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Characteristics of Event-related Potentials in Recognition Processes of Japanese Kanji and Sentences for Chinese Bilinguals

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Abstract This paper investigates the recognition process of Japanese kanji and sentences for Chinese bilinguals and Native Japanese speakers (NJS), by analyzing the event-related potential (ERP) differences between the two groups while they visually recognized Japanese kanji and sentences. The results showed that no significant differences were found between the two groups while they recognized Japanese kanji, but significant differences were found in the Japanese sentences condition. The results demonstrated that the neural mechanisms of recognition processes of Japanese sentences including kana between the two groups were not identical. When recognizing ambiguous sentences, Chinese bilinguals' P600 only appeared over the right frontal lobe, reflecting that syntactic integration and revision of ambiguous sentences for Chinese bilinguals was related with the right hemisphere. The results showed, for Chinese bilinguals, the difficulty of Japanese language learning was the recognition and understanding of Japanese sentences with kana, not Japanese kanji. We would like to provide a scientific learning method for Chinese bilinguals to enhance their Japanese language learning efficiency from the aspect of brain science. *J Physiol Anthropol 28(4): 191–197, 2009* http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.28.191]

Keywords: event-related potential, N400, P600, Chinese bilinguals, Japanese language processing

Introduction

Over the past few decades, a growing effort has been made to exploit event-related potentials (ERP) to investigate the central representations of Chinese and Japanese language processing due to their unique characteristics. Some previous researches (Luo and Wei, 1998; Chen and Song, 2003; Ye et al., 2006; Koyama et al., 1991, 1992) have verified that N400 amplitude was closely related to semantic processing both in Chinese and Japanese language recognition. The left and right hemisphere are both involved in the semantic processing of N400, where a high percentage of the left hemisphere was used.

Although Japanese kanji derived from Chinese characters, there are many differences between the two languages. Chinese language is only composed of ideographic script 'Chinese characters', while Japanese language includes 'kanji' and 'kana'. Previous studies have demonstrated that kanji has obviously different recognition of grapheme, syllable, and meaning from kana. Kanji accesses the semantic system first, before invoking phonological aspects, but kana accesses the phonological system first (Sakuma et al., 1998; Sasanuma et al., 1992; Wydell et al., 1993). Recognition of kanji and kana also has been claimed to involve different areas (Iwata, 1984; Sakurai et al., 2000). The ventral stream is essential for orthographic and semantic processing of kanji. On the other hand, the dorsal stream is essential for kana processing.

All the above ERP studies focused on the recognition on Chinese characters or sentences of the native Japanese or native Chinese speakers, but ERP studies on Japanese recognition for Chinese bilinguals are lacking. The neural mechanisms of Chinese bilinguals with respect to Japanese language processing are still unknown. According to our investigations, for Chinese bilinguals, the most difficult aspect is the learning of kana and grammar. For this reason, we were interested in how Chinese bilinguals recognized Japanese kanji, kana, and Japanese sentences. Moreover, we sought to clarify the ERP differences of Japanese semantic and syntactic processing involved in Japanese kanji and sentence processing between NJS and Chinese bilinguals. We expected that the two groups would perform the same recognition process of Japanese kanji which originated from Chinese characters. We hypothesized that there were some significant ERP differences about Japanese sentence recognition between the two groups because the grammatical distinctions of the two languages might be expected to elicit certain recognition distinctions. To test this hypothesis, we used the ERP technique to explore the neural mechanisms of the Japanese recognition process for the two groups, by comparing the ERP differences (especially comparing N400 and P600) in the recognition process of Japanese kanji and sentences. Another objective of our research was to provide scientific learning methods for Chinese bilinguals to improve their Japanese learning effects, using the evidence of our results.

Methods

Participants

Ten Japanese college students (4 males and 6 females, age range 19–32 years, average 22.8 years) and 10 Chinese college students or doctoral candidates (5 males and 5 females, age range 22–36 years, average 29.1 years, all with middle or advanced level Japanese) participated voluntarily. All participants were right-handed and healthy, and had normal or corrected-to-normal vision, screened to exclude those with current or past neurological or psychiatric disorders. Participants' consent was obtained following the guidelines of the Institutional Review Board of Tokushima University before the experiment started.

Materials

Experimental materials consisted of two kinds of stimuli (Table 1). 200 two-character Japanese kanji (100 meaningful nouns and 100 meaningless pseudo-words) were presented randomly in 2 blocks in the Japanese kanji condition. 200 Japanese sentences (100 semantically consistent sentences and 100 ambiguous sentences) were presented randomly in 2 blocks in the Japanese sentences condition. Short breaks were provided in each block. Because most Japanese kanji originate from Chinese characters, so the grapheme and meaning of many Japanese kanji are the same as they are in Chinese. The intercommunity allows Chinese bilinguals to recognize Japanese kanji as they do Chinese characters. In order to eliminate the facilitation of Chinese characters in the Japanese kanji recognition process, we deliberately selected two-character Japanese kanji nouns which have the same grapheme as Chinese characters but with a different meaning. For example, "tegami" means "letter" in Japanese but it means "toilet paper" in Chinese. When Chinese bilinguals learn these Japanese kanji, they must remember their correct meaning and cannot understand them basing their understanding of the Chinese meaning.

Procedure

The participant was seated in a comfortable chair in a dimly illuminated, shielded, and acoustically isolated chamber. We explained the experiment contents, procedure, and request to the participants before the experiment. The stimuli were presented on a white screen in black form in front of the participants. The participants' eyes were horizontal with the stimulus, 150 cm away from the screen. To prevent eye blink and EEG artifacts, they were instructed to move or blink their eyes as little as possible during the presentation of the stimulus. Each stimulus was shown for 2 seconds. The participants were asked to say 'Yes' (if the stimulus was a meaningful noun or a semantically consistent sentence) or 'No' (if the stimulus was a pseudo-word or an ambiguous sentence) after the previous stimulate disappeared. The next trial started after an inter-trial interval of 5 seconds. The experimental block designs are shown in Fig. 1.

Table 1 Examples of Japanese kanji and sentences conditions

Meaningful nouns	Pseudo-words	Semantically consistent sentences	Ambiguous sentences
相手	秋足	台所が広い	台所が強い
手紙	意牛	気分が良い	気分が太い
田舎	日角	料理が辛い	料理は歌う
映画	豆秋	宿題が多い	宿題は踊る
切手	車電	手紙が短い	花火が寝る

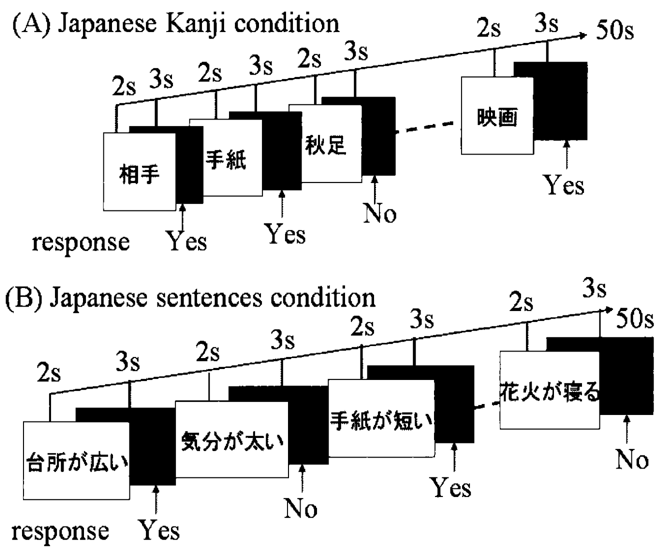

Fig. 1 Experimental block design of Japanese kanji condition (A) and Japanese sentences condition (B). Each block included 10 stimuli and lasted 50 s. Each stimulus was shown for 2 s the participant answered "Yes" or "No" to the previous stimulate during the next 3 s interval.

EEG recording

We recorded the raw EEG by using an EEG recording analysis system of Japan Photoelectric Neurotop Company. Continuous EEG was recorded from 19 electrodes located at symmetrical sites on the scalp (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, and Pz) according to the international 10–20 system. Vertical electro-oculograms (VEOG) and horizontal electro-oculograms (HEOG) were recorded with two pairs of electrodes, one placed above and below the left eye, and another placed beside the two eyes. Linked ear lobes served as the reference, the earth point being the middle point between Fpz and Fz. The EEG and EOG both were sampled at 1 KHz rate, the EEG band pass was set from 0.05 to 60 Hz, the EOG band pass was set from 0.05 to 30 Hz, and EOG and other artifacts were rejected off-line. Electrode impedance was kept below 5 KΩ. The continuous EEG data were stored on a computer hard disk to be averaged off-line later.

Statistical analyses

Recorded ERP data were averaged off-line to obtain a grand averaged ERP waveform by using Kissei Comtec Company BIMUTA II analysis software. Eye-movements were rejected off-line. The data analysis interval in each trial was 1100 ms, including a 100 ms baseline. The analysis period was divided into eight time intervals, namely 150–250 ms, 250–400 ms, 400–500 ms, 500–600 ms, 600–700 ms, 700–800 ms, 800–900 ms, and 900–1000 ms.

To verify the interaction of the ERP mean voltage and two groups in each time interval, three-way ANOVA was used to assess the effects of two groups×eight time bins×individual difference. If there were significant differences, then we used a One-Sample T Test to analyze the differences of ERP interval variation which were generated in the eight time intervals of the two groups. The p value was less than 0.05.

Results

Behavioral data

Average response accuracy data for the two groups under each condition are shown in Table 2. Accuracy of all tasks exceeded 92%. Response accuracy in the Japanese Kanji and sentences conditions were very high and had significant differences between the two groups [meaningful nouns: $t(19)=3.446$, $p<0.05$; pseudo-words: $t(19)=4.331$, $p<0.001$; semantically consistent sentences: $t(19)=3.446$, $p<0.05$; ambiguous sentences: $t(19)=3.446$, $p<0.05$]. These showed that the response accuracy of group 1 was higher than that of group 2. Namely, the NJS recognized Japanese kanji and sentences more correctly than the Chinese bilinguals did.

The differences of ERP waveforms between the two groups on every condition

N400 was broadly distributed over the whole scalp when the two groups recognized Japanese kanji and sentences. The N400 amplitude was higher in the left than that in the right hemisphere, and higher over the frontal–central than over the parietal-occipital sites. N400 amplitude was the largest at the Cz electrode site. N400 amplitude of meaningful nouns, pseudo-words, and semantically consistent and ambiguous sentences gradually increased with the growth of the semantic violation degree. In the case of the meaningful nouns, for Chinese bilinguals, a more negative component appeared following N400. Conversely, for NJS, a positive deflection appeared following N400. During the Japanese sentences recognition, in the whole brain except the right frontal sites F8, Fp2, the N400 latency appeared earlier for NJS than for Chinese bilinguals. In the left prefrontal cortex and central sites, the N400 amplitude for NJS was higher than that for Chinese bilinguals. In contrast, in the right hemisphere and occipital site, the N400 amplitude for Chinese bilinguals was higher. In all electrodes, the N400 duration for Chinese bilinguals lasted longer (Fig. 2 and Fig. 3). During the

Table 2 Average response accuracies of Japanese kanji, pseudo-words, semantically consistent sentences and ambiguous sentences for the two groups

Behavioral data

	Accuracy (%)	
	Group 1	Group 2
Meaningful nouns	99.9	98.1
Pseudo-words	99.5	96.7
Semantically consistent sentences	99.6	94.9
Ambiguous sentences	99.1	92.7

Group 1 represented native Japanese speakers. Group 2 represented Chinese bilinguals.

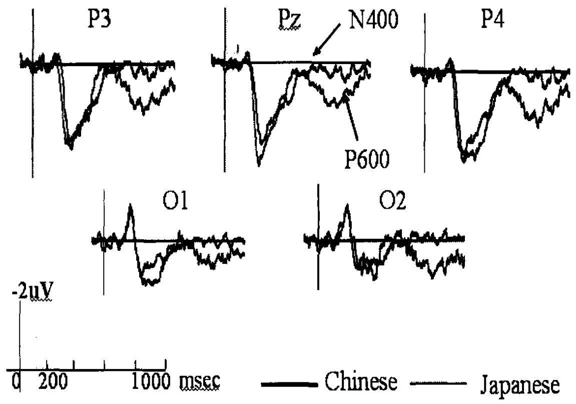

Fig. 2 The comparisons of the ERP waveforms of the semantically consistent sentences between the two groups. The origin of the x-axis corresponds to the onset of the stimulus and the negative voltage is plotted upwards.

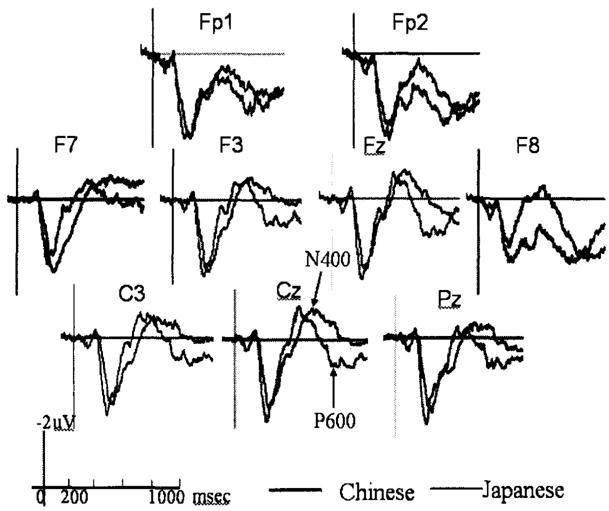

Fig. 3 The comparisons of the ERP waveforms of the ambiguous sentences between the two groups. The origin of the x-axis corresponds to the onset of the stimulus and the negative voltage is plotted upwards.

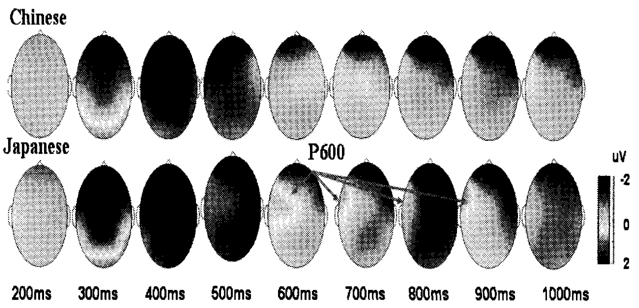

Fig. 4 Topographic maps elicited by the recognition of semantically consistent sentences of the two groups. Topography maps were presented in 100 ms averages going forward from 200 ms to 1000 ms.

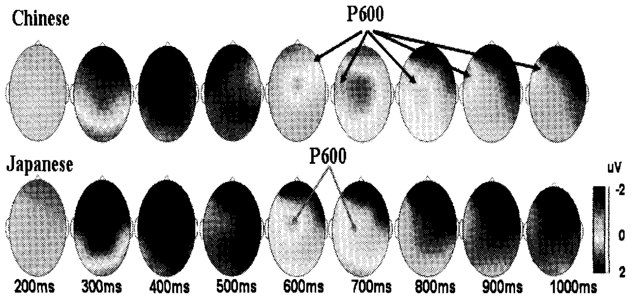

Fig. 5 Topographic maps elicited by the recognition of ambiguous sentences of the two groups. Topography maps were presented in 100 ms averages going forward from 200 ms to 1000 ms.

semantically consistent sentences recognition process, for NJS, an obvious positive deflection P600 appeared following N400 in the left Broca's area, whereas, for Chinese bilinguals, P600 did not appear (Fig. 4). During the ambiguous sentences recognition process, P600 both appeared following N400 for the two groups. In addition, the P600 duration for Chinese bilinguals was longer than for NJS (Fig. 5). For Chinese bilinguals, P600 first appeared in the right prefrontal cortex subsequently, it shifted to the left hemisphere and lasted from 600 ms to 1000 ms. Opposite to the case for Chinese bilinguals, P600 for NJS lasted much shorter and appeared only in the left hemisphere.

The differences of ERP temporal variation of the two groups

The results showed that meaningful nouns failed to show a significant difference in the N400 amplitude (p>.05) between the two groups, and significant difference was only elicited by pseudo-words in the left inferior temporal cortex T5 (T^2=85.824, F=6.556, p<.01). In contrast, in the Japanese sentences condition, a significant difference in the N400 amplitude was observed broadly at many electrodes. The significant difference of the semantically consistent sentences was observed at the P3, P4, O1, O2, and Pz electrodes over the parietal-occipital sites during 400–500 ms. The significant difference of the ambiguous sentences was observed at the Fp1, Fp2, F3, C3, F7, F8, Fz, Cz, and Pz electrodes (Table 3).

Table 3 The significant differences of N400 amplitude between the two groups in Japanese sentences conditions

(a) Semantically consistent sentences

Electrode	T^2	F	p
P3	44.44	3.39	0.05
P4	72.443	5.533	0.01
O1	50.424	3.852	0.05
O2	43.646	3.334	0.05
Pz	45.876	3.504	0.05

(b) Ambiguous sentences

Electrode	T^2	F	p
Fp1	39.42	3.011	0.05
Fp2	46.29	3.536	0.05
F3	67.739	5.175	0.01
F7	39.732	3.035	0.05
F8	51.925	3.966	0.05
C3	44.634	3.409	0.05
Fz	44.141	3.372	0.05
Cz	61.268	4.68	0.01
Pz	54.275	4.146	0.01

Discussion

Since N400 is one kind of slow electrical potential, it is very difficult to determine its negative peak latency. This study referred to the methods of some previous studies (Ye et al., 2006; Friedrich and Friederici, 2006) which used time interval methods to examine the interval variation of ERP depending on the average voltage in each time interval. By employing Japanese Kanji and sentences as experimental conditions, we examined the temporal variation of the ERP between Chinese bilinguals and NJS in eight time intervals.

When the two groups recognized meaningful nouns, the N400 amplitude in the left was higher than that in the right hemisphere, and it was higher in the prefrontal–central sites than in the posterior site. The N400 amplitude was the highest at the Cz electrode. All of these suggested that the two groups performed the same processing model when they recognized meaningful nouns and Chinese characters which both belong to the family of ideograms. The meaningful nouns which were used in the study had the same grapheme and different meaning with Chinese character, so Chinese bilinguals may compare their Japanese meaning with that in Chinese automatically after completing the semantic recognition of these meaningful nouns, and performed a further post-lexical integration process, which induced a larger negative component after N400. A previous study suggested that the negative component after N400 was related to the post-lexical integration process of the Chinese characters (Wang et al., 2006). Our results were consistent with the above view. Conversely, when NJS completed the semantic processing of meaningful nouns, a positive deflection appeared after N400.

The appearance of positive deflection might reflect the fact that the NJS performed with meaningful nouns more easily than Chinese bilinguals did.

Some previous studies reported that related words, irrelevant words, mismatched words and ambiguous words all evoked larger N400 (Holcomb, 1993; Luo and Wei, 1998; Chen and Jin, 2003; Koyama et al., 1991, 1992), which demonstrated that N400 was closely related with semantic processing. In line with the above view, we found that the N400 amplitude of pseudo-words was higher than that of meaningful nouns in the two groups, which suggested that semantic processing of pseudo-words was more difficult. However, a significant difference in the N400 amplitude was only found in the left inferior temporal between the two groups namely, the N400 amplitude of the NJS was remarkably higher than that of the Chinese bilinguals. A previous study (Iwata, 1984) reported that the dorsal stream was essential for orthographic and semantic processing of kanji. We conjectured that greater activation in the left inferior temporal was found in pseudo-word recognition for NJS than that for Chinese bilinguals.

The latency and amplitude of ERP components reflected the speed and difficulty of recognition processes. The significant differences of ERP components which were evoked by Japanese sentences recognition existed between the two groups: (1) The N400 latency of NJS appeared earlier in the whole brain except at the prefrontal sites F8 and Fp2, so we conjecture that the speed of the recognition processes of Japanese sentences for NJS was quicker than that for Chinese bilinguals. (2) The N400 duration of Chinese bilinguals at all electrode sites lasted longer, which reflected that the difficulty and processing load of the Japanese sentences recognition were heavier than those for NJS. (3) The significant differences of the N400 amplitude between the two groups mainly appeared in the visual areas (P3, P4, O1, O2, Pz) which are located in the dorsal stream. This revealed that the N400 amplitude of Chinese bilinguals was obviously higher than NJS. The dorsal stream is essential for kana processing (Iwata, 1984). Based on the above results, we conjectured that the significant differences have been elicited in the visual information processing stage between the two groups when they visually recognized the semantically consistent sentences, maybe because Chinese bilinguals visually recognized kana with more difficulty than NJS did. During the recognition process of kana, the phonological system is accessed first and then the semantic system. On the other hand, the recognition process of Kanji is the opposite. (Sakuma et al., 1998; Sasanuma et al., 1992; Wydell et al., 1993). The oppositional process of kanji and kana recognition resulted in a situation where Chinese bilinguals visually recognize kana with more difficulties than NJS do. Consequently, the amplitude of N400 for Chinese bilinguals was higher and the duration of N400 was longer than for NJS moreover, the positive potential P600 did not appear after N400 for Chinese bilinguals. Opposite to the case for Chinese bilinguals, for NJS, a positive deflection of P600 after N400 appeared in Broca's area of the left hemisphere from 600 ms to 800 ms after NJS completed the semantic processing of semantically consistent sentences (Fig. 4), which suggested that NJS recognized semantically consistent sentences including kana and their word order as differing from Chinese sentences faster than Chinese bilinguals did. Accordingly, we conjectured that the difficulties of Japanese learning for Chinese bilinguals were kana and Japanese sentences.

During the recognition processes of ambiguous sentences, the ERP significant differences in amplitude mainly appeared in the left hemisphere and centro-frontal regions (F7, F3, C3, Fz, Cz and Pz) in the third time interval. The ERP amplitude was remarkable higher for NJS than that for Chinese bilinguals. It revealed that the left language area and left temporal-parietal cortex were strongly activated while NJS recognized the ambiguous sentences. It suggested that NJS had an obvious left hemisphere advantage in ambiguous sentence recognition. Our results were consistent with Ikuta's results (Ikuta et al., 2006). In Ikuta's study, they presented constituents of a sentence one by one at regular intervals. Some left brain areas were activated in temporal order, which indicated that Japanese had a remarkable left hemisphere advantage in sentence comprehension.

In contrast, in the eighth time interval, the ERP amplitude in the prefrontal (Fp1, Fp2) and right frontal cortex (F8) were remarkably higher for Chinese bilinguals than for NJS (Fig. 3), which suggested that activation in these brain areas for Chinese bilinguals was significantly greater than for NJS. Some previous studies have reported right frontal activation and attributed the activation to 'task difficulty' (Poldrack et al., 1999; Wagner et al., 2001). The activation was associated with specific processing of the Chinese logographic system (Dong, 2005), and the right hemisphere had a special advantage in Chinese character recognition (Nakagawa, 1994). Moreover, from the brain topographic maps we can find (Fig. 7), P600 of Chinese bilinguals first appeared in the right prefrontal cortex, then it shifted to the left hemisphere and lasted till 1000 ms. Opposite to the case of Chinese bilinguals, for NJS, the duration of P600 which appeared in the left hemisphere was remarkably shorter. A previous study reported that P600 was closely related to syntactic violation it also appeared in a sentence which had no syntactic error but a sentence structure that needed to be revised (Osterhout, 1994). The present result also illuminated that the difficulty of syntactic integration and revision about the ambiguous sentence for Chinese bilinguals was remarkably greater than for NJS. Moreover, the activation of brain areas and procedures between the two groups were different. For Chinese bilinguals, the right prefrontal cortex was activated first, which suggested that the right hemisphere was also involved in the ambiguous sentences recognition process for Chinese bilinguals. It was a recognition process in which both the left and right hemispheres were involved. It differed from the left hemisphere advantage of NJS. All of these results revealed that the two groups had different neural mechanisms during the recognition of the ambiguous sentences.

Conclusions

In the current research, when Chinese bilinguals and NJS recognized Japanese Kanji which belong to the common Chinese characters morpheme, no significant differences in the ERP amplitude were observed and they both had a left hemisphere advantage in Japanese Kanji processing. In the case of the recognition processes of Japanese sentences, remarkable significant differences in amplitude and scalp distributions were observed between the two groups. Chinese bilinguals visually recognized kana with more difficultly than NJS did during the semantically consistent sentences recognition. But during the ambiguous sentences recognition, the right prefrontal lobe was more significantly activated P600 first appeared over the right frontal lobe and lasted longer than that of NJS, suggesting that syntactic integration and revision of ambiguous sentences for Chinese bilinguals was related to the right hemisphere, and the processing was more difficult than for NJS. All of these demonstrated that the two groups had different neural mechanisms in Japanese sentences processing. We conjectured that differences were produced by the different recognition processes of kana and Japanese grammar. It showed that the difficulty of Japanese language learning for Chinese bilinguals was kana and grammar, not Japanese kanji. The scientific learning methods for Chinese bilinguals are to understand kana and grammars based on mastering Japanese kanji. Especially they should focus on the pronunciation and meaning of Japanese words including kana, the usage of Japanese particle and the morphological change of the predicate. Those are the key points to learn Japanese well.

Language is complicated and there are various learning methods. In the present research, since we only examined how Chinese bilinguals visually recognized Japanese kanji and simple statement sentences, we could not summarize the general characteristics of Japanese language processing. Hence, in future research, in addition to examining the recognition of many kinds of Japanese sentences, and comparing the recognition differences of kanji with kana for Chinese bilinguals, we should also attempt to adopt other stimuli representation of different sensory pathways.

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