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〔 **Original Paper** 〕

Cerebral functional localization of word recognition process during silent reading of native and non-native languages : a study of event-related potentials

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SUMMARY

To clarify the cerebral areas activated by word recognition process, twenty-one channel visual event-related potentials (ERPs) were recorded during silent reading of kanji or English words, or the Arabic numerals in either the native or non-native language in six Japanese, four Chinese and four Uighur subjects. Grand averaged ERPs revealed the negative potentials with latency ranges between 200 and 300 ms after the onset of word or numeral presentation. The amplitude topographies revealed that the recognition task for kanji activated the central, and bilateral-parietal and -temporal areas, that that for English over the left middle- and posterior-temporal, and parietal areas, and that for numeral over the bilateral temporal and occipital areas. It was also found that the left hemisphere was more powerfully activated by word recognition in the non-native language (English and numeral) than by that in the native one (kanji and numeral). It is suggested that word recognition of native and non-native languages activate separate cortical neural networks in the brain. The cortical functional difference observed in the present study is also suggested to depend on the differences of language system such as phonographic or ideographic one.

Key words : event-related potentials, word recognition, native and non-native languages, cerebral localization

I. Introduction

The cerebral organization of bilinguals with respect to language is still disputed in despite of many investigations using different modalities. Some investigators suggest that different cerebral networks support native and non-native language acquisition, and that only one language was specifically impaired in polyglot aphasia[1,2]. For example, a type

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阿不拉 地里夏提，中島祥夫，下山一郎：事象関連脳電位による黙読時の母国語，外国語単語認知に関与する脳の機能局在解析．
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of bilingual aphasia is described where the patient's performance in one language was improved while performance in another language was deteriorated (antagonistic recovery)[1]. Aglioti et al[3]reported a unique case of a bilingual aphasia whose native language ability was much more impaired than that of the non-native one less practiced. April and Tse[4]reported that a right-handed Chinese man with crossed aphasia following the right cerebral infarction complained of severer speech and language dysfunction in performing Chinese than English. Such clinical symptoms seem to support the existence of distinct and separate neural bases in performing different languages. Using electrical stimulation of the cortex, this dissociation is assumed that the brain areas recruited in learning and processing of the native language are different from those of the non-native one[5]. Paradis[6] proposed that bilinguals might master each language by using different sets of implicit and explicit memory systems, which rely upon separate neural structures. Although brain imaging studies of bilingual subjects revealed different cortical areas activated by native and non-native language recognition processes[7-11], it seems that studies such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) cannot provide sufficient temporal resolution to analyze the time course of neural activity during language processing. Furthermore, many neuropsychological and brain imaging studies of bilingual brain adopted a variety of language sets as a task, but no attention was paid to the effects of phonographic and ideographic languages on cerebral activation.

Kanjis are ideographic letters of Chinese origin used in the Chinese and Japanese reading and writing systems to represent a lexical morpheme of spoken Chinese and Japanese, and each kanji corresponding to morphograms has a phonetic as well as a semantic value. Furthermore, the Arabic numerals represent an ideographic system, which is similar to kanji in their lack of phonographic information in reading and writing. Since most of Japanese and Chinese use ideographic letters, kanji, as the native and phonographic ones, English, as the non-native language in reading and writing, the present study was aimed to estimate cerebral areas activated during word recognition task of the two different language systems using event-related potentials (ERPs). The question in the present study was whether or not the recognition process of native language activates cortical areas that are different from those activated by non-native language recognition.

Several studies of ERPs[12], PET[13]and magnetoencephalography (MEG)[14] on language recognition process suggested that visual kanji recognition task activated the left and right hemispheres. Ji et al[15] also reported that visual numeral recognition task activated the bilateral temporal regions. On the other hand, some PET[16,17]and fMRI[18]studies revealed that visually presented English words activated the left medial extrastriate cortex and the left temporal area. These results seem to mean that the neural basis for ideographic recognition process is different from that for phonographic one.

In the present study, we performed two experiments. In the first experiment, the visual ERPs in silent reading of kanji or English words in either the native or non-native language, respectively, were recorded in normal Japanese and Chinese volunteers. In the second experiment, visual ERPs in the silent reading of the Arabic numerals in either the native or non-native language were recorded in Japanese and Uighur (from the Xinjiang Uighur Autonomous Region of China) volunteers to confirm whether the cortical areas estimated in the first experiment are in fact specifically related to the effects of different language systems (ideographic versus phonographic) or to those of different languages accustomed to use (native versus non-native).

II. Materials and Methods

Subjects. In experiment 1, five Japanese (whose native language is Japanese) and four Chinese (whose native language is Chinese) male subjects participated. Their ages ranged from 29 to 47 years-old (mean 35.2±5.7). They began to learn English at 12-14 years of age (mean 12.3). Among them, two subjects were scientists and the remains graduate students of university. In experiment 2, six Japanese (five of whom had previously participated in experiment 1) and four Uighur volunteers (mean 34.8±6.1 years-old; nine males and one female) participated. The time interval between the first and second experiments was more than a month in the subjects repeatedly participated. All Uighur subjects (whose native language is Uighur, a Turkish dialect) began to learn Chinese at school after the age of 12 years. Among them, two subjects were scientists and the remains graduate students of university. All subjects in these two experiments were right-handed (examined with Edinburgh Inventory[19]) and had no history of neurological disease. The experiments were performed according to the Declaration of Helsinki, and all of the subjects gave informed consent in oral and written forms.

Stimulation. In experiment 1, we prepared 40 kinds of Japanese and 40 kinds of Chinese words consisting of two kanji letters, and 40 kinds of English ones consisting of five letters. Thus, we prepared 80 kinds of visual stimulation pattern composed of kanji and English words. Japanese and Chinese letters consisted of kanjis with a similar ideographic meaning. Kanji words were selected from those learned during the first six years in elementary school. English words were selected from the important one-thousand words listed in an English-Japanese dictionary [20]. After the experiment, all subjects evaluated the familiarity of the words on a scale between 0 (the least familiar) and 5 (the most familiar). The mean value obtained was 4.6 for the kanji and 4.5 for the English words. All words used in the present study were composed of imaginable nouns, but the individual words in one language system were independent of the other one in terms of meaning. There was no statistical difference in the familiarity between the kanji and English words.

In experiment 2, we prepared 40 kinds of numerals consisting of two digits (e.g., 85, 41) as test stimuli and 40 kinds of two symbols (e.g., %$, &!) as control ones.

The stimuli used in the present experiments were displayed as white-on-black on a TV monitor screen under the control of a personal computer, which was connected with another computer to trigger EEG averaging. A small circle was always presented at the center of the screen as an ocular fixation point.

Procedure. The subjects sat on a comfortable chair with a headrest in an electrically shielded and air-controlled room. After dark adaptation, they were asked to look at the fixation point on the TV monitor placed 120 cm in front of them and not to move their eyes.

In experiment 1, patterns consisting of Japanese kanji and English words were displayed as test word stimuli for the Japanese subjects, while those of Chinese kanji and English words as test ones for the Chinese subjects. One stimulation epoch consisted of two stimuli ; warning (triangle) and the test word stimuli. At first, the warning stimulus (upward or downward triangle) was presented for 100 ms at a visual angle of 1.4° above or below the fixation point. Five hundred milliseconds after the warning stimulus, kanji and English words were displayed for 50 ms above and below the fixation point, respectively. Their visual angles were 2.4° wide by 1.5° high for kanji and 2.7° wide by 1.4° high for English words. The subjects were instructed to look at the fixation point throughout the session, and to read silently either kanji or English word according to the prior warning instruction. That is, the subject was instructed silently to read kanji word when the upward warning stimulus was displayed upper than the fixation point (native word task), or English one when the downward warning triangle lower than the fixation point (non-native word task). The warning stimuli were randomly presented in a range of 3-4 s (Fig. 1). One recording block composed of 80 epochs of the visual word stimuli was repeated three-times in each subject with a several minutes' rest between blocks.

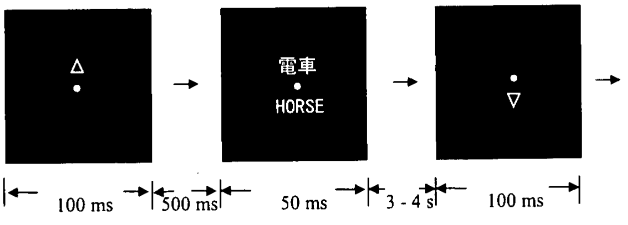

Fig. 1 Time sequence of the visual warning and word stimuli.

In experiment 2, two digit Arabic numerals or two symbols were randomly displayed on the TV-monitor for 50 ms at random intervals of 3-4 s with a visual angle of 0.95° wide by 0.95° high. The subject was asked silently to read the numerals either in the native or non-native language (native or non-native numeral task, respectively), but to overlook the symbols (overlooking task). One recording block was composed of 80 epochs of the visual stimuli of the numeral and symbol, and the recording block either in the native or non-native task was repeated three-times at random order in each subject with a several minutes' rest between blocks.

Measurement of EEGs. Electroencephalograms (EEGs) were recorded from 21 electrodes affixed to the scalp according to the international 10-20 system (Fig. 2) using a balanced non-cephalic reference[21] and a 0.05-60 Hz band-pass filter. An electrooculogram (EOG) was simultaneously recorded to eliminate EEG signals contaminated by artifacts such as eye movements and electromyograms. The twenty-one EEGs, EOG and the trigger pulses generated in the personal computer were recorded on a magnetic tape using a data recorder (MR9000, TEAC, Japan) for the further off-line data acquisition. The twenty-one EEG signals for a 1000-ms period (-100 to 900 ms from the onset of the word and numeral stimulation) were digitized for each task at 1000 Hz and stored as a potential file on a hard disk of a workstation for the further analysis.

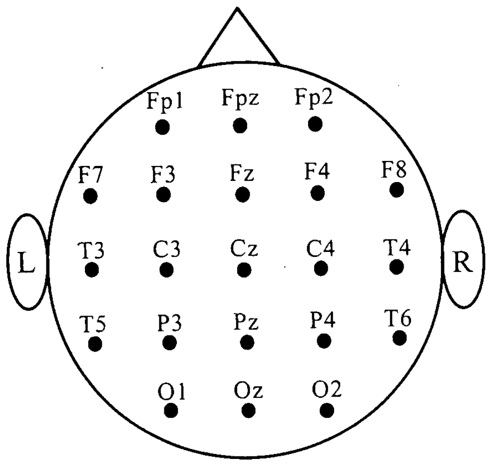

Fig. 2 Electrode positions used for EEG recording.

Data analysis. EEGs were averaged to obtain ERPs during silent reading of word or numeral in either native or non-native language. Mean ERP amplitude during pre-trigger 100 ms period in each recording channel was used to adjust a zero potential level. The mean ERP amplitudes were calculated in a stepwise manner from the stimulus onset (0 ms) to 900 ms using a 100 ms-window. The one-way repeated measure analysis of variance (ANOVA) was applied to the mean amplitudes in each period to obtain a statistically significant level between all tasks and electrode locations (21 recording sites for tasks, and 16 recording sites except five midline ones for laterality). Subsequently, a *post-hoc* test (Fisher's PLSD) was also applied for the second experiment. Probability value of less than equal 5 percent was adopted as a significant level.

III. Results

Experiment 1. Grand averaged ERPs of nine subjects in the silent reading of either the kanji or English words revealed the large negative potentials between 200 and 300 ms after the stimulus onset over the central, bilateral-parietal, and bilateral-temporal areas (Fz, Cz, Pz, C3, C4, P3, P4, T3, T4, T5 and T6) during the native word task, and over the left middle- and posterior-temporal, parietal, and occipital areas (T3, C3, Cz, T5, P3, Pz, P4, O1, Oz and O2) during the non-native word task (Fig. 3). The topographies of the averaged potentials between 200 and 300 ms after the stimulus onset also showed the maximal negative potential areas at the central, and bilateral-parietal and -temporal areas during the native word task, and over the left middle- and posterior-temporal, and parietal areas during the non-native word task (Fig. 4). Significant differences were found between the native and non-native word

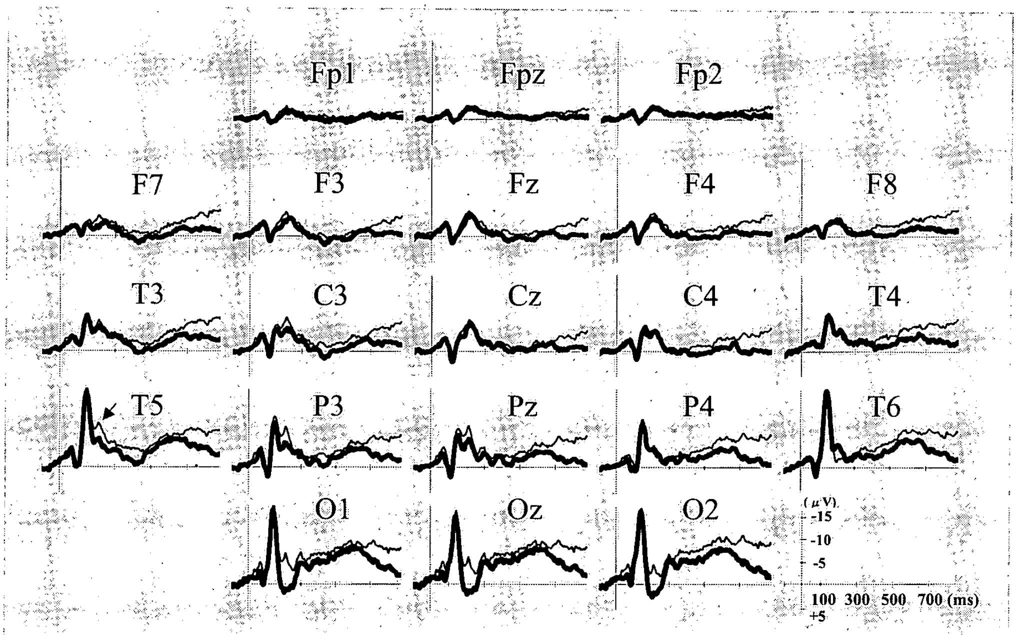

Fig. 3 Grand averaged ERPs of nine subjects during silent reading of kanji (thick lines) and English words (thin lines). Time and voltage calibrations are shown at the right bottom. The negative potential between 200 and 300 ms after the stimulus onset is indicated by an arrow at T5 as a representative.

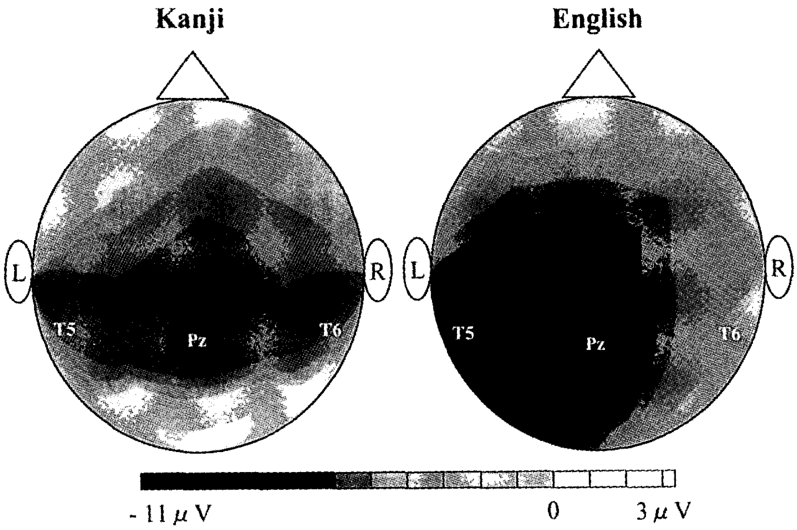

Fig. 4 Topographies of the averaged potentials between 200 and 300 ms after the stimulus onset of kanji or English word. The left column Kanji was obtained during silent reading in the native language, while the right column English during silent reading in the non-native language. The darker tones indicate larger negative amplitudes. Voltage calibration is shown at the bottom. Representative electrode positions, T5, Pz and T6 are shown on the topographies. Note that the maximum negative potential values are obtained at the central, and bilateral-parietal and -temporal areas for kanji, and over the left middle- and posterior-temporal, and parietal areas for English word recognition.

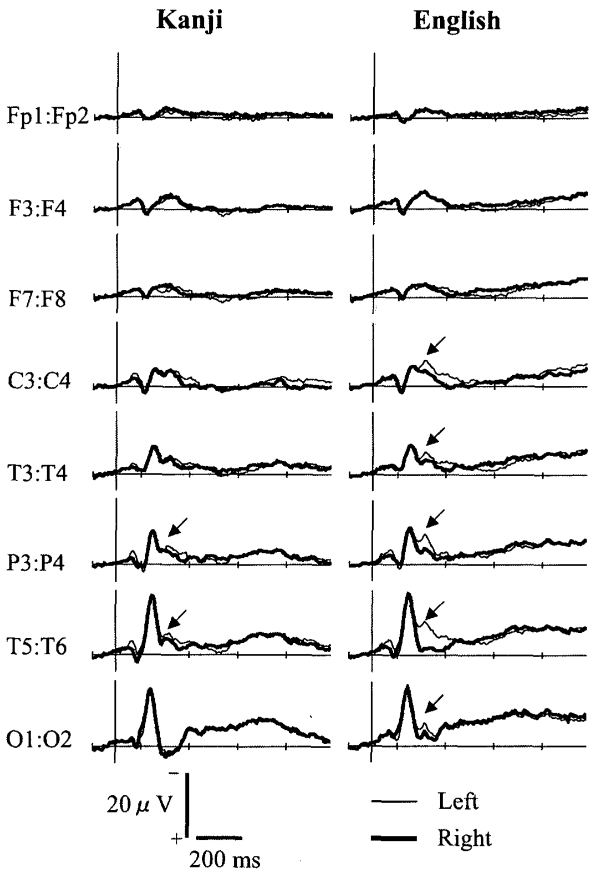

Fig. 5 Selected ERPs to show the significant lateralization effects during silent reading of kanji (left column) and English (right column) words. Thick lines : ERPs recorded from the electrodes on the right side. Thin lines : those recorded from the electrodes on the left side. Note that the negative potentials indicated by arrows during the native word task have no amplitude difference on the left and right sides, whereas those during the non-native word task have larger amplitude on the left side than the right one. Time and voltage calibrations are shown at the left bottom.

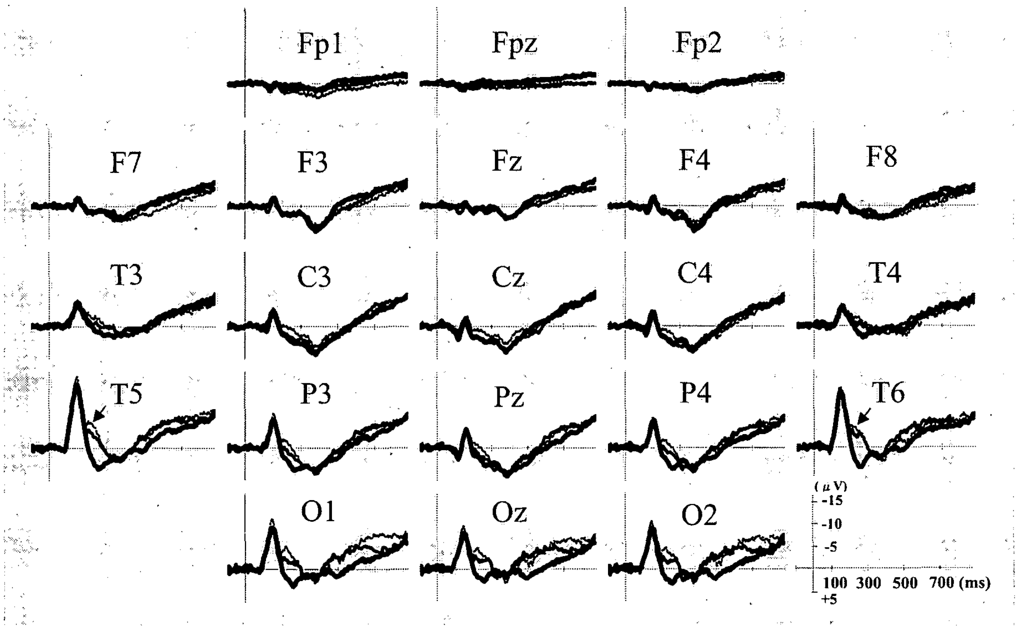

Fig. 6 Grand averaged ERPs of ten subjects in silent reading of numerals in native language (thin dotted lines), in non-native language (medium solid lines), and in overlooking of symbols (thick solid lines). Time and voltage calibrations are shown at the right bottom. The negative potentials between 200 and 300 ms after the stimulus onset are indicated by arrows at T5 and T6 as representatives.

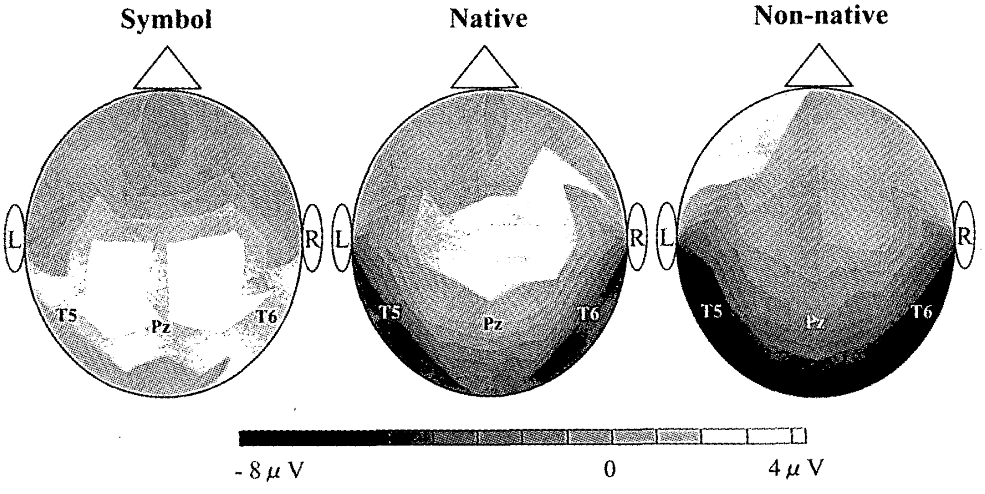

Fig. 7 Topographies of the averaged potentials between 200 and 300 ms after the stimulus onset of numeral or symbol. The darker tones indicate larger negative amplitudes. Symbol: during overlooking of the symbols. Native: during silent reading of numerals in the native language. Non-native: during silent reading of numerals in the non-native one. Voltage calibration is shown at the bottom. Representative electrode positions, T5, Pz and T6 are shown on the topographies. Note that the negative potential values are obtained at the bilateral posterior temporal and occipital areas during silent reading of numerals in native and non-native languages (middle and right columns).

tasks in the following periods: 200-300 ms ($F_{1,20}=4.61$, $P<0.05$), 400-500 ms ($F_{1,20}=6.15$, $P<0.05$), 600-700 ms ($F_{1,20}=4.17$, $P<0.05$), 700-800 ms ($F_{1,20}=12.61$, $P<0.001$) and 800-900 ms ($F_{1,20}=19.31$, $P<0.001$), but no significant differences were found between the native and non-native word tasks during the periods of 0-100 ms, 100-200 ms, 300-400 ms and 500-600 ms after the stimulus onset.

The significant lateralization effects elicited by the native and non-native word tasks are shown in Fig. 5 ; the maximum negative potentials between 200 and 300 ms were elicited on P3 and T5 during the native word task, and on C3, T3, P3, T5 and O1 during the non-native word task. For the laterality, no significant differences were detected in the kanji task in any period, but a significant difference was found in the non-native word task ($F_{1,7}=6.18$, $P<0.05$) in the period of 200-300 ms. There was no statistical difference in either the tasks between Japanese and Chinese subjects.

Experiment 2. The grand averaged ERPs (Fig. 6) of ten subjects in silent reading of the numeral in either the native or non-native language showed the upward negative potentials appearing between 200 and 300 ms after the stimulus onset over the bilateral posterior temporal and occipital areas (T5, T6, P3, P4, O1, O2, Pz and Oz) for both the native and non-native numeral tasks. The largest negative potential was observed during the non-native numeral task in this period. However, the downward positive potentials appeared at the same latency range during the overlooking task. Figure 7 shows topographies of the averaged ERP amplitude between 200 and 300 ms. This figure also shows that the maximal negative potential values during the native and non-native numeral tasks appear on the bilateral posterior temporal as well as the occipital areas. The task difference between 200 and 300 ms was statistically significant ($F_{1,20}=12.28$, $P<0.001$), whereas there was no significant difference in any other periods. A *post-hoc* test also indicated a significant effect in the period of 200-300 ms between amplitudes during the overlooking and native numeral tasks ($P<0.01$), the overlooking and non-native numeral tasks ($P<0.001$), and the native and non-native numeral tasks ($P<0.05$). No significant differences were detected in inter-hemispheric distribution of the stimulus effect and in either task between Japanese and Uighur subjects.

Ⅳ. Discussion

The present study demonstrated that separate cortical areas were activated during the silent reading of kanji (native language) and English (non-native language). The main findings were : 1) the negative potentials were elicited by the words (kanji and English) and the numeral stimuli between 200 and 300 ms after the stimulus onset, 2) the ERP amplitude in silent reading of the English and numeral in the non-native language was larger than that of the kanji and numeral in the native language, 3) the left hemisphere was more powerfully activated by the phonographic words (English) than the right one, and 4) cortical areas were bilaterally activated by the ideographic words (kanji and numeral).

Hatta[22], Sasanuma et al[23], and Klein and McInnes[24] reported that the right hemisphere is dominantly active during ideographic recognition process, whereas Iwata[25] and Uchida et al[26] described the left hemispheric dominance. Concerning the numeral recognition, controversial implications are proposed. Diamond and Beaumont[27], Coltheart[28], Katz[29], Troup et al[30] and Klein and McInnes[24] submitted that the right hemisphere plays an important role in recognition of the Arabic numerals, whereas Besner et al[31] and Hoff and McKeever[32] described the left hemisphere dominance in Arabic numeral recognition. Using a comparative judgment task, a task to decide which of two digits is numerically larger, Besner et al[31] reported the left hemispheric dominance for this task, while Katz[29] observed the right hemispheric dominance. Katz[29] suggested that methodological differences involving stimulus size, display duration and inter-trial intervals might be responsible for the discrepancies in the findings of the two studies.

At present, we can not determine which viewpoints on ideographic (kanji and numeral) recognition process is acceptable, because the tasks, the above mentioned authors used, are different from each other, and also different from those of the present study. But it is pointed out that the size of stimuli is the main cause of hemispheric asymmetries in the brain activity[33,34].

The present study was conducted to overcome some of the methodological problems ; in the present study, the letter size and luminance of kanji and English word were kept same in the both tasks in experiment 1. Because kanji and alphabetic letters are different in their form, size and luminance, it was supposed that they would influence evoked potentials, when kanji and English words are presented separately. Therefore, kanji and English words were simultaneously displayed on the TV-monitor, and the subject was instructed to read either kanji or English word according to the prior warning stimulus in the first experiment. In experiment 2, we presented Arabic numerals as ideogram, because they can be recognized by every person and read in many languages. This procedure enabled to analyze the ERPs elicited by silent reading of the same numeral in separate languages without interference of stimulus form difference.

The present study suggested that recognition of kanji and the Arabic numeral activates large areas in the left and right hemispheres in all subjects. It seems that recognition of ideographic words activates the bilateral hemispheres even when recognized in either native or non-native language. Shimoyama et al[12], Sakurai et al[13] and Koyama et al[14] also reported that the visual kanji-reading task activates the bilateral posterior inferior temporal areas, and Ji et al[15] reported that the visual numeral-reading task bilaterally activates both the temporal regions. Our results agree with the above findings. Concerning visual processing of ideographic and phonographic words, it seems that the recognition of ideographic words rely on a direct cortical linkage between visuospatial information processing and semantic evaluation, but that that of the phonographic ones uses only cortical phonographic evaluation processing. Therefore, it was concluded that the visual input of ideographic words activated image recognition center in the right hemisphere as well as the classical speech center in the left hemisphere.

Some reports of brain imaging[7,8] and electrical cortical stimulation[5] studies described that native and non-native language activate separate cortical areas in the dominant left hemisphere. In the present study, the left hemisphere was activated by English words. Our results are not contradictory with those of previous reports, because alphabetical languages were almost always used as native and non-native language in their studies. Some PET[16,17] and fMRI studies[18] on English recognition process showed that the visually presented words activated the left medial extrastriate cortex and temporal areas. Therefore, we supposed that the left hemisphere plays an important role in phonographic recognition process.

In the present study, the amplitude of the negative potential during word recognition in the non-native language was larger than that in the native one between 200 and 300 ms after the onset of the stimulation in the both experiments. Therefore, it seems that the brain is more activated during word recognition in non-native than in native language. Other studies using ERPs suggested that the ERP components with a latency of around 200 ms are related to stimulus analysis[35], and that the bilateral occipital, posterior temporal lobes are activated in association with two major ERP peaks appearing between 100 and 200 ms and around 300 ms after the stimulus onset of kanji[12]. Behavioral study estimates that the lexical access of isolated several words requires 150-250 ms to be accomplished[36]. A MEG study suggests that cortical activation by kanji and kana (phonographic letter in Japanese) were found in the bilateral hemispheres in a latency range of 150-300 ms[14]. Taken together, word and numeral recognition processes seem to be finished around 150-300 ms after the onset of the visual presentation.

The present study was performed only in restricted subjects such as Japanese and Chinese whose native language involves ideographic system. Further study should be performed on bilingual people whose native language mainly consists of phonographic language system.

要　旨

母国語，外国語の認知過程における脳機能局在差異を明らかにすることを目的に，TVモニターに呈示された，1）母国語として漢字単語を外国語として英単語を黙読したとき，2）2桁のアラビア数字を母国語と外国語で黙読したときの21チャンネル事象関連脳電位を記録し，解析した。1）での被験者は右利き健常成人9名（日本人5名，中国人4名），2）では右利き健常成人10名（日本人6名，ウイグル人4名）であった。その結果，単語認知及び数字認知の両タスクにおいて，刺激後200-300msの間で陰性電位が見られ，その振幅は外国語認知で母国語認知より大きかった。漢字と英単語を黙読したとき，漢字では両側側頭葉及び中心部に陰性電位活動が見られ，英語では左側側頭葉により大きい陰性電位活動が観察された。アラビヤ数字を母国語と外国語で黙読したときは全ての被験者で両側側頭葉及び後頭葉に陰性電位が観察された。これらの結果から，単語及び数字認知時の脳活動は母国語よりも外国語処理で強く，視覚呈示後200-300msで認知処理が最大となると考えられた。また，母国語（漢字と数字）の認知過程には右脳のイメージ処理と左脳の言語処理が同時に関わり，外国語（英語）の認知過程では従来指摘されている言語中枢との関連で左半球が優位であることが示唆された。

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