Visual Analysis and Lexical Access of Chinese Characters by Chinese as Second Language Readers[*]

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To assess the learning of word form, pronunciation, and meaning in an unfamiliar writing system, we carried out Event Related Potential (ERP) experiments with learners of Chinese at the end of their first and second terms of Chinese class at an American university. The subjects were required to recognize a target Chinese character or English word with ERP recorded. They named filler targets indicated by a signal 1000ms after the onset of the stimuli. The orthographic processing of characters and words was extracted as a 200ms component by Principle Component Analysis (PCA). The semantic processing was extracted as a 400ms component (N400). The 200ms PCA component was negative at occipital (N200) and positive at frontal electrodes (P200). It was sensitive to visual analysis and lexical access respectively. ERP results showed that the visual analysis of Chinese was more difficult than English at the first term, but not the second term. The lexical access was more difficult and the semantic processing was slower for Chinese than English at both terms. Faster lexical access was obtained for familiar characters at the first term, but not the second term. The separation of visual analysis and lexical access at the second term indicates a threshold style processing of Chinese characters for the learners with moderate reading proficiency.

Key words: Chinese as a second language, ERP, sinograms

1. Introduction

One issue that recently raised lots of interest was how the characteristic of writing system influences the reading process. A particular interesting contrast is between Chinese and English. Chinese, a non-alphabetic writing system, provides a case of high contrast for alphabetic systems. Its graphic units, characters, do not represent phonemes, but rather morphemic (meaning-bearing) syllables.

Chinese characters are composed of **radicals**, basic units that can sometimes give a cue to the pronunciation and meaning of characters. For example, 日 *rì* 'sun' is a simple character consisting of only one radical. There are also lots of compound characters containing two radicals, such as 青 *qīng* 'green', which is composed by a top and a bottom radical. There are also even more complex characters composed of three or more radicals. For example, 晴 *qíng* 'sunshine' consists of 日 ＋ 青. This three-radical compound is related in meaning to its left radical and in pronunciation to its right radical (notice that the pronunciation similarity in this case includes phonemes but not tone). But the compound pronunciation and meaning are not always consistent with its radicals (Perfetti, Zhang & Berent 1992, Y. Zhou 1978). In the modern Simplified Chinese writing system there are a total of 7,785 characters with 623 radicals (Li & Liu 1988).

Even though a writing system with these properties encourages the hypothesis that reading in Chinese is strictly a visual-form-to-meaning process (e.g., Baron & Strawson 1976, Chen, Yung & Ng 1988, Hoosain & Osgood 1983, Tzeng & Hung 1978, Wang 1973, Zhou & Marslen-Wilson 1996), recent behavioral studies lead to the conclusion that automatic activation of both meaning and pronunciation occurs in reading Chinese characters, as it does in English (Chua 1999, Perfetti & Tan 1998, Perfetti & Zhang 1995, Xu, Pollatsek & Potter 1999, Zhang, Perfetti & Yang 1999). Thus, despite the differences in their input units (characters vs. letters) and mapping functions (syllables vs. phonemes), Chinese and alphabetic systems are similar at this general level, with important processing differences in details (Perfetti, Liu & Tan 2005). More specifically, Chinese is processed at a threshold style and English at a cascade style (Coltheart, Rastle, Perry, Langdon & Ziegler 2001).

The threshold style processing of Chinese is illustrated by the interactive constituency model (Perfetti, Liu & Tan 2005). The model is a network of linked units of orthographic, phonological, and semantic constituents across which activation spreads. In the model, a successful lexical access needs the activation of all three constituents. Its input units are radicals and spatial relationship between the radicals. The radical input and the phonological levels of the model can be considered distributed representations, whereas the orthographic and semantic representations can be considered localized representations.

Simulation clearly captures the pattern of graphic priming at shorter SOA, whereas it turns into inhibition under longer SOA. The facilitation occurs because visually similar orthographic units are activated by the same radical; so with a graphic prime, the activation level of the target, which shares a radical with the prime, is nearer to threshold than it would be otherwise; hence, initial graphic facilitation without the orthographic unit of prime character itself reaching threshold.

When an orthographic unit does reach threshold, it sends its activation to the phonological and semantic units, allowing phonological and semantic priming effects to occur. But because it has reached threshold, the orthographic unit of the prime is competing with the target. More importantly, the appearance of the target keeps the prime orthographic unit activated longer than it should be, because of the radical shared by the prime and target orthographic units. This competition can occur with a prime that is not graphically similar to the target, but because it does not share a radical with the target, the target unit can suppress the prime unit very quickly. The net result is a competition that delays the identification of the target longer for the graphically related condition than unrelated control. Thus, two important form priming effects are simulated successfully within the same processing timeline. After a brief period of pre-threshold graphic facilitation, graphic inhibition and phonological facilitation simultaneously emerge, followed by a semantic facilitation.

The theory currently applies mainly to native speakers of Chinese. What about those learning **Chinese as a second language** (CSL)? What relevance is the theory to alphabet-users when they read Chinese? Does a CSL learner read Chinese in a way similar to native Chinese speakers? There are three components related to the issue: orthographic analysis, phonological access, and meaning retrieval. Of these components, orthographic analysis of component radicals and their positional information is important for character recognition, and they feed input to the orthographic units. Shu & Anderson (1999) found that first and second graders can differentiate legal or illegal radical positions in non-characters. Children in higher grades and adults were also found to be sensitive to radical legality effects (Peng, Li & Yang 1997, Taft, Zhu & Peng 1999).

Wang, Perfetti & Liu (2003) found CSL learners were also sensitive to the structure composition of Chinese characters, and were able to identify simple characters better than compound characters. This result suggests that learners acquired the orthographic analysis skill rather quickly and process the character form similarly to native Chinese speakers. Liu, Wang & Perfetti (2006) tapped into the issue of constituency processing more specifically by using a primed naming paradigm with a fixed 500ms SOA on the learners. The results showed 61ms of orthographic facilitation at the end of the first term of learning, with no phonological (-5ms) or semantic (-11ms) effect. This pattern is similar to native Chinese speakers when the SOA is as short as 43ms (Perfetti & Tan 1998). However, at the end of the second term, the orthographic facilitation disappeared. Instead, there were 66ms semantic facilitation and a marginal phonological facilitation (27ms) at the end of the second term, which is similar to the longer SOAs of native speakers (Perfetti & Tan 1998). The result showed that the first term learners were not able to reach the orthographic threshold within the 500ms SOA, but the second term learners could. It was concluded that the learners process Chinese in a threshold

style similar to native Chinese speakers.

Besides behavioral measures, neuroimaging measures have also been used to compare Chinese and English reading. Evidence from alphabetic research has converged on identification of a network of brain areas that functions in skilled reading, including a left ventral occipito-temporal pathway for orthographic processing, a left superior temporal and inferior parietal region for phonological processing, and a left inferior frontal gyrus for semantic processing (Fiez & Petersen 1998, Mechelli, Gorno-Tempini & Price 2003, Price 2000).

Recently, neuroimaging studies of Chinese have developed a picture of the functional neuroanatomy that is partly convergent and partly divergent with the results of alphabetic studies. For example, the left fusiform gyrus is activated in Chinese reading as it is in alphabetic reading (Chee, Tan & Thiel 1999, Chee, Weekes, Lee, Soon, Schreiber, Hoon & Chee 2000, Tan, Liu, Perfetti, Spinks, Fox & Gao 2001, Tan, Spinks, Gao, Liu, Perfetti, Xiong, Stofer, Pu, Liu & Fox 2000). However, Chinese shows additional right hemisphere activation in occipital and fusiform regions (Tan, Laird, Li & Fox 2005, Tan et al. 2001, Tan et al. 2000), a result also seen in an ERP study by Liu & Perfetti (2003). In addition, in frontal areas, Chinese shows less activation in the left inferior frontal gyrus and more activation in the left middle frontal gyrus at BA 9 (Siok, Jin, Fletcher & Tan 2003, Siok, Perfetti, Jin & Tan 2004, Tan et al. 2001, Tan, Spinks, Feng, Siok, Perfetti, Xiong, Fox & Gao 2003, Tan et al. 2000).

Even though behavioral experiments can provide valuable information on the reading process, they are indirect measures of brain functions. Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) are more direct measures, but they cannot separate cognitive processes that happen within tens or hundreds of milliseconds. Event Related Potential (ERP), on the other hand, provides millisecond level neuronal activity data during a cognitive task. ERP recordings produce characteristic voltage shifts (components) that have been associated with reading processes, including the N200, which is sensitive to orthographic and phonological level processing (Kramer & Donchin 1987), and the N400 (N450) which is sensitive to both phonology and meaning (Kutas & Hillyard 1980, Rugg 1984). Bentin et al. (1999) identified a fuller range of time points for reading process associated with inferred brain regions. ERP results also confirmed the ERP components, such as N200 (negative at occipital and positive at frontal electrodes) and N400, which had very similiar temporal features in Chinese reading (Liu, Perfetti & Hart 2003, Valdes-Sosa, Gonzalez, Liu & Zhang 1993).

Recent development of high spatial density ERP recording (more than 64 channels) made it possible to more accurately locate the cortex source for the scalp recorded electrical signal. Liu & Perfetti (2003) used 128 channel ERP to compare the reading of

Chinese and English by Chinese-English bilinguals. The results showed a left to right occipital shift during 100-200ms when Chinese-English bilinguals read Chinese, but not English. It was also found that the temporally similar N400 components of Chinese and English have different sources in the cortex.

In order to explore temporal and spatial brain activity during Chinese and English word processing by CSL learners, we adopted the design of the above study and applied it to learners. High density ERP was recorded to compare the reading of Chinese and English at two levels of reading proficiency. The task was delayed naming, a task that (a) allows the examination of a single word reading event and (b) requires a specific reading process, namely the preparation of a spoken word form for overt reading. This task assures that orthographic and phonological processes are engaged and may be detected in the 1000ms time window prior to the actual naming which may cause artifacts in the ERP signal. Furthermore, if ERP records are sensitive to word reading, then we should see a specific ERP indicator of a well-established word processing variable such as word frequency for both Chinese and English. By temporally and spatially comparing the ERP indicators of learners with the results from native Chinese speakers in the literature, we can obtain evidence on whether learners read Chinese in a cascade or threshold style.

2. Methods and materials

2.1 Participants

Twenty four undergraduate students (14 male and 10 female), enrolled in an elementary Chinese class at the University of Pittsburgh, participated in the experiment at the end of their first term (12-15 weeks learning, 12 hours a week). The age of the subjects ranged from 19 to 28. Twenty-two subjects had English as their native language and the other three had alphabetic writing system languages (Tai and Vietnamese). None of the subjects had been formally exposed to any Chinese environment before taking the class. All subjects had normal or corrected to normal vision and were free of medication within one week before the experiment and had no history of neurological diseases. They were paid for their participation.

2.2 Stimuli

The Chinese-corpus based character frequency (Li & Liu 1988) does not apply to these learners very well, although they tend to start from more commonly used characters as native Chinese speakers do. Instead, we created a computerized curriculum file based on the textbook (Barnes, unpublished manuscript) and tallied the number of appearances

for each character by a computer program. In total, there were 261 characters in the first term curriculum occurring from 3 to 287 times. Any character that appeared fewer than three times did not enter further material selection. The teaching method used at University of Pittsburgh discouraged any additional study of Chinese beyond the textbook, which enabled our curriculum-based frequency to serve as a corpus-based frequency and provide a very good estimate of the character familiarity level. Furthermore, the subjective familiarity assessed by the same group of subjects was highly correlated with the curriculum-based frequency (Wang, Perfetti & Liu 2003). Thus in the present study, we used this curriculum-based frequency to select Chinese materials.

Four experimental conditions were defined by language and frequency: high frequency Chinese characters (43.35/6248 curriculum), low frequency Chinese characters (9.675/6248 curriculum), high (136.1/million) and low frequency (1.2/million) English words (Kucera & Francis 1967). The radical and stroke numbers were matched between high and low frequency Chinese characters. Word length of high and low frequency English words were also matched. Thirty-two experimental stimuli and 8 fillers of the same type appeared in each condition. One Chinese and one English block were presented, each randomly mixed with high and low frequency characters or words.

2.3 Procedure

Participants named 20% of the stimuli in all conditions, with the English and Chinese blocks counter-balanced across subjects. Each trial began with a waiting signal (~***~) that remained in the center of the screen until the subject initiated the trial. Subjects were told not to move their eyes or blink them once a trial had begun, but were encouraged to blink between trials. When the subject pressed the space bar, a fixation "+" appeared on the screen for 500ms, followed by the stimulus, which was exposed for 1500ms. Subjects were told to have the pronunciation of the word in mind and be ready to produce when the naming signal appeared. In 20% of the trials (fillers), a naming signal appeared 1500ms after the onset of the stimulus, followed in two seconds by the waiting signal of the next trial. For the other 80% of the trials (experimental stimuli), a two-second blank interval occurred instead of a naming signal indicating naming was not required.

2.4 EEG recording and averaging

A 15-inch CRT monitor working at 60Hz refresh rate presented the stimuli. A 128 Channel Geodesic Sensor Net (Electrical Geodesics Incorporated, Oregon, USA) recorded the EEG data. All impedances were kept below 40KΩ (Ferree, Luu, Russell &

Tucker 2001). A vertex reference was used in the recording and the data were recomputed off-line against the average reference. Six eye channels allowed rejection of trials with eye movements and blinks. The signals were recorded at 500 Hz. The hardware filter was between 0.1 and 200 Hz. ERPs were averaged off-line over the experimental trials in each condition after the elimination of artifacts followed by a baseline correction and a 30 Hz software low pass filter.

2.5 Data analysis

Twenty subjects provided data for ERP analysis (data from four subjects with a high percentage of trials that contained artifact were rejected). The grand averaged ERP waveforms were calculated for each condition, based on the recordings of experimental trials that contained no artifact, from target onset to 1000ms post-onset. Temporal Principle Component Analysis (PCA) was used to analyze the data instead of traditional mean amplitudes. As a data driven method, PCA extracts a small number of uncorrelated components from a large number of variables, which in temporal PCA are time points. Each PCA component has a factor loading on each time point which is more objective than the human defined 0/1 weighted time window in the mean amplitude method. Simulations have shown that PCA can effectively decompose ERP signal into latent components (Chapman & McCrary 1995, van Boxtel 1998)

Our temporal PCA was carried out on subject averages, based on 100 10-ms time samples. Input for the PCA was a data matrix of 10,320 observations (129 electrodes, 20 subjects and 4 stimuli types) by 100 time samples. The computation used correlation matrix with Varimax rotation (Picton, Bentin, Berg, Donchin, Hillyard, Johnson, Miller, Ritter, Ruchkin, Rugg & Taylor 2000). PCA scores were used as dependent measures in ANOVAs to test the effects of experimental manipulations.

3. Results

Grand averaged outputs from 13 electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, T7, T8, O1, and O2 in 10-20 system) are shown in Figure 1 in microvolts. By visually inspecting the waveforms, three large shifts at Cz can be seen: a 100ms negative shift, a 200ms positive shift, and a 400ms negative shift. Waveforms at the frontal electrodes have similar polarity as Cz, but the parietal and occipital electrodes are reversed in polarity to Cz at some time points. The most salient reversion is that at 200ms, there are negative shifts at both O1 and O2.
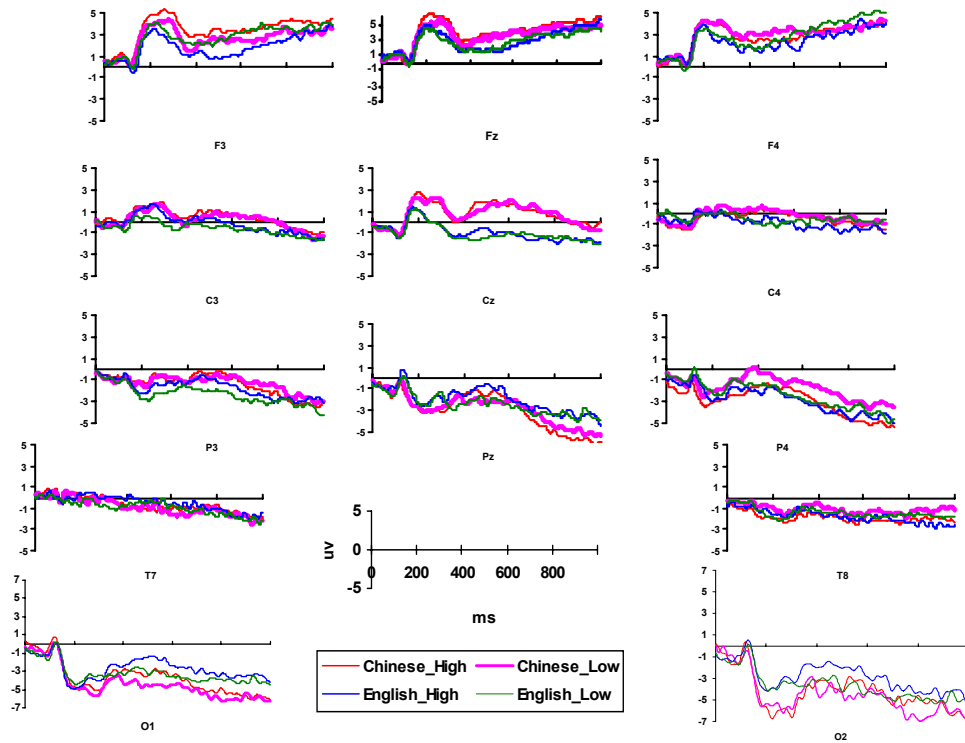
Figure 1: Term 1 Grand Averaged Waveforms

3.1 PCA components

The PCA extracted a small number of uncorrelated components from the 100 variables corresponding to 100 10-ms ERP time samples. Five components had eigenvalues larger than 1, explaining 95.5% of the total variance. The eigenvalues of these five components are shown in Figure 2 and the component loadings at each time sample are shown in Figure 3 (note that "component" here does not refer to a voltage shift but to a PCA component).

Component 1 (46.9% explained variance), a slow wave component, rises slowly from 200ms to its maximum at 1000ms. This slow-wave component is widely found in PCA on ERP, sometimes a result of the baseline correction and autocorrelated nature of ERP data (Wastell 1981).

Component 2 (20.3% explained variance) rises from 150ms with a peak loading at 190ms. The loading lasts until 350ms. The average component scores are positive at all frontal and central electrodes, and negative for all parietal and occipital electrodes. In

the ERP waveform, a 150-300ms parietal and occipital negative shift and a frontal and central positive shift can be observed (Figure 1).

Component 3 (17.2% explained variance) is a very early component. It starts from the onset of stimuli and the component loading turns lower than .5 at 150ms.

Component 4 (9.6% explained variance) peaks at 450ms. It lasts from 350ms to 600ms and is negative at most electrodes.

Component 5 (1.5% explained variance) peaks at 130ms.

Of the five components above, two and four respectively correspond to N200/P200 and N400 based on their latency and shape. These two components fit our temporal window of interest and entered further analysis.
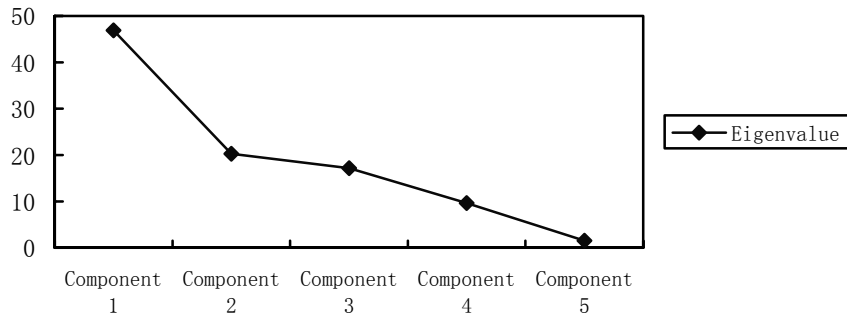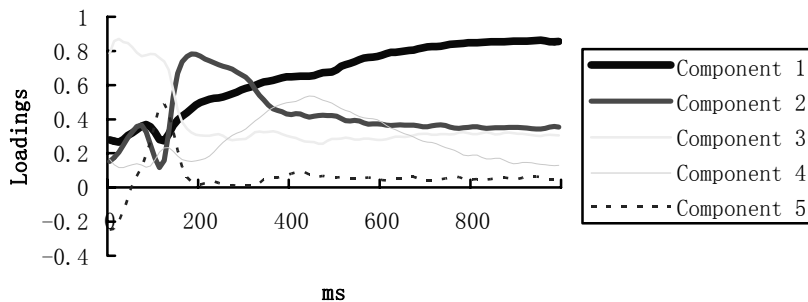
Figure 2: Term 1 PCA Components Eigenvalues

Figure 3: Term 1 PCA Component Loadings

3.2 ANOVA

We carried out two ANOVAs, one testing the PCA scores for three medial electrodes (Fz, Cz, and Pz) and one for ten lateral electrodes (F3, F4, C3, C4, P3, P4, T7,

T8, O1, and O2). Each was a repeated-measure ANOVA with language (Chinese and English), frequency (high and low), and site (frontal, central, and parietal) as factors. The ANOVA for the lateral electrodes added occipital and temporal to the site factor and hemisphere as the fourth factor. The Greenhouse & Geisser (1959) correction was applied when the sphericity assumption was not satisfied. The Epsilon value is reported here only when adjustment of freedom was performed. Post hoc t-tests between conditions (without adjustment for multiple comparisons) were carried out (t values not presented here) when the overall ANOVA showed reliable condition effects.

Both N200/P200 and N400 components produced reliable differences among conditions. The component scores are shown for selected electrodes (Figure 4).

N200/P200. Both language and frequency effects were observed in this component. The component scores were positive at frontal and central electrodes and negative at posterior electrodes (medial site effect, $F_{(2,38)}=21.60$, $p<.001$, MSE=1.568, Epsilon=.623; lateral site effect, $F_{(4,76)}=23.38$, $p<.001$, MSE=2.417, Epsilon=.515). For Chinese stimuli, the P200 component scores were more positive at frontal electrodes, and the N200 scores were more negative at parietal and right occipital electrodes than for English (medial language x site, $F_{(2,38)}=6.46$, $p<.01$, MSE=.249, Epsilon=.723; lateral language x site, $F_{(4,76)}=5.674$, $p<.01$, MSE=.390, Epsilon=.495). The P200 of Chinese high frequency characters were more positive than low frequency characters at central frontal electrodes (medial frequency x site, $F_{(2,38)}=5.78$, $p<.01$, MSE=.096), and the P200 of English high frequency words were more positive than low frequency words at left central electrode (lateral frequency x site, $F_{(4,76)}=4.28$, $p<.05$, MSE=.215, Epsilon =.569).

N400. English were significantly more negative than Chinese at medial frontal, central and parietal electrodes (medial language, $F_{(1,19)}=31.20$, $p<.001$, MSE=.532), right frontal and right central electrodes (lateral language, $F_{(1,19)}=15.402$, $p<.01$, MSE=.261). Compared with high frequency English words, low frequency English words elicited more negative N400 at a left frontal electrode (lateral frequency, $F_{(1,19)}=8.68$, $p<.01$, MSE=.181).
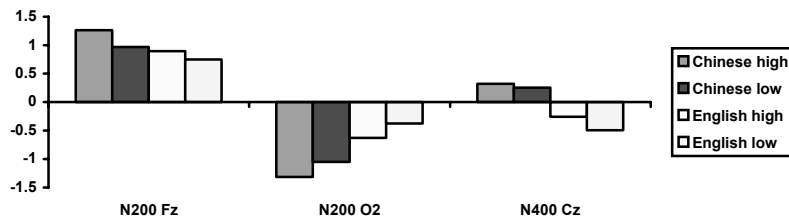

Figure 4: Term 1 Component Scores of N200 at Fz and O2, N400 at Cz

4. Experiment 2

4.1 Participants

Seventeen undergraduate students (nine male and eight female), enrolled in the same elementary Chinese class as in Experiment 1, participated in the experiment at the end of their second term (27-30 weeks learning including first term, 12 hours a week). The age of the subjects ranged from 19 to 28. All subjects had normal or corrected to normal vision and were free of medication within one week before experiment and had no history of neurological diseases. They were paid for their participation.

Experiment procedures and materials were the same as those used in experiment 1.

4.2 Results

Fourteen subjects provided data for further analysis after the artifact rejection. Grand averaged waveform is shown in Figure 5. The amplitude shifts in the waveforms are similar to experiment 1. PCA extracted a small number of uncorrelated components from the 100 time sample variables. Six components had eigenvalues larger than 1, explaining 95.7% of the total variance. The eigenvalues of these six components are shown in Figure 6. It can be seen that there is a sharp decrease of eigenvalue from the fifth to the sixth component. The first five component loadings are shown in Figure 7 and their features are described below.

Component 1 (48.2% explained variance), a slow wave component, rises slowly from 450ms to its maximum at 1000ms.

Component 2 (28.5% explained variance) peaks at 430ms, rises from 270 through 600ms.

Component 3 (18.9% explained variance) rises from 150ms with a peak loading at 230ms. The loading lasts until 330ms. The average component scores are positive at all frontal and central electrodes, and negative at all parietal and occipital electrodes. There are a 150-300ms parietal and occipital negative shift and a frontal and central positive shift in the ERP waveform (Figure 5). This component is similar to the N200/P200 in experiment 1.

Component 4 (11.6% explained variance) is a very early component. It starts to rise from the onset of stimuli and the component loading turns lower than .5 at 90ms.

Component 5 (11.1% explained variance) peaks at 120ms.

Among the five components above, N200/P200 (component 3) and N400 (component 2) fit our temporal window of interest and entered further analysis.
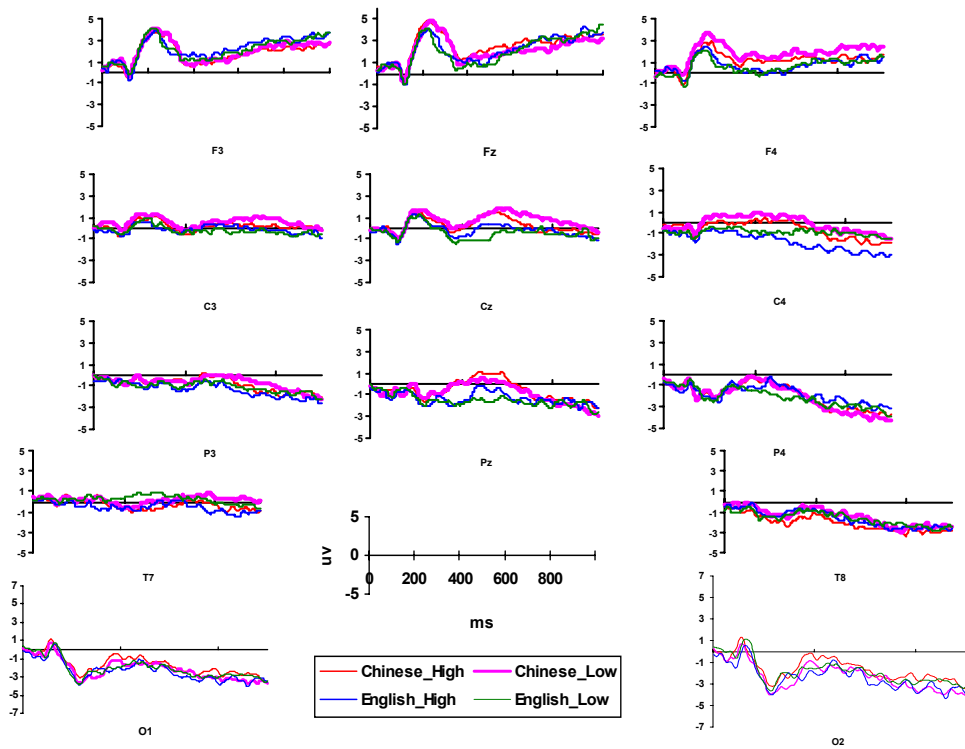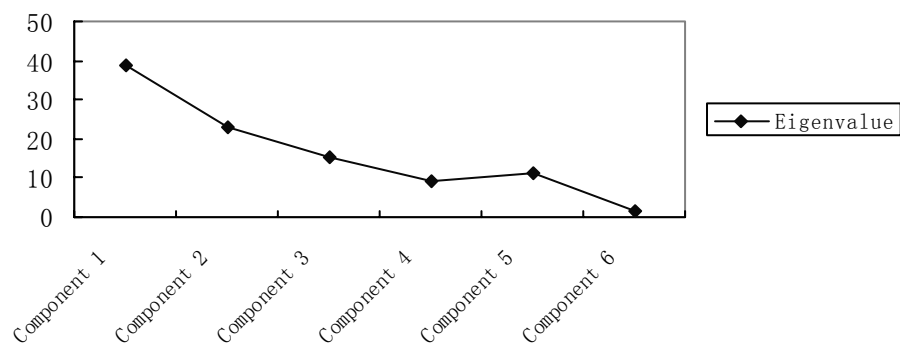
Figure 5: Term 2 Grand Averaged Waveforms

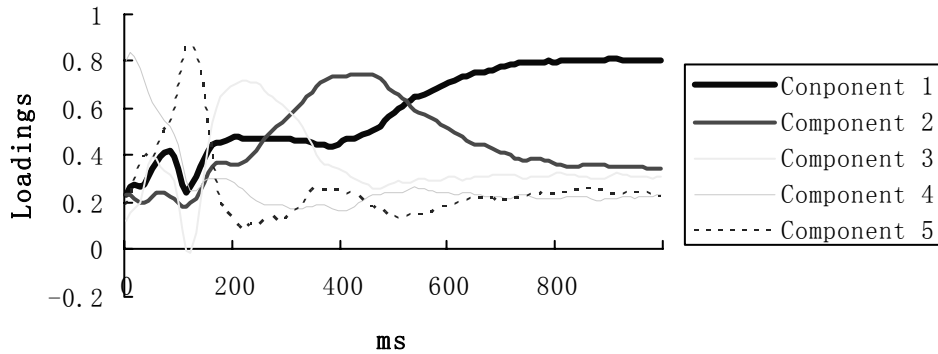**Figure 6:** Term 2 PCA Components Eigenvalues

Figure 7: Term 2 PCA Component Loadings

4.3 ANOVA

The ANOVA procedure was the same as in Experiment 1. The slow wave, N200/P200 and N400 components produced reliable differences among conditions. PCA scores of N200/P200 and N400 are shown in Figure 8 for selected electrodes.

N200/P200. The P200 was much more positive for Chinese than English at left and middle frontal (lateral language x lobe, $F(4,52)=7.025$, $p<.01$, MSE=.593, Epsilon=.414).

N400. There was significant language effect. The N400 was significantly more negative for English than Chinese at Fz, Cz, and Pz, F4, C4, P4 (medial site language effect, $F(1,13)=27.619$, $p<.01$, MSE=.523; lateral site language effect, $F(1,13)=5.309$, $p<.05$, MSE=.681; lateral site language x hemisphere interaction, $F(1,13)=4.943$, $p<.05$, MSE=.957). There was also near significant frequency effect in medial site ($F(1,13)=4.401$, $p=.056$, MSE=.192) which was due to the low frequency English words being more negative than high frequency English words at Cz ($p<.05$ with no adjustment).
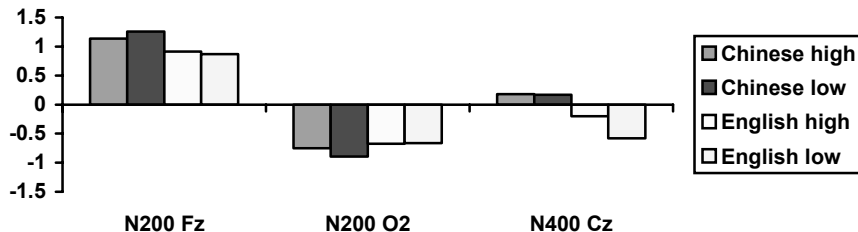

Figure 8: Term 2 Component Scores of N200 at Fz and O2, N400 at Cz

5. Discussion

We found that at the first term, both N200/P200 and N400 components showed language difference between Chinese and English stimuli. N200/P200 was larger for Chinese than English at both frontal and occipital electrodes. Conversely, N400 was larger for English than Chinese at frontal and central electrodes. At the second term, P200 was significantly more positive for Chinese than English at left and middle frontal electrodes, and N400 was significantly more negative for English than Chinese at right frontal, central, and parietal electrodes, but N200 did not show language difference at occipital electrodes. Chinese familiarity effect was only observed at the first term: A larger P200 for high familiarity words at frontal electrodes. There was no Chinese familiarity effect at the second term.

N200/P200 has been found by Liu & Perfetti (2003) as a component sensitive to orthographical processing. Its amplitude was reduced when the target Chinese character was preceded by an orthographically similar prime character. The reduction has been attributed to the pre-activation of orthographic form of the target. In another study by Liu & Perfetti (2003), Chinese-English bilinguals performed a delayed naming task with ERP collected. The amplitude of N200 was larger for English (the second language) than Chinese (the first language). The N200/P200 in above studies had a similar distribution as the present study: positive at frontal and central electrodes, and negative at occipital electrodes.

It has also been found in other paradigms that two components between 180 and 300ms were sensitive to object detection (Potts & Tucker 2001). They were named P2a and N2b respectively. N2b preceded the P200 by nearly 30ms in the object detection task. The P2a and N2b interacted between orbitofrontal cortical areas of salience representation and posterior cortical areas of stimulus feature representations. The N200/P200 in the present study has some functional relations with the P2a/N2b component, because word processing does require feature detection of visual object and meaningful words are salient to the readers.

The left occipital/fusiform region is a visual word form analysis region widely found in English reading by fMRI and other methods (Cohen, Lehericy, Chochon, Lemer, Rivaud & Dehaene 2002, Dehaene, Naccache, Cohen, Bihan, Mangin, Poline et al. 2001, Nobre, Allison & McCarthy 1998). In Chinese reading, not only the left but also the right occipital/fusiform regions are involved. Comparing Chinese and English directly, Tan et al. (2001, 2003) found that Chinese materials elicited stronger activation at right occipital/fusiform (visual analysis) and left middle frontal regions (lexical access) than English. In the present study, the N200 component was significantly larger at right occipital and the P200 was significantly larger at left and middle frontal electrodes

for Chinese than English, which well matched the fMRI findings (Tan, Spinks, Eden, Perfetti & Siok 2005).

Because the N200 and P200 were highly correlated temporally, our temporal PCA did not separate them into two components. However, the difference between first and second terms unveiled the functional difference of their underlying processing. For the first term learners, Chinese had larger amplitude at N200/P200 which indicated more visual processing (occipital) and lexical access (frontal and central) effort were needed for processing Chinese because of high demand of visual analysis and lexical retrieval. For the second term learners, the lexical access difference at frontal was retained, which indicated that reading Chinese was still a demanding task at the lexical access level, but visual analysis had been rather quickly accommodated. This result was consistent with the behavioral finding that learners can quickly learn the character structure (Wang, Perfetti & Liu 2003).

The spatial and functional separation of the N200/P200 component also provides further evidence that the learners might process Chinese characters in threshold style at the second term. Liu et al. (2006) found significant orthographic priming in the first term learners. In that study, the orthographically similar pairs either shared some strokes that appear at the same spatial position, or one radical at the same position. Both types of similarities facilitated the target identification at visual analysis level. The occipital N200 reflects the fact that the visual processing of Chinese and English had different speed and strength at the first term. However, the visual analysis skill on Chinese characters was significantly improved at the second term so that no significant language difference was found at occipital electrodes, even though very likely there is some kind of fine grain difference not measured by ERP. This finding is consistent with the behavioral result that no orthographic priming was found at second term (Liu, Wang & Perfetti 2006). The observed separation of visual analysis and lexical access at 200ms supports the assumption that accompanying the increase of reading proficiency, the sinogram is lexically accessed after the orthographic processing has been completed at visual analysis level, which indicates a threshold style processing.

The first term Chinese familiarity effect suggests that the N200/P200 is an informative indicator of orthographic processing speed. Larger P200 at frontal electrodes reflects the earlier lexical access of high frequency characters in the first term. However, at the second term, visual analysis was faster for both familiar and unfamiliar characters which caused earlier lexical access for both and reduced the speed difference between them. Furthermore, because the vocabulary of the subjects was limited, after the lexical access is started, the difficulty of accessing familiar and unfamiliar characters is not very different. There is a possibility that with more experience in Chinese (a larger vocabulary), the frontal P200 might show more lexical access difficulty for low frequency characters

(Liu & Perfetti 2003).

There was also a P200 familiarity effect (familiar > unfamiliar) at left central electrode for English, but only in the first term. So it is possible that this component shows some similarity between Chinese and English processing. However, the underlying source on the cortex might be different because the observed difference is more left lateralized and inferior for English which is consistent with fMRI findings (Tan, Spinks, Eden, Perfetti & Siok 2005). It is hard to explain why the English familiarity is only observed among the first term students. One possibility is that it is a rather localized effect and the p value of ANOVA test is larger than .01, the 14 subjects in the second term might not be able to provide enough statistical power to observe this effect.

N400 has been widely used as an indicator of semantic and phonological processing (Kutas & Hillyard 1980, Rugg 1984). The N400 in the present two experiments was only observed in English materials, but not for Chinese characters. It showed that the semantic processing on Chinese of the learners was too slow to be in the measuring range of N400. Even though Liu et al. (2006) found semantic priming with a 500ms SOA, still it is much longer than the 85ms SOA used for native speakers (Perfetti & Tan 1998). Since ERP components require the neuronal activity to reach a certain level to be measured, not being able to observe a strong N400 component indicates that the semantic and phonological activations are still weak even though the orthographical threshold has been reached within 200ms.

In summary, we found that for Chinese learners with alphabetic writing system background, processing Chinese orthography can be separated into a visual analysis stage and a lexical access stage. The visual analysis stage focuses on stroke and radical processing which can be learned quite fast and accomplished within 200ms from the character onset. After the completion of visual analysis, lexical access follows immediately. However, the retrieval of semantic and phonological information is still slow and difficult to be observed via ERP.

The present study supports the contention that learners read Chinese characters similar to native Chinese speakers after two terms of learning. The learners might start out their character reading in a way similar to English reading. However, because the alphabetic way does not work well on a non-alphabetic system, and to fit the new learned writing system, the brain non-coincidentally develops a processing method that is used by native Chinese speakers: threshold-style processing. Brain regions used by native Chinese speakers are also recruited to accomplish the task. We propose an accommodation hypothesis whereby the brain of alphabetic users accommodates to the Chinese writing system during the learning process.

References

Baron, J., and C. Strawson. 1976. Use of orthographic and word-specific knowledge in reading words aloud. *Journal of Experimental Psychology: Human Perception and Performance* 2.3:386-393.

Bentin, S., Y. Mouchetant-Rostaing, M. H. Giard, J. F. Echallier, and J. Pernier. 1999. ERP manifestations of processing printed words at different psycholinguistic levels: time course and scalp distribution. *Journal of Cognitive Neuroscience* 11.3: 235-260.

Chapman, R. M., and J. W. McCrary. 1995. EP component identification and measurement by principal components analysis. *Brain and Cognition* 27.3:288-310.

Chee, M. W., B. Weekes, K. M. Lee, C. S. Soon, A. Schreiber, J. J. Hoon et al. 2000. Overlap and dissociation of semantic processing of Chinese characters, English words, and pictures: evidence from fMRI. *Neuroimage* 12.4:392-403.

Chee, M. W., E. W. Tan, and T. Thiel. 1999. Mandarin and English single word processing studied with functional magnetic resonance imaging. *Journal of Neuroscience* 19.8:3050-3056.

Chen, M. J., Y. F. Yung, and T. W. Ng. 1988. The effect of context on the perception of Chinese characters. *Cognitive Aspects of the Chinese Language*, ed. by M. Liu, H.-C. Chen, and M. J. Chen, 27-39. Hong Kong: Asian Research Service.

Chua, F. K. 1999. Phonological recoding in Chinese logograph recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25.4:876-891.

Cohen, L., S. Lehericy, F. Chochon, C. Lemer, S. Rivaud, and S. Dehaene. 2002. Language-specific tuning of visual cortex? Functional properties of the Visual Word Form Area. *Brain* 125.5:1054-69.

Coltheart, M., K. Rastle, C. Perry, R. Langdon, and J. Ziegler. 2001. DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review* 108.1:204-256.

Dehaene, S., L. Naccache, L. Cohen, D. L. Bihan, J. F. Mangin, J. B. Poline et al. 2001. Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience* 4.7:752-758.

Ferree, T. C., P. Luu, G. S. Russell, and D. M. Tucker. 2001. Scalp electrode impedance, infection risk, and EEG data quality. *Journal of Clinical Neurophysiology* 112.3: 536-544.

Fiez, J. A., and S. E. Petersen. 1998. Neuroimaging studies of word reading. *Proceedings of the National Academy of Sciences of the United States of America* 95, 914-921.

Greenhouse, S. W., and S. Geisser. 1959. On methods in the analysis of profile data. *Psychometrika* 24.2:95-112.

Hoosain, R., and C. E. Osgood. 1983. Information processing times for English and Chinese words. *Perception and Psychophysics* 34:573-577.

Kramer, A. F., and E. Donchin. 1987. Brain potentials as indices of orthographic and phonological interaction during word matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 13.1:76-86.

Kucera, Henry, and W. N. Francis. 1967. *Computational Analysis of Present-Day American English*. Providence: Brown University Press.

Kutas, M., and S. A. Hillyard. 1980. Reading senseless sentences: brain potentials reflect semantic incongruity. *Science* 207:203-205.

Li, G., and R. Liu. (eds.) 1988. *A Dictionary of Chinese Character Information*. Beijing: Science Press.

Liu, Y., and C. A. Perfetti. 2003. The time course of brain activity in reading English and Chinese: an ERP study of Chinese bilinguals. *Human Brain Mapping* 18.3: 167-175.

Liu, Y., C. A. Perfetti, and L. Hart. 2003. ERP evidence for the time course of graphic, phonological and semantic information in Chinese meaning and pronunciation decisions. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 29.6:1231-1247.

Liu, Y., M. Wang, and C. A. Perfetti. 2006. Threshold-style processing of Chinese characters for adult second language learners. *Memory and Cognition* (in press).

Mechelli, A., M. L. Gorno-Tempini, and C. J. Price. 2003. Neuroimaging studies of word and pseudoword reading: consistencies, inconsistencies, and limitations. *Journal of Cognitive Neuroscience* 15.2:260-271.

Nobre, A. C., T. Allison, and G. McCarthy. 1998. Modulation of human extrastriate visual processing by selective attention to colors and words. *Brain* 121.7:1357-1368.

Peng, D., Y. P. Li, and H. Yang. 1997. Orthographic processing in the identification of Chinese characters. *Cognitive Processing of Chinese and Related Asian Languages*, ed. by H. C. Chen, 86-108. Hong Kong: The Chinese University Press.

Perfetti, C. A., and L. H. Tan. 1998. The time course of graphic, phonological, and semantic activation in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 24.1:101-118.

Perfetti, C. A., and S. Zhang. 1995. Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21.1:24-33.

Perfetti, C. A., S. Zhang, and I. Berent. 1992. Reading in English and Chinese: evidence for a "universal" phonological principle. *Orthography, Phonology, Morphology, and Meaning*, ed. by R. Frost, 227-248. Amsterdam: North-Holland.

Perfetti, C. A., Y. Liu, and L. H. Tan. 2005. The lexical constituency model: some

implications of research on Chinese for general theories of reading. *Psychological Review* 112.1:43-59.

Picton, T. W., S. Bentin, P. Berg, E. Donchin, S. A. Hillyard, R. Johnson Jr., G. A. Miller, W. Ritter, D. S. Ruchkin, M. D. Ruggs, and M. J. Taylor. 2000. Guidelines for using human event-related potentials to study cognition: recording standards and publication criteria. *Psychophysiology* 37.2:127-152.

Potts, G. F., and D. M. Tucker. 2001. Frontal evaluation and posterior representation in target detection. *Cognitive Brain Research* 11.1:147-156.

Price, C. J. 2000. The anatomy of language: contributions from functional neuroimaging. *Journal of Anatomy* 197.3:335-360.

Rugg, M. D. 1984. Event-related potentials in phonological matching tasks. *Brain and Language* 23.2:225-240.

Shu, H., and R. C. Anderson. 1999. Learning to read Chinese: the development of metalinguistic awareness. *Reading Chinese Script: A Cognitive Analysis*, ed. by Jian Wang and Albrecht W. Inhoff et al., 1-18. Mahwah: Lawrence Erlbaum Associates.

Siok, W. T., C. A. Perfetti, Z. Jin, and L. H. Tan. 2004. Biological abnormality of impaired reading is constrained by culture. *Nature* 431:71-76.

Siok, W. T., Z. Jin, P. Fletcher, and L. H. Tan. 2003. Distinct brain regions associated with syllable and phoneme. *Human Brain Mapping* 18.3:201-207.

Taft, M., X. Zhu, and D. Peng. 1999. Positional specificity of radicals in Chinese character recognition. *Journal of Memory and Language* 40.4:498-519.

Tan, L. H., A. Laird, K. Li, and P. T. Fox. 2005. Neuroanatomical correlates of phonological processing of Chinese characters and alphabetic words: a meta-analysis. *Human Brain Mapping* 25.1:83-91.

Tan, L. H., H.-L. Liu, C. A. Perfetti, J. A. Spinks, P. T. Fox, and J.-H. Gao. 2001. The neural system underlying Chinese logograph reading. *NeuroImage* 13.5:836-846.

Tan, L. H., J. A. Spinks, C. M. Feng, W. T. Siok, C. A. Perfetti, J. Xiong, P. T. Fox, and J. H. Gao. 2003. Neural systems of second language reading are shaped by native language. *Human Brain Mapping* 18.3:158-166.

Tan, L. H., J. A. Spinks, G. F. Eden, C. A. Perfetti, and W. T. Siok. 2005. Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences of the United States of America* 102, 8781-8785.

Tan, L. H., J. A. Spinks, J. H. Gao, H. L. Liu, C. A. Perfetti, and J. Xiong et al. 2000. Brain activation in the processing of Chinese characters and words: a functional MRI study. *Human Brain Mapping* 10.1:16-27.

Tzeng, O. J. L., and D. L. Hung. 1978. Reading Chinese characters: some basic experimental studies. *Acta Psychologica Taiwanica* 20:45-49.

Valdes-Sosa, M., A. Gonzalez, X. Liu, X. L. Zhang et al. 1993. Brain potentials in a phonological matching task using Chinese characters. *Neuropsychologia* 31.8: 853-864.

van Boxtel, G. J. M. 1998. Computational and statistical methods for analyzing event-related potential data. *Behavior Research Methods, Instruments, and Computers* 30.1:87-102.

Wang, M., C. A. Perfetti, and Y. Liu. 2003. Alphabetic readers quickly acquire orthographic structure in learning to read Chinese. *Scientific Studies of Reading* 7.2:183-208.

Wang, W. S. Y. 1973. The Chinese language. *Scientific American* 228:50-60.

Wastell, D. G. 1981. On the correlated nature of evoked brain activity: biophysical and statistical considerations. *Biological Psychology* 13:51-69.

Xu, Y., A. Pollatsek, and M. C. Potter. 1999. The activation of phonology during silent Chinese word reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25.4:838-857.

Zhang, S., C. A. Perfetti, and H. Yang. 1999. Whole word, frequency-general phonology in semantic processing of Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25.4:858-875.

Zhou, X., and W. Marslen-Wilson. 1996. Direct visual access is the only way to access the Chinese mental lexicon. *Proceedings of 18th Annual Conference of the Cognitive Science Society*, ed. by G. Cottrell, 714-719. Hillsdale: Lawrence Erlbaum Associates.

Zhou, Y. 1978. To what degree are the "phonetics" of present-day Chinese characters still phonetic? *Zhongguo Yuwen* 1978.3:172-177.

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第二語言學習中漢字視覺分析
與詞彙通達的事件相關電位

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　　我們使用事件相關電位 (Event Related Potential) 研究了美國大學生在中文學習過程對中文形音義的加工。實驗分別在第一年中文課程的第一和第二學期期末進行，實驗任務是對單個呈現的漢字或英文單詞進行識別，然後在 1000 毫秒後出現命名信號時讀出剛剛看到的字或詞。對 ERP 信號的主成分分析 (Principle Component Analysis) 提取出了一個在 200 毫秒左右的字形加工成分，和一個在 400 毫秒左右的語義加工成分。這個字形加工成分在枕葉電極上表現爲負電位，在額葉電極上表現爲正電位。這兩個正負電位變化分別對視覺形狀分析和詞彙通達敏感。ERP 結果顯示在第一學期末，對中文的視覺分析比英文要更加困難，但在第二學期末就和英文很接近了。然而，對中文的詞彙通達在兩個學期末都比英文更加困難。此外，對熟悉的漢字的詞彙通達在第一學期更快速，但第二學期熟悉度差異明顯減弱。在第二學期的視覺分析與詞彙通達的分離表明在中文學習過程中漢字的加工與中文母語者相同，是閾限形式的。

關鍵詞：中文，第二語言，事件相關電位