown in white on the black background.

C. EEG/ERP Recording

The electroencephalographies (EEGs) were recorded from 21 scalp electrodes (Fpz, Oz and 19 electrodes according to the international 10-20 system) with an electrocap (Electro-cap international). Fig.2 shows the electrode placement. A ground electrode was placed on the forehead. All scalp electrodes were referenced to linked earlobes. Simultaneously, electro-oculograms (EOGs) were recorded from 2 electrodes one placed below the right eye and the other on the left outer canthus. The signals were amplified and 0.5-100Hz band-pass filtered by an amplifier (BIOTOP, NEC). The impedance of electrodes was kept under $10\text{k}\Omega$. The signals were stored into a PC with a 512Hz sampling rate. After recording, the signals were digitally low-pass filtered below 40Hz to reduce line noise. Trials containing more than 70μV EOG amplitude were removed from the subsequent analyses because of the

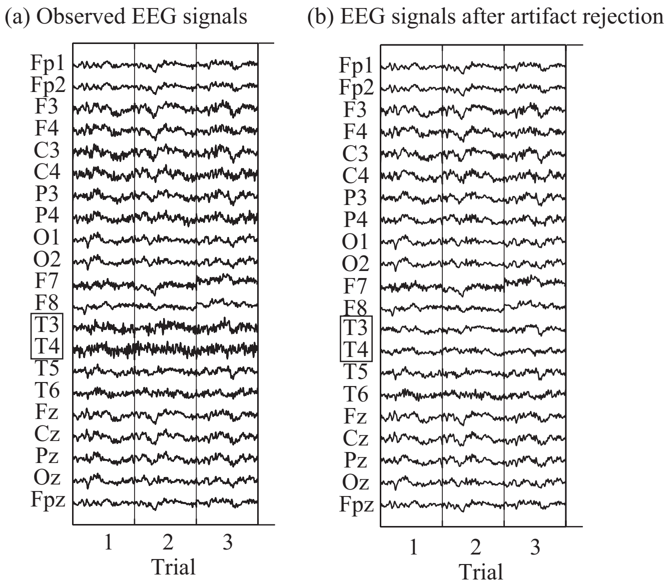

Fig. 3 EEG waveforms (a) before and (b) after artifact rejection

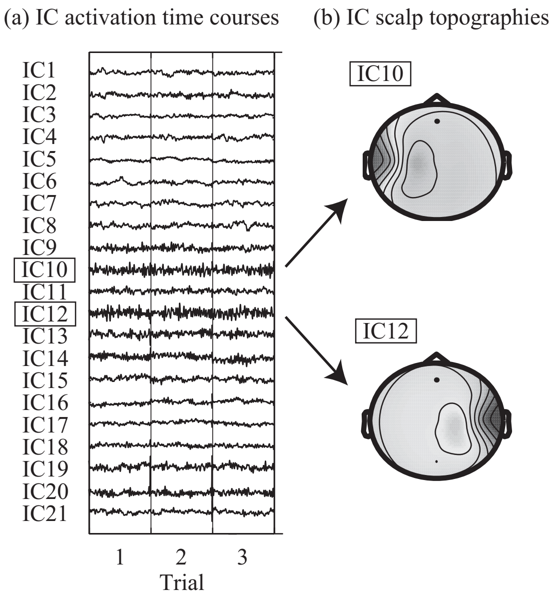

Fig. 4 (a) activation timecourses and (b) scalp topographies of independent components

big artifactual influences of eye movements on the EEGs [8]. For each electrode, a subject's single trial raw EEGs were taken from 100ms before to 1000ms after stimulus onset in all correct trials and subtracted the baseline voltages from those raw EEGs to obtain the subject's single trial EEGs. As the baseline for each trial and for each electrode, we used the average voltage in the electrode in the preceding 100ms interval before stimulus onset in the trial. The correct trials were the trials in which the subject behaviorally correctly discriminated characters presented. If necessary, we removed artifacts from the subject's single trial EEGs with ICA [8], [9], [16], as we will explain next. A subject's ERPs were obtained by averaging the subject's single trial EEGs across trials. The grand averaged ERPs were obtained by averaging ERPs across subjects.

III. PRE-PROCESSING OF EEG SIGNALS: ARTIFACT REJECTION USING ICA

From the following reasons, we adopted a method using independent component analysis (ICA) to remove artifacts from EEG signals [8], [9] First, eyes, muscles or line noise, which are the sourses of common artifacts, are spatially fixed and those activities are independent from the brain activities involved in performing our task. Therefore ICA seems to be effective to separate and remove those aftifacts from EEG signals by decomposing EEG signals into statistically independent components. Second, A study [9] reported that a method using ICA have some advantages over other conventional methods [10], [11] used in artifact rejection. Third, the source codes used in the previous studies [8], [9] are open to the public as EEGLAB [16]. Therefore the algorithms of the processing are clear. Finally, in our study, after we conducted artifact rejection using ICA, we didn't find any problems on the EEG signals. We will explain an example about this later.

ICA is a method to decompose signals into statistically independent components (ICs). That is, ICA computes a matrix $W(N_c \times N_c)$ which converts from observed signals $X(N_c \times N_t)$ into ICs $S(N_c \times N_t)$: $S = WX$. N_c is the number of electrodes, N_t is the number of time points of the observed signals. Because, as stated, artifacts are usually independent from brain activities at least in appropriate experimental settings, some of ICs can be identified as accounting primarily for eye movements, muscle or line noise. Therefore, only from the remaining ICs S^*, we reconstruct EEG signals X^* in which artifacts are eliminated or reduced: $X^* = W^{-1}S^*$.

We show an example of artifact rejection using ICA. Fig.3(a) shows the observed EEG signals of a subject. For displaying purposes, only three consecutive trials are shown. One trial is the 1100ms interval from 100ms before to 1000ms after stimulus onset. As can be seen, the left temporal T3 and right temporal T4 EEG signals contain high frequency components which can be considered as muscle artifacts [9]. By applying ICA to the observed 21 channel EEG signals in all trials, 21 ICs were obtained. Fig.4(a) shows the activation time courses of all ICs in the three trials in Fig.3(a). As can be seen, IC 10 and IC 12 contain high frequency components like the T3 and T4 EEG signals (Fig.3(a)). Fig.4(b) shows the scalp topographies of IC 10 and IC 12. Because, as stated, the matrix W converts the EEG signals into ICs, the elements of W mean the weights of the EEG signals at each electrode on each ICs In Fig.4(b), the values of the elements of W corresponding to IC 10 and IC 12 are plotted on the electrode positions in a gray scale. In areas other than the electrodes, the values are simply interpolated. Darker areas represent larger values. The unit is arbitrary. The black dots represent the 21 electrode

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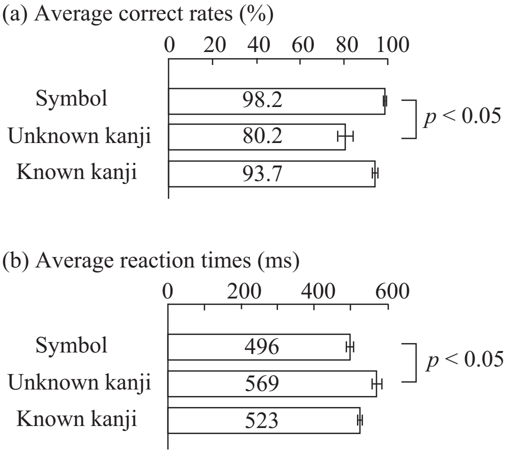


Fig. 5 Behavioral results

positions. As can be seen, IC 10 and IC 12 are mainly derived from the EEG signals in the left temporal and right temporal areas respectively. Thus, based on the activation time courses and scalp topographies, IC 10 and IC 12 were thought to be the muscle artifacts contained in the T3 and T4 EEG signals. Then, EEG signals were reconstructed only from the remaing 19 ICs. Fig.3(b) shows the reconstructed EEG signals. As can be seen, the reconstructed EEG signals revealed underlying EEG activity at the T3 and T4 electrodes that was masked by the muscle artifacts in the observed EEG signals (Fig.3(a)). Also little effects can be seen on the reconstructed EEG signals at the other electrodes. Thus, this method appears to be very effective. We decided to adopt it and used it if necessary as a pre-processing of the EEG signals.

IV. BEHAVIORAL RESULTS

At first, we examined if processing is different between the unknown Kanji trials and symbol trials in behavioral results. Fig.5(a) shows the average correct rates across subjects. The average correct rate for unknown Kanji characters was lower than that for symbols. To examine this statistically, we conducted a paired t-test about the correct rates across subjects. The difference was significant ($p < 0.05$, $t(5)$=2.67).

Fig.5(b) shows the average reaction times across subjects. The average reaction time for unknown Kanji characters was longer than that for symbols. We counducted a paired t-test about the average reaction times across subjects. The difference was significant ($p < 0.05$, $t(5)$=3.97). The longer reaction time in the unknown Kanji trials suggests that it took more time to judge when judging unknown Kanji characters because of need for Kanji character lexical access, compared to when judging symbols in which Kanji character lexical access is not involved.

These behavioral results suggest that the unknown Kanji characters and symbols were differently processed in the brain.

V. GRAND AVERAGED ERPS AT ALL ELECTRODES

Before we examine the hypothsis, we examined if the ERPs were reliably mesuared by checking if there were several ERP components which are known to appear when seeing presented words or single Kanji characters. Fig.6 shows the grand averaged ERP waveforms at all 21 electrodes. The grand averaged ERP waveforms are the averaged ERP waveforms across subjects. Each panel corresponds to each electrode. In each panel, the abscissa is the time after stimulus onset and the ordinate is the voltage. The voltage at each time point is plotted as an ERP waveform. The three ERP waveforms in symbol, unknown Kanji and known Kanji trials are superimposed. The arrows indicate ERP components.

P100, N170, and P250 are ERP components which usually appear in the posterior electrodes after presentation of visual stimuli including words and characters. The number represents the approximate peak time and P or N denotes the polarity, positive or negative. P100 is known to be related to attention [17] and also a study reported that P100 is related to Kanji perception [18]. N170 and P250 are known to be related to word recognition [12], [19]. VPP (Vertex Positive Potential) is an ERP component which appears around the anterior electrodes in a similar time range to N170 and is suggested that it is strongly related to N170 [12].

As can be seen from the figure, in our recording, those ERP components appeared as in the previous studies. Therefore we conclude that the ERP waveforms were reliably measured while performing the task.

VI. FRONTAL ERP RESULTS

To examine the hypothesis that the frontal ERP waveforms reflect two discrimination processes in separate time periods: one based on visual analysis and the other based on lexical access, we compared the frontal ERP waveforms in the unknown Kanji trials and symbol trials.

To see the patterns of the frontal ERP waveforms, we magnify the Fz ERP waveforms in symbols and unknown Kanji trials in Fig.7(a). As can be seen, there were clear differences in the ERP waveforms between the unknown Kanji trials and the symbol trials in the 100-200ms and 250-400ms time periods. Importantly, the subjects' responses were the same in the unknown Kanji trials and symbol trials (clicking the right mouse button). Therefore, the outcomes of judgement were the same. But this result suggest that the process of judgement was different between when judging unknown Kanji characters and when judging symbols.

To see the time course of the differences in the ERP waveforms, we calculated the difference waveform by subtracting the ERP waveform in the symbol trials from that in the unknown Kanji trials. Fig.7(b) shows the Fz difference waveform. The figure format is the same as in Fig.7(a). As can be seen, there were two peaks: around 160ms and around 310ms after stimulus onset. This suggests a possibility that processing of the unknown Kanji characters and the symbols affects judgement processes in the frontal area in the two time periods: around 160ms and 310ms after stimulus onset.

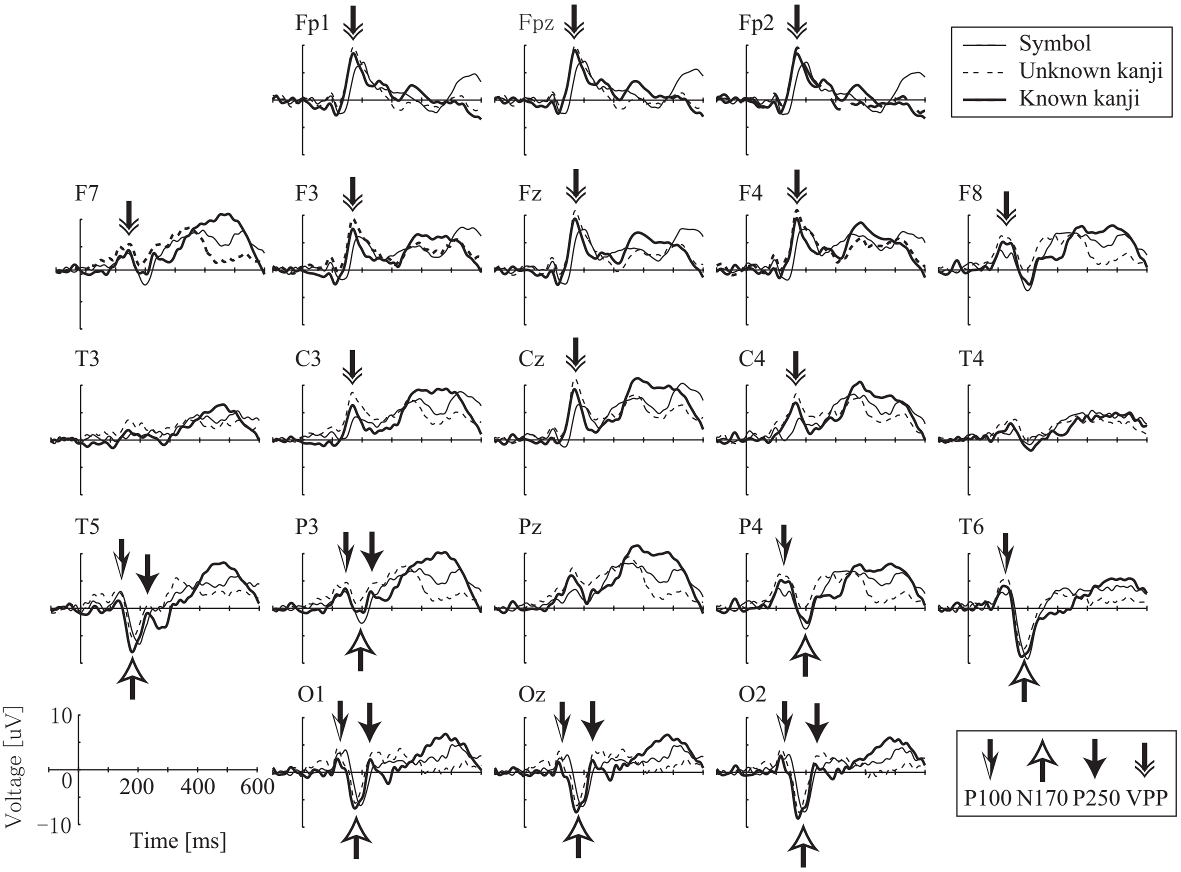


Fig. 6 Grand average ERP waveforms at all 21 electrodes

To statistically examine this difference in the ERP waveforms [2], we conducted a series of paired t-tests at each time point about the mean ERP amplitudes across subjects between the unknown Kanji trials and symbol trials. In Fig.7(c), we plotted the time course of the t-scores. The abscissa is the time after stimulus onset and the ordinate is the t-score. The t-score obtained in the paired t-test about the ERP amplitudes at a time point across subjects is plotted as a function of time. The horizontal broken lines indicate the significance level (p=0.05) and the gray areas indicate the time periods in which there were significant differences between the unknown Kanji trials and symbol trials. As can be seen, around the two peaks: around 160ms and around 310ms after stimulus onset, the Fz ERP waveforms were significantly different between the unknown Kanji trials and symbol trials.

We conducted the same analysis for other frontal ERP waveforms and obtained similar results. Fig.8 shows the t-score time courses at all 8 frontal electrodes: the Fp1, Fp2, Fpz, F3, F4, Fz, F7, F8 electrodes. The figure format is the same as in Fig.7(c), but, in this figure, the t-score time courses at the 8 electrodes are superimposed. As can be seen, all t-score time courses in the frontal area showed two peaks: around 170ms and 300ms after stimulus onset. Thus, all frontal ERP waveforms showed a similar result about the differences between the unknown Kanji trials and symbol trials. Therefore, these results support our hypothesis.

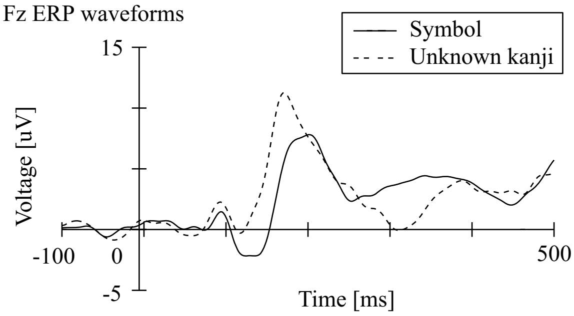
VII. CONCLUSION

In Kanji character discrimination, we hypothesized that frontal ERP waveforms reflect two discrimination processes in separate time periods: one based on visual analysis and the other based on lexical access. To examine this hypothesis, we recorded and analyzed ERPs while performing a Kanji lexical decision task. In this task, either a known Kanji character, an unknown Kanji character or a symbol was presented and the subject had to report if the presented character was a known Kanji character for the subject or not. The same response was required for the unknown Kanji trials and symbol trials.

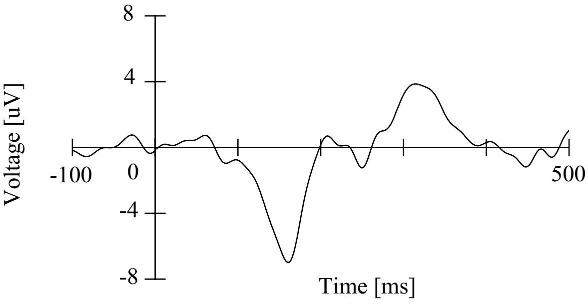
As the result, the frontal ERP waveforms showed significant differences between the unknown Kanji trials and the symbol trials in the two time periods: around 170ms and around 300ms after stimulus onset. This result supports our hypothesis.

Therefore, in the intermediate time period between the two time periods, lexical access seems to occur to retrieve information about the Kanji character presented. P250, which appears around 250ms after stimulus onset, is suggested to be related to lexical access [6], [7]. And, as can be seen from Fig.7 and Fig.8, in the second time periods, the difference

(a) Fz ERP waveforms



(b) Fz difference waveform



(c) Fz *t*-score time course

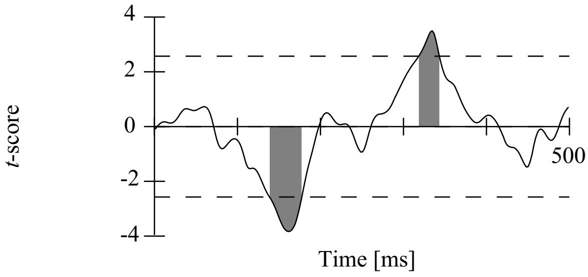


Fig. 7 Analysis of the ERP waveforms at the Fz electrode

between the unknown Kanji trials and symbol trials arose from around 260ms after stimulus onset. When judging an unknown Kanji character, it can be considered that Kanji character lexical access should be fully completed to find out that no information is stored in the brain. Therefore, Kanji character lexical access may be fully completed by around 260ms after stimulus onset.

In future studies, it is necessary to study about the interaction between the discrimination process in the frontal area and Kanji character lexical access in other areas, especially while subjects are reading a word or a sentence.

REFERENCES

[1] M.S. Gazzaniga, R.B. Ivry, and G.R. Mangun, “Cognitive Neuroscience,” W.W. Norton & Company, Newyork, 1998.
[2] S. Thorpe, D. Fize, and C. Marlot, “Speed of Processing in the Human Visual System,” *Nature,* vol. 381, pp. 520-527, 1996.
[3] R. VanRullen, and S.J. Thorpe, “The time course of visual processing: from early perception to decision-making,” *J. Cogn. Neurosci.,* vol. 13, pp.454-461, 2001.

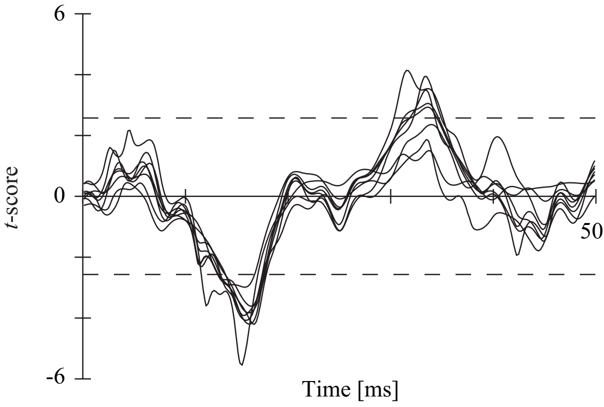


Fig. 8 *t*-score time courses at all 8 frontal electrodes

[4] R. VanRullen, and S.J.Thorpe, “Is it a bird? Is it a plane? Ultra-rapid visual categorisation of natural and artifactual objects,” *Perception,* vol. 30, pp. 655-668, 2001.
[5] S. Dehaene, L. Cohen, M. Sigman, and F. Vinckier, “The neural code for written words: a proposal,” *Trends Cogn. Sci.,* vol. 9, pp. 335-341, 2005.
[6] A.P. Rudell, “Rapid stream stimulation and the recognition potential,” *Electroencephalogr. Clin. Neurophysiol.* vol. 83, pp. 77-82, 1992.
[7] M. Martin-Loeches, J.A. Hinojosa, G. Gomez-Jarabo, and F.J. Rubia, “The recognition potential: an erp index of lexical access,” *Brain and Language,* vol. 70, pp. 364-384, 1999.
[8] S. Makeig, M. Westerfield, T.P. Jung, J. Covington, J. Townsend and T.J. Sejnowski, and E. Courchesne, “Functionally Independent Components of the Late Positive Event-related Potential during Visual Spatial Attention,” *J. of Neurosci.,* vol. 19, pp. 2665-2680, 1999.
[9] T.P. Jung, S. Makeig, C. Humphries, T.W. Lee, M.J. McKeown, V. Iragui, and T.J. Sejnowski, “Removing electroencephalographic artifacts by blind source separation,” *Psychophysiol.,* vol. 37, pp. 163-178, 2000.
[10] J.L. Kenemans, P.N. Molenaar, M.N. Verbaten, and J.L. Slangen : “Removal of the Ocular Artifact from the EEG: A Comparison of Time and Frequency Domain Methods with Simulated and Real Data”, Psychophysiology 28, pp.114-121 (1991)
[11] P. Berg, and M. Scherg : “Dipole Models of Eye Activity and Its Application to the Removal of Eye Artifacts from the EEG and MEG”, Clinical Physics and Physiological Measurements 12(Supplement A), pp.49-54 (1991)
[12] B. Rossion, C.A. Joyce, G.W. Cottrell, and M.J. Tarr, “Early lateralization and orientation tuning for face, word, and object processing in the visual cortex,” *Neuroimage,* vol. 20, pp. 1609-1624, 2003.
[13] N. Amano and K. Kondo (ed.), “Moji Tokusei (Character charasteristics),” Tokyo: Sanseido, 1999.
[14] M. Hayashi, Y. Kayamoto, H. Tanaka, and J. Yamada, “Semantic activation by japanese kanji: evidence from event-related potentials,” *Perceptural and Motor Skills,* vol. 86, pp. 375-382, 1998.
[15] M. Iwata, “Kanji versus kana neuropsychological correlates of the japanese writing system,” *Trends Neurosci.,* vol. 7, pp. 290-293, 1984.
[16] A. Delorme and S. Makeig, “An Open Source Toolbox for analysis of single-trial EEG dynamics,” *J. of Neurosci. Method,* vol. 134, pp. 9-21, 2004.
[17] M.J. Taylor, “Non-spatial attentional effects on P1,” *Clin. Neurophysiol.,* vol. 113, pp.1903-1908, 2002.
[18] H. Abe and M. Nakayama, “Event-related potential study of kanji perception process,” *J. Inst. Image Inf. Television Eng.,* vol. 60, pp. 397-404, 2006.
[19] S. Bentin, Y. Mouchetant-Rostaing, M.H. Giard, J.F. Echallier, and J. Pernier, “ERP manifestations of processing printed words at different psycholinguistic levels: time course and scalp distribution,” vol. 11, pp. 235-260, 1999.