INCIDENTAL READING OF FAMILIAR AND UNFAMILIAR WORDS: AN EVENT-RELATED POTENTIAL STUDY OF ENGLISH MONOLINGUAL AND CHINESE-ENGLISH BILINGUAL READERS

by

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Reading occurs automatically when words are presented to an adult skilled reader. During a nonreading task, can we find effects of orthography, lexical status, and frequency as evidence of incidental reading occurring automatically? This study used event-related brain potential (ERP) methodology to investigate lexical processing in 12 English monolinguals and 12 Chinese-English bilinguals as they searched for a triangle shape embedded in English and Chinese words and nonwords. We found some effects of orthography, lexicality, and pronounceability, but no effects of frequency. Results suggest that orthographic and some phonological information is processed automatically during passive viewing. Variations on this task can be utilized to minimize decision-related noise in the ERP signal.

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PREFACE

I gratefully acknowledge Ying Liu, Lei Qin, Bao Guo Chen, Rita Svetlova, Margaret Rodgers, Dayne Grove, and Eddie Wlotko for their contributions to this project. I thank members of my thesis committee, the Spring 2006 Writing Workshop, and the Reading and Language Group for feedback and support. I dedicate this effort to Byron, Amanda, Angela, and Ellie.

1.0 INTRODUCTION

Try not to read this word: AUTOMATIC. Could you easily ignore the word? Probably not, because word reading normally occurs automatically when a word is visually presented to a skilled reader. This phenomenon is most famously exhibited in the Stroop task, in which a word's form and meaning are difficult to inhibit (Stroop, 1935; see also Besner & Stolz, 1999; Liotti, Woldorff, Perez, & Mayberg, 2000; Schadler & Thissen, 1981). Is word identification during a nonreading task the same as word identification in language-related tasks that do require reading? The present study investigated lexical processing during incidental reading. If wordlike stimuli are presented during a task that does not require reading, to what extent does reading occur anyway?

Language research paradigms often measure effects of lexicality (whether an item is a real word or a nonword) and frequency (how often a word is encountered) by using response time and accuracy performance on naming or lexical decision tasks (e. g., see Dijkstra & Van Heuven, 2002). In naming tasks, a participant reads items aloud, which necessarily directs attention toward the phonology of the item to be pronounced. In lexical decision tasks, attention is drawn to the item's wordlike quality and orthographic form. Such tasks also introduce a decision component that does not emulate natural reading. It is possible that previously found effects of orthographic familiarity, lexicality, and frequency would be found only in tasks that require attention to and processing of the word stimuli. Would these effects persist if the naming or decision task were removed from the procedure?

This study used event-related brain potential (ERP) methodology to investigate incidental reading processes in monolingual speakers of English and in bilingual speakers of Chinese and English as they were viewing English and Chinese words and nonwords. ERP is a psychophysiological method well-suited for measuring the time course of cognitive processes with millisecond precision. For skilled readers, word identification happens quite rapidly. In

English and other alphabetic languages, a skilled reader identifies a letter string as a word, makes grapheme-phoneme correspondences, then retrieves semantic meaning, all in less than one second (e.g., Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999). In Chinese, a logographic language, a skilled reader can extract graphic, phonological, and semantic information from a character within 85 ms (Perfetti & Tan, 1998; Perfetti & Zhang, 1995). However, lexical processing in any language varies as a function of word frequency and lexicality. For example, high-frequency words are typically processed more quickly and accurately than low-frequency words (Sereno, Rayner, & Posner, 1998). Also, real words are processed more readily than pseudowords and consonant strings (Sereno, Rayner, & Posner, 1998). For a bilingual speaker, word reading in the second or less dominant language (L2) is generally slower than in the first language (L1; Dijkstra & Van Heuven, 2002; Hahne, 2001; Tokowicz & MacWhinney, 2005). Thus, orthographic familiarity, lexicality, and frequency impact word identification.

For this study, we took advantage of the automaticity of word reading and chose a passive viewing task in order to minimize naming and decision effects. Participants performed a nonreading distractor task—finding a triangle "hidden" within words and nonwords—which could be done without attending to orthographic or phonological aspects of the items. We predicted that participants would nonetheless attend to the words and nonwords, and that reading would occur for words in a participant's known languages. This would be evidenced by improved performance on a follow-up recognition test for items in L1, relative to L2 or to an unknown language (L0). Furthermore, we predicted that ERP recordings would show components reflecting lexical processing, to varying degrees depending on frequency and lexicality of items within a known language.

Word reading involves the use of multiple information sources—orthographic, phonological, semantic, syntactic, and contextual—that correspond to a word's linguistic status. ERP can provide temporal markers of when each of these information sources affects reading processes (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Previous studies have found several reading-related ERP components elicited by a broad range of stimuli and cognitive tasks. The present study investigated earlier reading processes (i.e., orthographic recognition, phonological activation) and did not manipulate semantic, syntactic, or contextual variables. Thus, our search focused on studies of earlier time windows (approximately 100-500 ms post-stimulus). In the next section, we describe how ERP components are labeled. We then review some ERP studies of orthographic and phonological reading processes in a person's first or second language.

1.1 ERP COMPONENTS IN READING

With ERP, electrical activity in the brain is measured as changes in voltage at the scalp. These voltage shifts fluctuate, thus creating positive-going and negative-going peaks and valleys in the waveform. An ERP component is defined by its temporal and directional features. When recorded voltage shifts (waves) occur in relation to the presentation of a stimulus or the performance of a task, then they can be labeled with P for positive-going and N for negative-going, plus a number that represents when occurred relative to stimulus presentation or a response. For instance, a negative-going wave that spans approximately 300 to 700 ms post-stimulus and peaks at 400 ms could be termed an N400. The mere presence of an N400 wave is not as informative as a comparison of the amplitude, latency, or distribution of different N400 waves elicited by different experimental conditions. An N400 effect, then, would result from differences in cognitive processing between two conditions. When one amplitude is greater (e.g., a more negative N400), this is thought to reflect more cognitive processing due to novelty or difficulty of the items (Bentin, McCarthy, & Wood, 1985; Bentin et al., 1999; Rugg, 1985). When latency is longer or slower, this reflects delayed processing. Different spatial distributions of effects indicate different neuronal generators involved for each condition.

The ERP components we expected to find in this study were identified from a literature review of the electrophysiological studies of reading and language, and were confirmed by a data-driven principal components analysis (PCA). Studies of English, French, and Chinese have all found similar reading-related components involved in lexical processing.

1.2 PREVIOUS ERP STUDIES

In an ERP study in which English speakers made lexical decisions on words and nonwords, Sereno, Rayner, and Posner (1998) found an early P100 effect of lexicality, with real words eliciting greater amplitude than nonwords over posterior parietal electrodes. They also found an early effect of frequency at 132 ms post-stimulus (considered an N150), with low-frequency words eliciting a more negative amplitude than high-frequency words at left temporal electrode sites. Behavioral results were consistent with the ERP results: Participants responded an average of 63 ms faster to high-frequency words than low-frequency words, which confirms a processing speed advantage for high-frequency words. The ERP results suggest that word processing does occur rapidly, with real words eliciting greater activation than nonwords. Yet for a given set of real words, low-frequency words appeared to require more cognitive processing than high-frequency words, as seen by their greater N150 amplitudes. The critical finding was that ERPs are sensitive to word frequency and lexicality in a lexical decision task. The present study was designed to test if frequency and lexicality effects persist in a passive viewing task, when the lexical decision is absent from the task.

As with English reading, ERP studies of French find a similar pattern of the availability of lexical information in single word reading. Bentin and colleagues investigated single word reading in native speakers of French as they performed size judgments, rhyme judgments, lexical decisions, or semantic judgments on French words, pseudowords, nonwords, and symbols (Bentin et al., 1999). Their tasks did not require a speeded response, since participants kept track of infrequent target items within sets of distractor items, and ERPs were actually measured for the nonresponse (distractor) items. This eliminates motor responses from muddying the signal, but there is still a linguistic judgment or decision to be made for every item presented. Results showed an N170 at occipital and temporal sites that was sensitive to orthography (letters versus nonalphabetic), an N350 sensitive to pronounceability (pseudowords versus consonant strings) with larger amplitudes for pronounceable items found at left and right frontal sites, and an N450 at left frontal central sites that was sensitive to semantic processing (deciding if a real word was abstract or concrete). The authors claimed that the N170 is the earliest endogenous ERP component that can be found in any visual task. They suggested that orthographic analysis starts at approximately 120 ms post-stimulus, with phonetic analysis starting later at approximately 270 ms post-stimulus.

In an ERP study with Chinese-English bilinguals, Liu and Perfetti (2003) had participants perform a delayed naming task with high- and low-frequency words in Chinese and in English. For Chinese words (L1), they found an early N250 component sensitive to frequency, with high-frequency words eliciting greater amplitudes than low-frequency words at frontal electrodes. For English words (L2), they found an early N250 component sensitive to frequency, again with high-frequency words eliciting greater amplitudes than low-frequency words, but the effect was found at occipital electrodes. The L1 effect in this time range was more anterior than the L2 effect. For English words, they also found a later N450 component sensitive to frequency, with low-frequency words having greater amplitude than high-frequency words at right hemisphere electrode sites. This might suggest that words in L2 are processed less efficiently, or over a longer period of time, than words in L1. Behavioral experiments have shown this to be the case. Thus, familiarity with the orthography and with the items has an influence on cognitive processing of written language.

In another investigation of phonological and semantic processing (Liu, Perfetti, & Hart, 2003), native Chinese speakers made meaning judgments and pronunciation judgments on pairs of Chinese characters that were either semantically related, graphically related, homophones of each other, or unrelated controls. Results showed processing of graphical features peaking at 200 ms post-stimulus, with positive-going waves at frontal and central electrodes and negative-going waves at parietal, temporal, and occipital electrodes. After orthographic processing, phonological effects were reflected in an N400 component at left and central electrodes. These authors suggest the P200 is an index of selective attention (see also Hackley, Woldorff, & Hillyard, 1990) or of stimulus classification (see also Barnea & Breznitz, 1998). Though their N400 showed sensitivity to phonology in phonological judgments, its time window began at 200 ms post-stimulus, much earlier than comparable N400s. Others have thought of the N400 as an indicator of postlexical processing, semantic analysis, contextual integration, or predictability (Barnea & Breznitz, 1998; Brown & Hagoort, 1993; Kutas & Van Petten, 1993; Perfetti, 1999).

To summarize, ERP components begin showing effects of orthographic variables as early as 170 ms post-stimulus, followed by phonological processing at approximately 200-400 ms (however, see also Connolly, Service, D'Arcy, Kujala, & Alho, 2001). Lexicality effects appear by 100-132 ms, and frequency effects show up by 132-164 ms. Later effects have also been found for semantic and syntactic violations (e.g., N400 and P600), but those were not the focus of the present investigation.

1.3 GOAL OF THE PRESENT STUDY

The present study recorded EEGs while participants were performing a passive viewing task with words and wordlike items. Because most ERP studies involve a decision and a planned motor or vocal response by the participant, it is possible that other cognitive processes besides word reading are reflected in the waveforms. Motor responses (e.g., speaking, pressing a button) that are not delayed will show up in the ERP signal. Additionally, there is a decision-related P300 that could be affecting the shape of other components, particularly the N400 (Kutas & Hillyard, 1989; Kutas & Van Petten, 1994; Picton et al., 2000). For this reason, we wanted to utilize a task that did not have a naming or a lexical decision-making aspect. Thus participants were instructed to search for a geometric shape—a triangle—embedded within stimuli on a small percentage of trials. We chose a triangle because it is neither a radical in Chinese nor a grapheme in English. It is equally nonlinguistic in both languages. In other words, aside from the label "triangle" (or perhaps "delta") or "sān jiǎo xíng," it holds no phonological significance and would not appear as a phonologically or semantically relevant subcomponent of a word in either language. If word reading occurred incidentally during the triangle search, reading processes should be reflected in the ERP waveforms. We would expect to find reading-related components similar to those found in ERP studies that use lexical decision or other language tasks.

1.4 PREDICTED COMPONENTS

As summarized in Table 1, we expected to find reading-related components for the stimulus items in a known language (English for the American monolinguals; both English and Chinese for the Chinese bilinguals) and no evidence of reading for items in an unknown language

(Chinese for the American participants). Within a known language, we expected to find differences for real words compared with nonwords, and for high-frequency words compared with low-frequency words. These components fall within the range of 100-500 ms post-stimulus.

Table 1. Predicted ERP components based on previous findings

Comparisons	Chinese Participants	American Participants
1. Chinese Real vs. English Real	N170 words different than characters at occipital and temporal sites latency L1 < L2	N170 words different than characters at occipital and temporal sites
2. Chinese High vs. Low Frequency	N250 high > low at frontal sites	no differences
3. Chinese Real vs. Pseudocharacters	P100 real > non at posterior parietal	no differences
4. English High vs. Low Frequency	N250 high > low at occipital sites N450 low > high at right hemisphere sites	N150 low > high at left temporal sites
5. English Real vs. Consonant Strings	P100 real > non at posterior parietal sites	P100 real > non at posterior parietal sites
6. English Nonword vs. Consonant Strings	N350 nonword > consonant strings at left and right frontal sites	N350 nonword > consonant strings at left and right frontal sites

1.5 RESEARCH QUESTIONS

1. Will the ERP components found in explicit reading tasks also be observed in our incidental reading task?

Previous studies have found early ERP components related to lexicality, frequency, and phonological activation. Yet these studies utilized tasks that guided attention to certain linguistic aspects of the stimuli. In a passive viewing task, we eliminated decision processes that might bias orthographic or phonological processing. We predicted that if previously found ERP components are reflecting reading-related processes, and if reading occurs automatically in a passive viewing task, then we would find the same ERP components in our study.

2. Does familiarity with the language facilitate automatic word reading?

This study was designed so that items were either familiar or unfamiliar to the participants. For the Chinese group, all the items were in a known writing system, but half were from their first, more dominant language (Chinese, L1) and half were from their second, less dominant language (English, L2); whereas for the American group, half the items were in a known writing system (English, L1) and half were in an unknown language (Chinese, L0). We also manipulated frequency of real words in both Chinese and English, as well as pronounceability of nonwords in English. Using this design, we tested whether familiarity with orthographic forms—as defined by language, lexicality, and frequency—had an influence on word recognition processes. We predicted frequency and lexicality effects for items in L1 and in L2, but not in L0. This would confirm that reading occurred automatically in the passive viewing task. Furthermore, we predicted earlier activation of L1 than of L2 for the bilingual participants, suggesting an advantage for the more familiar language.

2.0 METHOD

2.1 PARTICIPANTS

Participants were 24 Chinese and American students recruited from the University of Pittsburgh undergraduate and graduate student population.[1] ERP and behavioral data were collected from 12 native speakers of Mandarin Chinese with varying proficiency in English (6 female, 6 male; ages 25 to 41, *M* = 31.0, *SD* = 5.0), and 12 native speakers of American English with no knowledge of Chinese or any other Asian languages (7 female, 5 male; ages 19 to 45, *M* = 27.2 years, *SD* = 7.6). All participants were right handed and had normal or corrected-to-normal vision. None reported taking any prescription medications (e.g., antidepressants, antipsychotics) which might alter the brain's activity.

2.2 MATERIALS

2.2.1 ERP task—English stimuli

There were a total of 240 English stimuli used in the passive viewing task (see Appendix A). These comprised 60 pronounceable nonwords, 60 nonpronounceable consonant strings, and 120 real words. Nonwords were derived from real English words with one to two letters added, removed, or changed. Consonant strings were nonpronounceable series of consonants that would

[1] Originally, 49 people participated in this study. Data from 25 participants (51%) were discarded due to the presence of noise from eye blinks or movement. The research design did not allow regular pauses for eye blinks; thus we had a disproportionately high percentage of unusable data. Future studies could include regular breaks for blinking.

not make a real English word even if vowels were inserted. Of the 120 real words, 60 were high-frequency and 60 were low-frequency as defined by the Kuçera and Francis corpus (1967). The high-frequency words occurred in print at least 80 times per million words (*M* = 329/million); the low-frequency words appeared in print no more than 20 times per million words (*M* = 2.3/million). All items were 4-6 letters in length and one syllable, and were presented in lowercase Arial font. Twelve of the 240 English stimuli (three from each of the four stimulus types) had a nonlinguistic, geometric symbol—a triangle—embedded within them. The triangle was always the same size and orientation, but its location within the items varied (see Appendix B).

2.2.2 ERP task—Chinese stimuli

There were a total of 180 Chinese stimuli used in the passive viewing task (see Appendix A). These comprised 120 real characters written in simplified, not traditional, form (the common form for written characters in mainland China), and 60 pseudocharacters. Of the real characters, 60 were high-frequency and 60 were low-frequency characters. On average, the high-frequency characters appeared in print 252 times per million characters, and the low-frequency characters appeared in print 1 time per million characters (Modern Chinese Frequency Dictionary, 1986). The pseudocharacters were made from existing radicals in new, illegal combinations. Like the English consonant strings, the Chinese pseudocharacters were not pronounceable and had no meaning. Due to the nature of the Chinese writing system, there could be no pronounceable pseudocharacters equivalent to English nonwords. The three groups of items were matched for visual complexity—all the characters were made of two radicals and a total of 4-12 strokes. Nine of the 180 characters (three from each of the three stimulus types) had the triangle embedded within them. The triangle was the same size and orientation as in the English items, and its location within the characters varied (see Appendix B).

2.2.3 Norming frequency and lexicality of Chinese stimuli

To ensure that the real Chinese items did not differ visually from the pseudocharacters, and that the high-frequency characters did not differ visually from the low-frequency characters, we had a separate group of participants perform ratings on these stimuli. Forty-five native speakers of English with no knowledge of Chinese or any other Asian languages were given a packet with each of the stimulus items printed on it. For half of the items they were asked to judge whether the item was common (high-frequency) or rare (low-frequency) in Chinese. For the remaining half, they were asked to judge whether the item was real or not real in Chinese. Results showed that the naïve reader could not reliably distinguish reliably between high- and low-frequency words, $F(1, 110) = 1.39$, $p = .24$, or between real (high- and low-frequency) characters and pseudocharacters, $F(2, 177) = 1.52$, $p = .22$. Many participants claimed they used a guessing strategy based on visual complexity (i.e., number of strokes) or on the item's resemblance to an actual object, such as a ladder. This strategy, however, would not actually predict frequency or lexicality for our Chinese items, because they were matched for stroke count and number of radicals. Furthermore, the pseudocharacters were made from the same radicals as the real characters, but those radicals were in different combinations or positions. Therefore, these ratings provided support for our impression that the lists did not differ in any detectably systematic way.

2.3 DESIGN AND PROCEDURE

Each participant was tested individually. We used a 129-channel Geodesic Sensor net (Electrical Geodesics, Inc.) to measure electrical activity at the scalp during the passive viewing task. Stimuli were presented on a Dell PC (visual angle < 2 degrees) using E-Prime software. EEGs were recorded at 1000 Hz and analyzed with NetStation 2.0 software. After the ERP task, each participant filled out a recognition test on a subset of the experimental items. The procedure took approximately one hour; people were paid $10 for their participation.

For the ERP task, the participant was instructed to search for a triangle embedded within English or Chinese wordlike stimuli. After each run of 12 items, the participant pressed a numeric response (0, 1, or 2) for the number of triangles he or she saw in that run (see Figure 1).

Stimuli were presented in two blocks, Chinese and English, with a short break between blocks. The order of blocks (Chinese and English) was counterbalanced within each participant group (Chinese and American). In the Chinese block, there were 15 runs of 12 items each, plus one initial practice run. In the English block, there were 20 runs of 12 items each, plus one initial practice run. Each item appeared for 500 ms, with the interstimulus interval varying between 1400 and 1600 ms. Each run thus lasted between 21.4 and 23.6 seconds total, and was followed by a question mark probe indicating the participant was to press 0, 1, or 2 on the keyboard. As soon as a response was made, the next run began. Participants were not given any feedback about the speed or accuracy of their responses. The order of runs was randomized within each language block, but order of items in each run of 12 items remained consistent across participants. All items were presented in black font on a white background.

After the ERP recording of passive viewing trials, the participants were given a paper-and-pencil recognition test. The test included 30 Chinese items (10 of each stimulus type) that had been presented, 15 Chinese distractor items not previously presented, 40 English items (10 of each stimulus type) that had been presented, and 20 English distractor items not previously presented. The order of presentation of languages (Chinese and English items) was counterbalanced within each group of participants (Chinese and American). This recognition test was used to assess whether participants were indeed attending to and processing the linguistic stimuli during the triangle search task. If participants correctly recognized items on this test, it would indicate that they were paying attention to the items, automatically reading them as predicted, and even remembering them. If they performed at chance on this test, we cannot make any strong conclusions about whether or not they were doing the task as we expected. A participant could possibly process the words to some extent during passive viewing without committing them to memory.

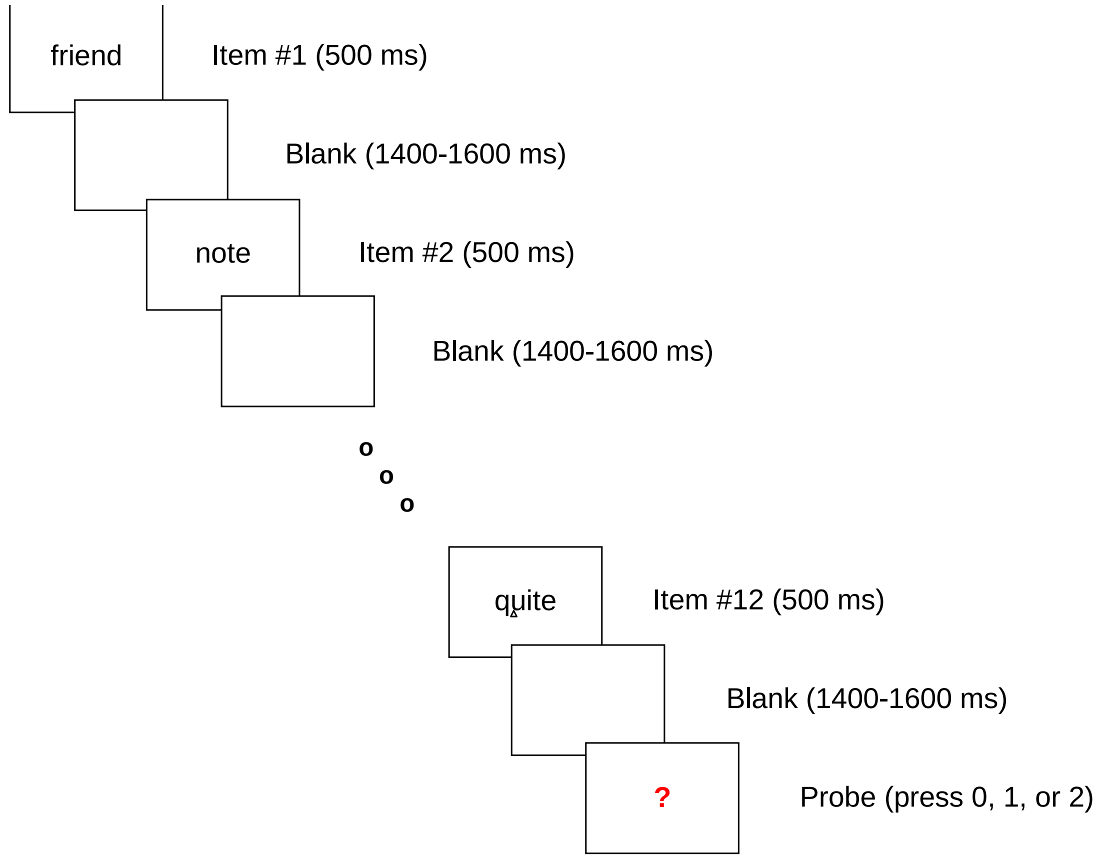


Figure 1. Example of one run in the triangle search task

3.0 ANALYSES

3.1 BEHAVIORAL DATA

Accuracy and response time data were recorded for every participant in each language block of the triangle search task. We performed a 2 (language = Chinese, English) x 2 (group = Americans, Chinese) analysis of variance on these averages to test for any differences. For the recognition test, *d*-prime scores were calculated to determine how accurately each group of participants recognized items in each language. We conducted a 2 (language = Chinese, English) x 2 (group = Americans, Chinese) analysis of variance on the *d*-prime scores to test for any differences.

3.2 ERP WAVE FORM DATA

EEG recording was done throughout the duration of each language block. ERP data were analyzed for all items except those in which a triangle was embedded and those following the second triangle item in a run of twelve. Since the maximum number of potential triangles in a run was two, conceivably the participant could pay less attention to remaining items after seeing a second triangle, until the response probe. We wanted to ensure our analyses included only trials in which they were likely to be performing the search as instructed, thus allowing a chance for incidental reading.

ERP data were preprocessed using a 30 Hz lowpass filter, a 200 ms baseline correction, and segmenting to 800 ms post-stimulus. Trials with blinking, movement, or other artifacts were not included. All participants had at least 24 good trials per condition.

A temporal principle components analysis (PCA) using a covariance matrix and varimax rotation was performed in order to determine components to analyze. This resulted in three time windows of interest:

- 100 to 200 ms (P150 or N150)
- 200 to 250 ms (P225 or N225)
- 300 to 500 ms (N400)

These time windows are similar to those analyzed in previous reading studies. For each of these three time windows, we calculated mean amplitudes, peak latencies, and adjusted means using 13 electrodes (see Figure 2) chosen from the 129 channels based on the 10-20 system. The 13 electrodes were divided into one group of nine electrodes (the left, midline, and right frontal, central, and parietal electrodes) and one group of four electrodes (left and right occipital, and left and right temporal). We expected earlier orthographic processing to be detected at occipital or temporal sites, and later effects of frequency or lexicality to be detected at frontal, central, or parietal sites. Therefore, we conducted separate ANOVAs on the anterior group of nine electrodes and the posterior group of four electrodes.

Using repeated measures ANOVAs, we investigated differences between the following conditions for each of the participant groups (Chinese, American):

1. Chinese Real Characters vs. English Real Words
2. Chinese High Frequency vs. Chinese Low Frequency
3. Chinese Real Characters vs. Pseudocharacters
4. English High Frequency vs. English Low Frequency
5. English Real Words vs. English Consonant Strings
6. English Nonword vs. English Consonant Strings

For making the first five comparisons, we used a 3 (lobe = frontal, central, parietal) x 3 (hemisphere = left, midline, right) x 2 (language of stimuli = Chinese, English) x 3 (lexicality = high-frequency, low-frequency, pseudocharacter/consonant string) repeated measures ANOVA for the anterior group of nine electrodes, and a 2 (lobe = occipital, temporal) x 2 (hemisphere = left, right) x 2 (language of stimuli = Chinese, English) x 3 (lexicality = high-frequency, low-frequency, pseudocharacter/consonant string) repeated measures ANOVA for the posterior group of four electrodes. Pronounceable English nonwords were not included in these comparisons because there is no equivalent run of stimulus items in Chinese. For the sixth comparison, we used a 3 (lobe = frontal, central, parietal) x 3 (hemisphere = left, midline, right) x 2 (pronounceability = nonword, consonant string) repeated measures design for the anterior group of nine electrodes, and a 2 (lobe = occipital, temporal) x 2 (hemisphere = left, right) x 2 (pronounceability = nonword, consonant string) repeated measures design for the posterior group of four electrodes. Greenhouse-Geisser degrees of freedom and *p*-values are reported only when the sphericity assumption has been violated.

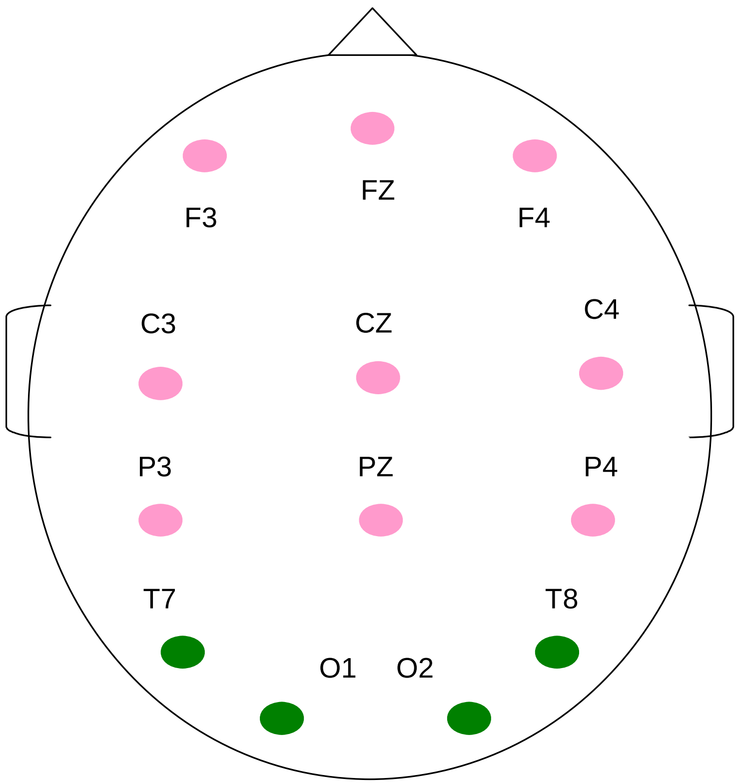


Figure 2. Electrodes used in analyses

4.0 RESULTS

4.1 BEHAVIORAL RESULTS

As can be seen in Figure 3, participants performed at ceiling on the triangle search. It was intended to be an easy task, one that served to ensure participants were oriented to the screen and attending to the items. An analysis of variance for the accuracy showed that the groups (Chinese, American) did not differ within or between language blocks (Chinese, English), $F(1, 11) = 1.66$, $p = .22$. Response times appeared more variable (see Figure 4), but again there were no statistically significant differences by language group or block, $F(1, 11) = 1.21$, $p = .29$. Responses were delayed until the end of each run of 12 items, and thus were not expected to be informative about cognitive processing difficulty.

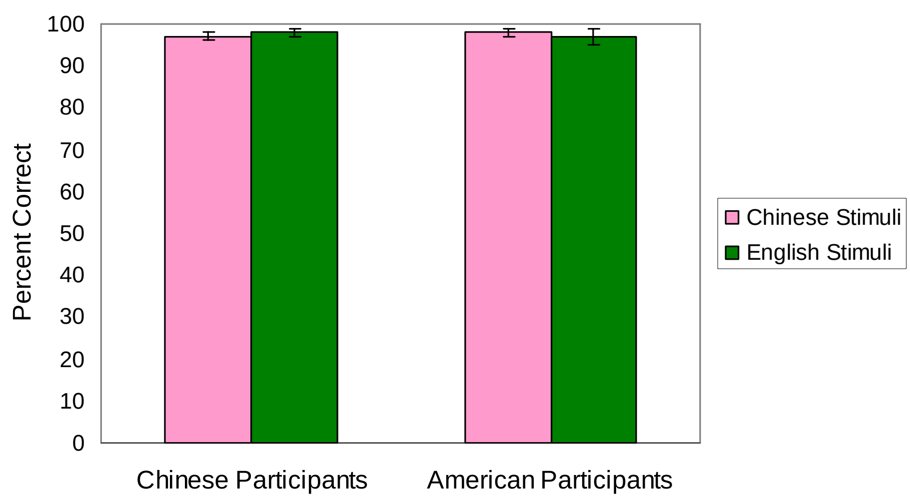


Figure 3. Accuracy for the triangle search task

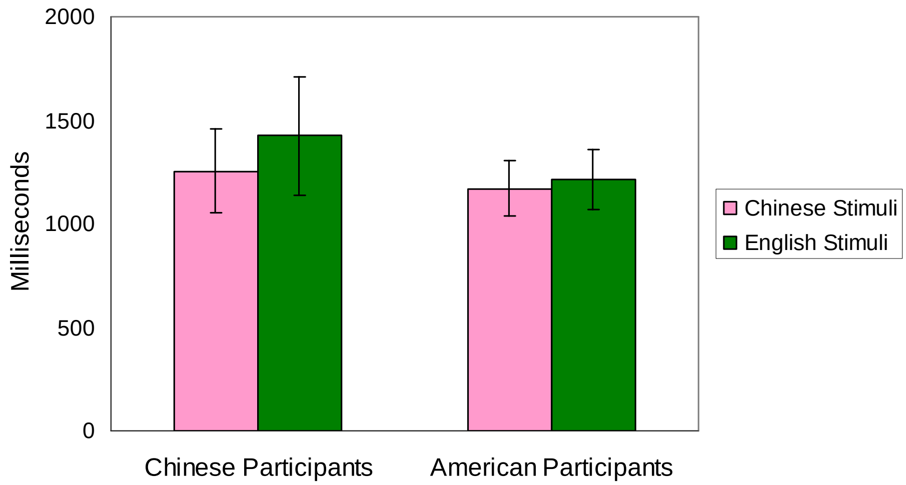


Figure 4. Response times for the triangle search task

4.2 RECOGNITION TEST RESULTS

The mean proportions of hits and false alarms on the recognition test for items in each language for each group of participants are shown in Table 2. Recognition accuracy was defined by the signal sensitivity measure, $d' = z(\text{Hit}) - z(\text{False Alarm})$. An ANOVA done on these d' scores showed an interaction of group and language, $F(1, 164) = 6.08$, $p < .05$. Chinese participants had higher scores for L1 Chinese than L2 English; American participants had higher scores in L1 English than L0 Chinese. For Chinese items, Chinese participants had higher scores than American participants. The two participant groups had equal performance for English items. Individual *t*-tests on the Chinese group's d' scores for each item category showed the following categories to be significantly different from zero: English low frequency, English consonant strings, all English items combined, Chinese low frequency, Chinese pseudocharacters, and all Chinese items combined (all *p*s < .05). Individual *t*-tests on the American group's d' scores for each item category showed the following categories to be significantly different from zero: English high frequency, English low frequency, English nonword, English consonant strings, all English items combined, and all Chinese items combined (all *p*s < .05).

Table 2. Sensitivity of recognition test

	Chinese Participants n = 12			American Participants n = 12		
	Hit	FA	*d′*	Hit	FA	*d′*
English High Frequency	.32	.29	0.72	.18	.13	1.07 *
English Low Frequency	.48	.26	0.91 *	.37	.14	1.20 *
English Nonwords	.25	.22	0.36	.24	.10	1.16 *
English Consonant Strings	.42	.18	1.20 *	.23	.07	1.03 *
All English Items	.37	.24	0.80 *	.25	.11	1.12 *
Chinese High Frequency	.42	.32	0.40	.18	.18	0.26
Chinese Low Frequency	.48	.31	1.89 *	.24	.17	0.75
Chinese Pseudocharacters	.46	.17	1.39 *	.21	.14	0.48
All Chinese Items	.45	.23	1.23 *	.21	.16	0.50*

* significantly different from zero

4.3 ERP RESULTS

For each group of participants, we analyzed mean amplitude and latency-to-peak values for each of the three time windows (100-200 ms, 200-250 ms, and 300-500 ms) across conditions. First we compared real words in Chinese to real words in English. Next, within each language, we compared real words to nonwords, and high-frequency words to low-frequency words. For English nonwords, we compared pronounceable pseudowords to nonpronounceable consonant strings. In this section, we start by reporting significant findings, then we list comparisons done which showed no significant differences for amplitude or latency.

4.3.1 Chinese participants L1 versus L2

Language significantly affected both latency, $F(1, 11) = 14.58$, $p < .01$, and the adaptive mean[2], $F(1, 11) = 9.25$, $p < .05$, of the N225 at left, midline, and right frontal, central, and parietal sites for the Chinese participants, such that Chinese L1 was earlier and more negative than English L2. Figure 5 shows the vertex electrode for these participants, where the effect of language can be seen most clearly. As in all following figures, positive voltage is plotted at the top of the y-axis.

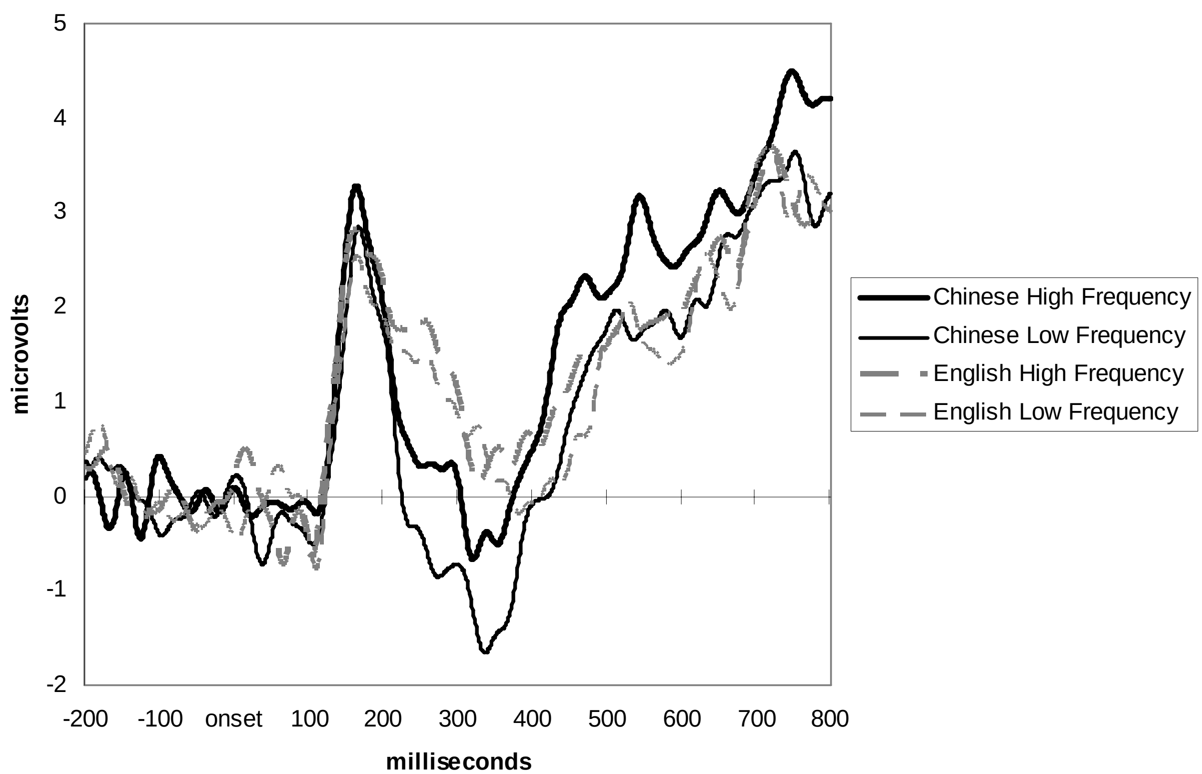
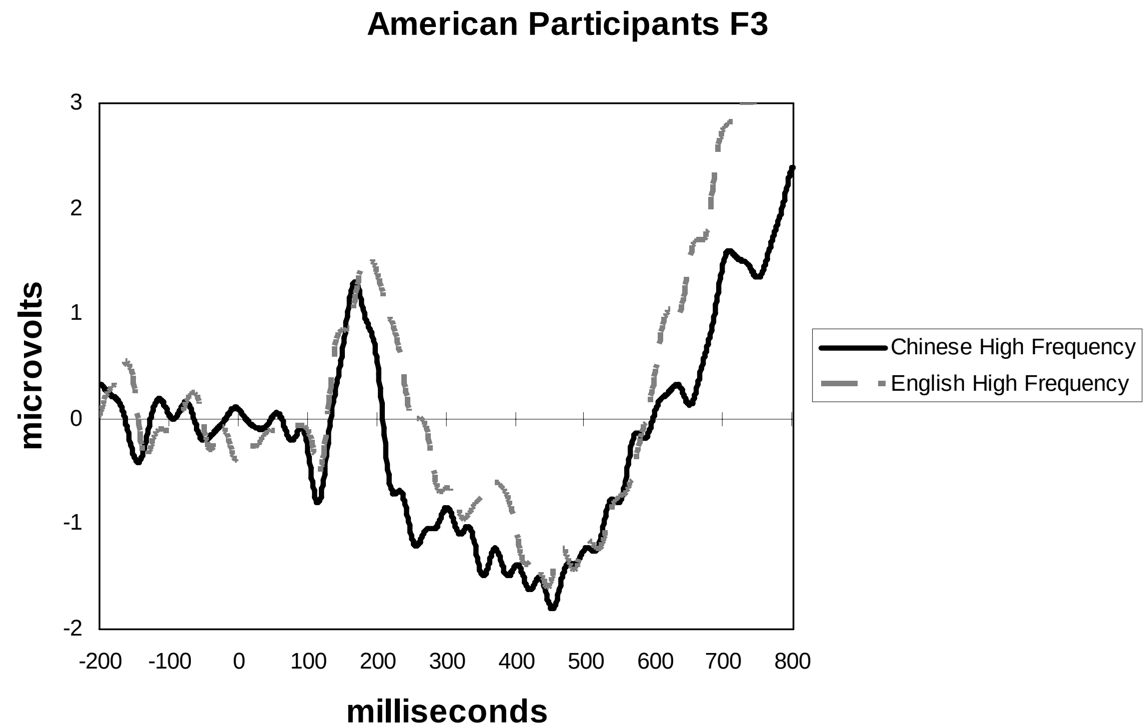


Figure 5. Chinese participants L1 versus L2—N225 effect at vertex electrode

[2] The adaptive mean is a measure of the mean amplitude with the peaks aligned. When latencies of two conditions are significantly different, the adaptive mean is reported instead of the mean amplitude.

4.3.2 American participants L1 versus L0

For the American participants, several differences were found between items in English L1 and Chinese L0. The mean amplitude of the N225 at the left frontal electrode was greater for Chinese high-frequency items than English high-frequency items, $F(8, 88) = 2.87$, $p < .01$. The mean amplitude of the N225 at the right frontal electrode was greater for Chinese low-frequency items than English low-frequency items, $F(8, 88) = 2.87$, $p < .01$. The mean amplitude of the N400 at the right frontal electrode was also greater for Chinese low-frequency items than English low-frequency items, $F(8, 88) = 2.14$, $p < .05$. These results are depicted in Figure 6.The adaptive mean of the P225 at both left and right occipital electrodes was greater for Chinese items than English items, $F(1, 11) = 5.48$, $p < .05$. These results are depicted in Figure 7.



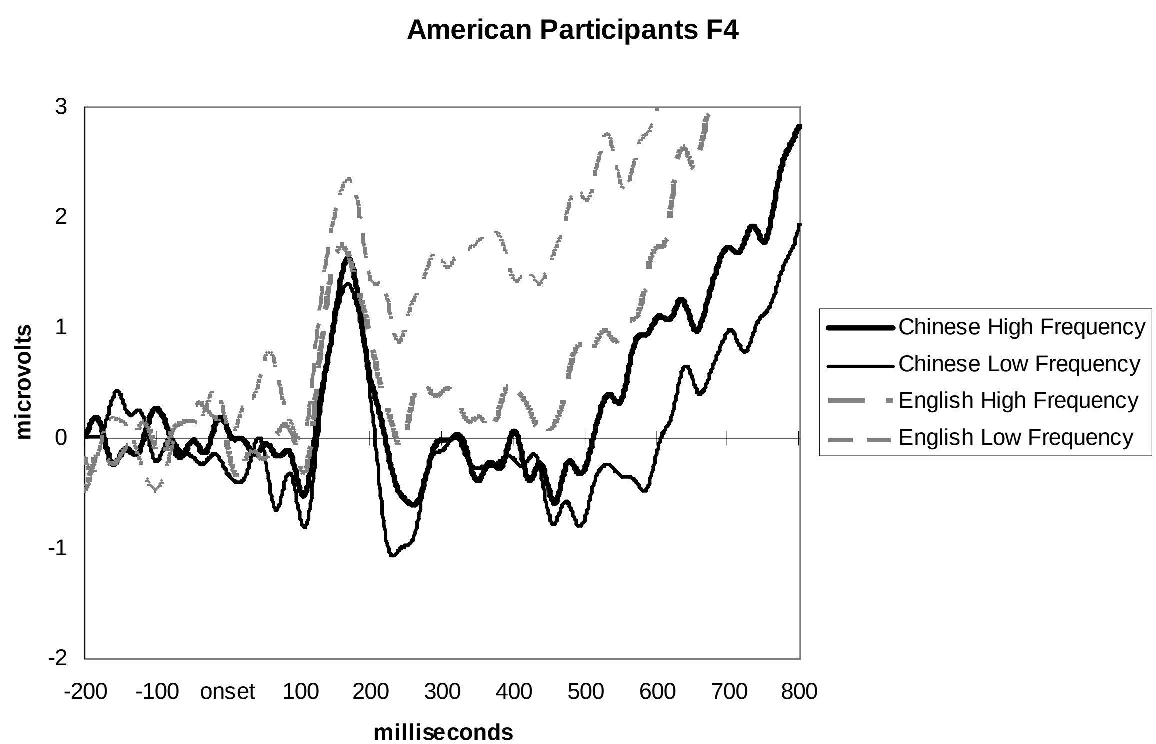


Figure 6. American participants L1 versus L0—frontal electrodes

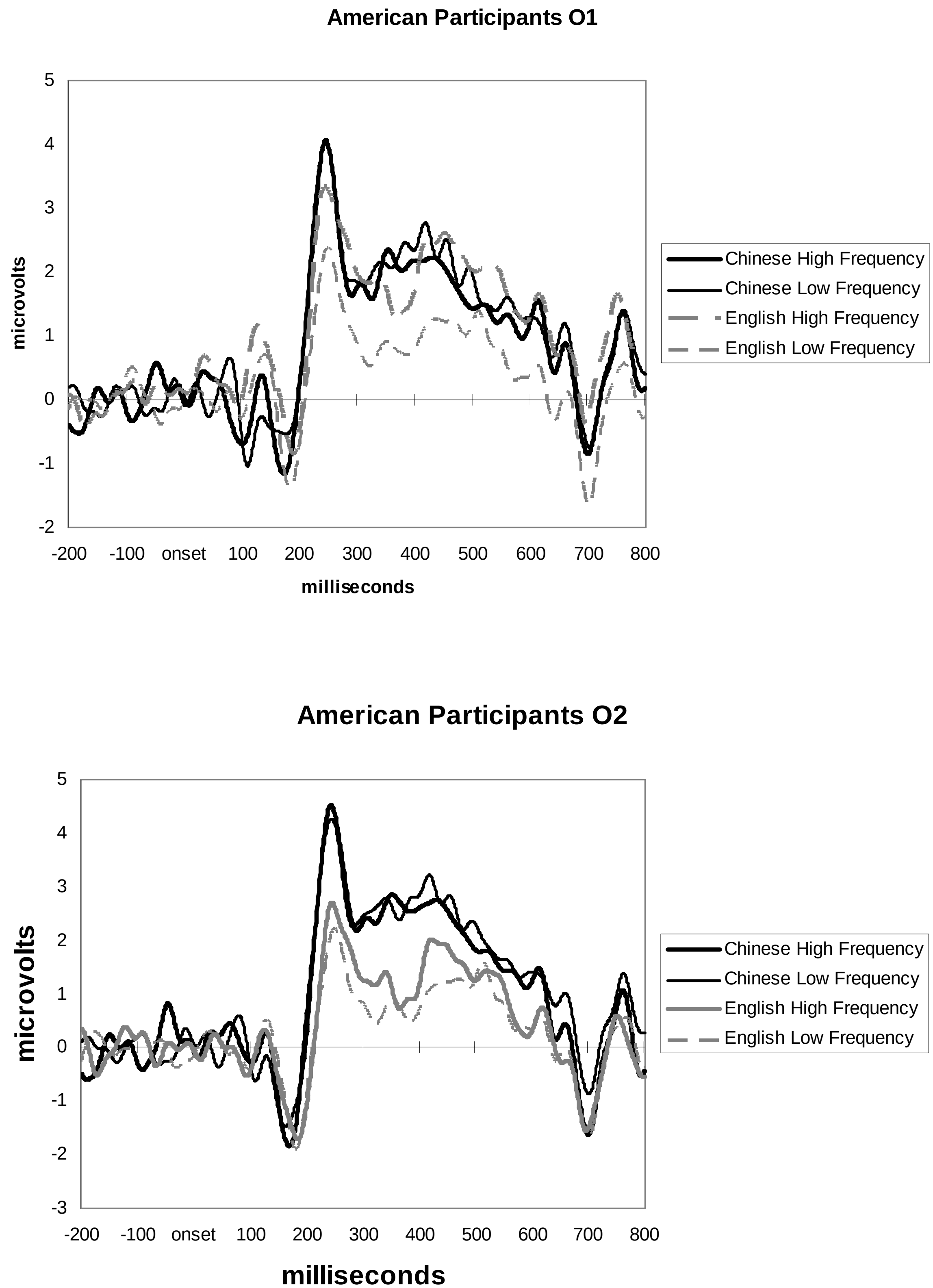


Figure 7. American participants L1 versus L0—occipital electrodes

4.3.3 American participants L0 high-frequency versus low-frequency

For the American participants, frequency affected mean amplitudes of the N400 such that Chinese high-frequency characters had a greater amplitude than Chinese low-frequency characters at left, midline, and right frontal, central, and parietal electrodes. This difference is shown in the left frontal electrode illustrated in Figure 8.

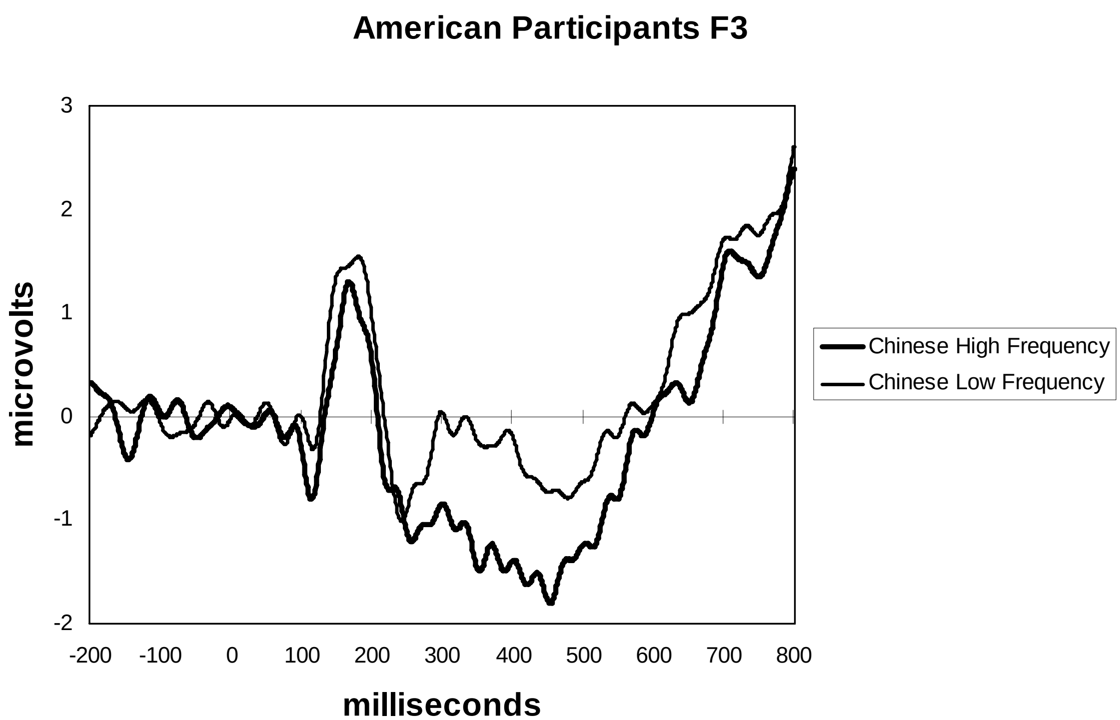


Figure 8. American participants L0 high-frequency versus low-frequency

4.3.4 American participants L1 real versus nonwords

For American participants, there was a language by lexicality interaction found for the latency of the N400 at the occipital and temporal electrodes, such that English real words (high- and low-frequency) had earlier peaks than English consonant strings, $F(2, 22) = 3.55$, $p < .05$. This effect is illustrated in Figure 9.

American Participants O1

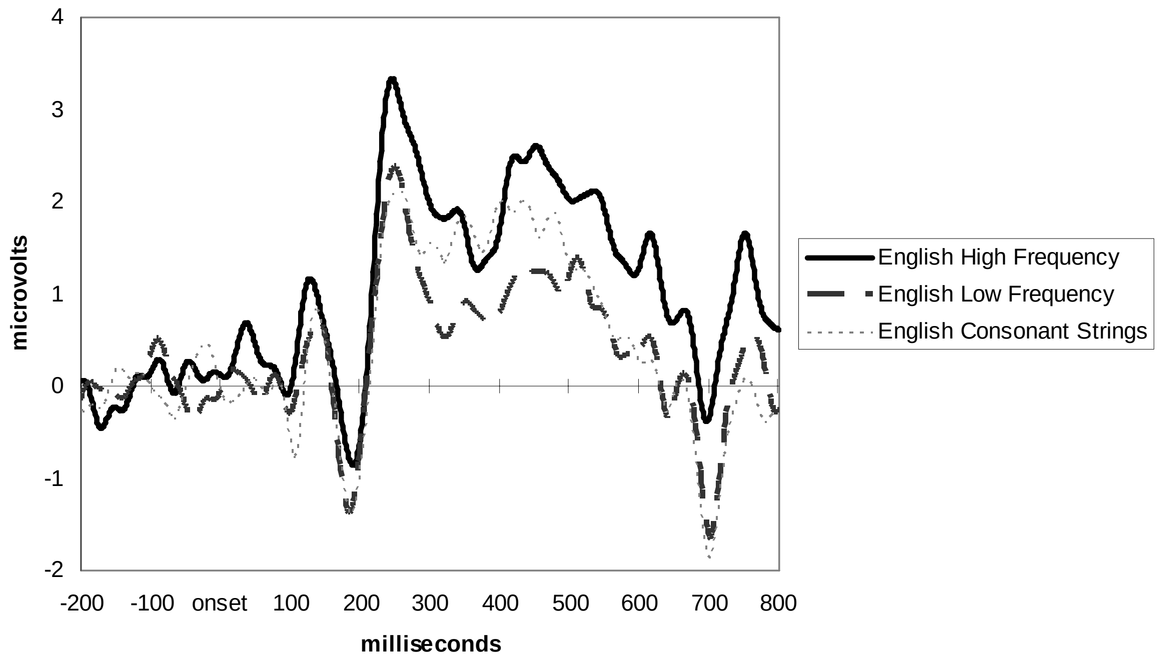


Figure 9. American participants L1 real words versus nonwords

4.3.5 Chinese participants L2 pronounceable nonwords versus consonant strings

For the Chinese participants, pronounceability significantly affected P150 latency at temporal sites, such that pronounceable nonwords elicited (10 ms) earlier peak amplitudes than the consonant strings, $F(1, 11) = 7.14$, $p < .05$. Figure 10 shows this effect at the right temporal electrode.

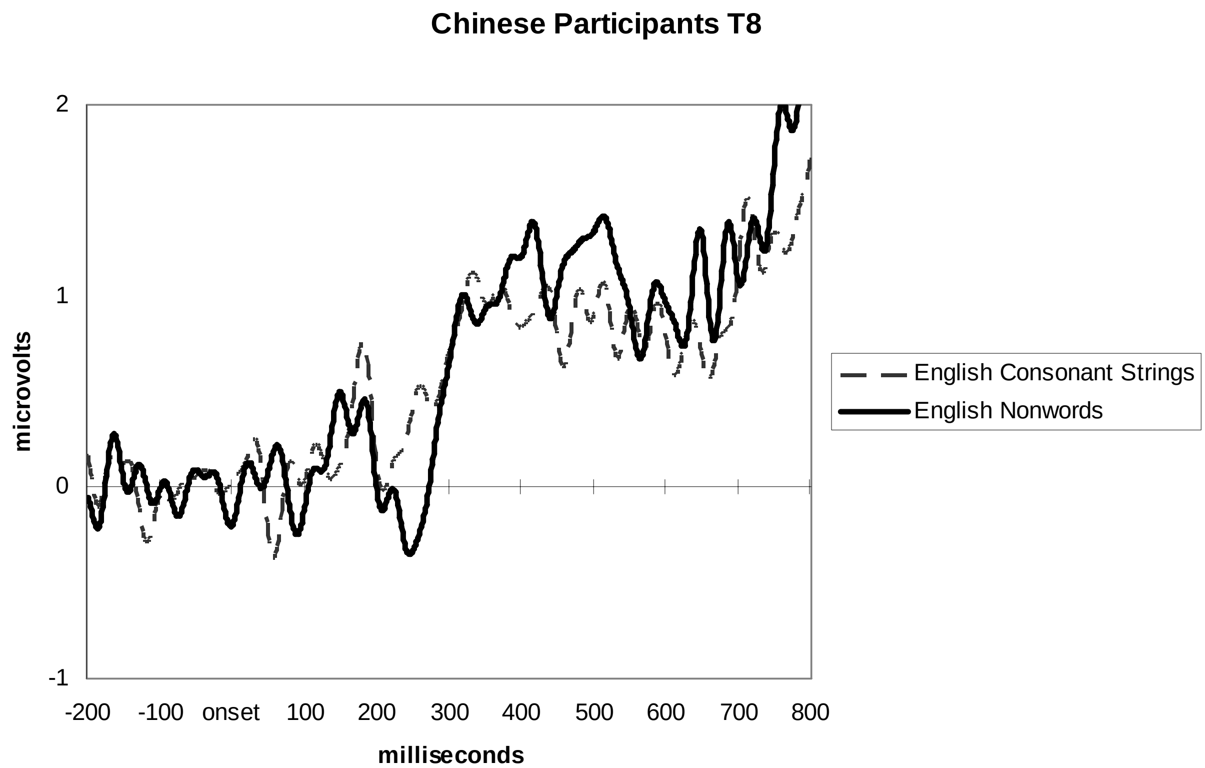
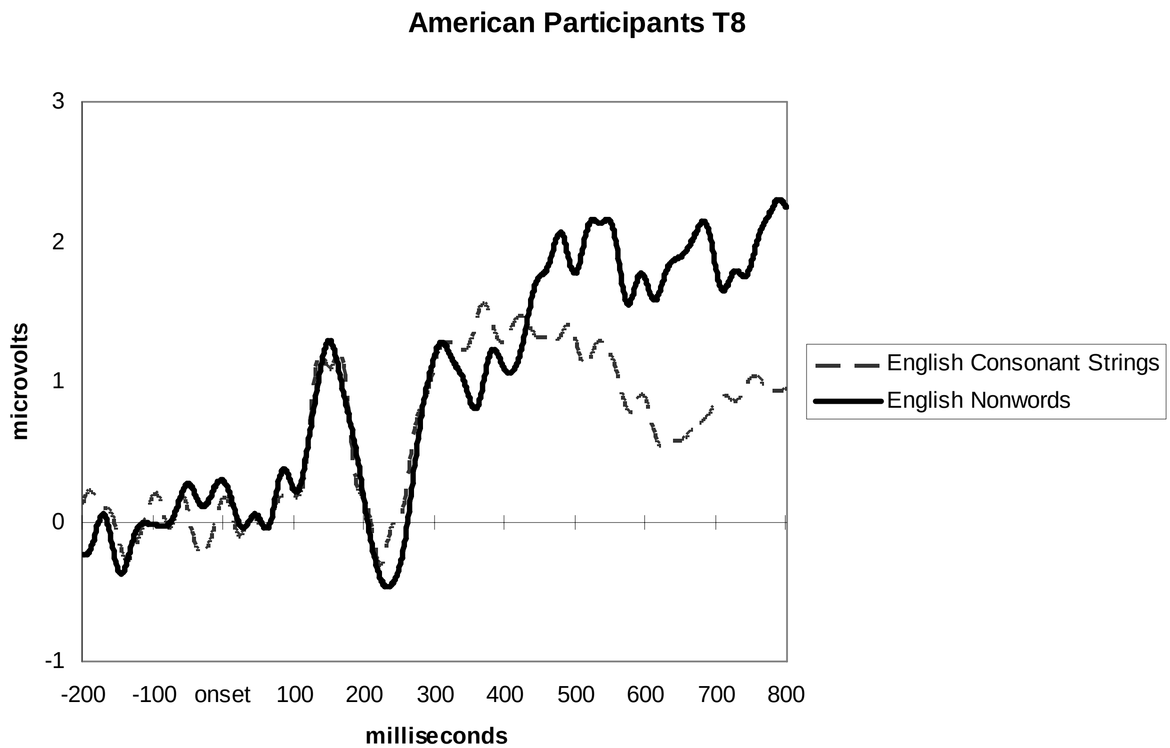


Figure 10. Chinese participants L2 nonwords versus consonant strings

4.3.6 American participants L1 pronounceable nonwords versus consonant strings

For the American participants, pronounceability significantly affected the N225 latency at the right temporal site (T8) such that pronounceable nonwords elicited peak amplitudes an average of 23 ms earlier than the consonant strings, $F(1, 11) = 10.97$, $p < .01$. Pronounceability also significantly affected N400 latency at frontal, central, and parietal sites such that pronounceable nonwords elicited peak amplitudes an average of 19 ms earlier than the consonant strings, $F(1, 11) = 8.75$, $p < .05$. Figure 11 shows these effects.



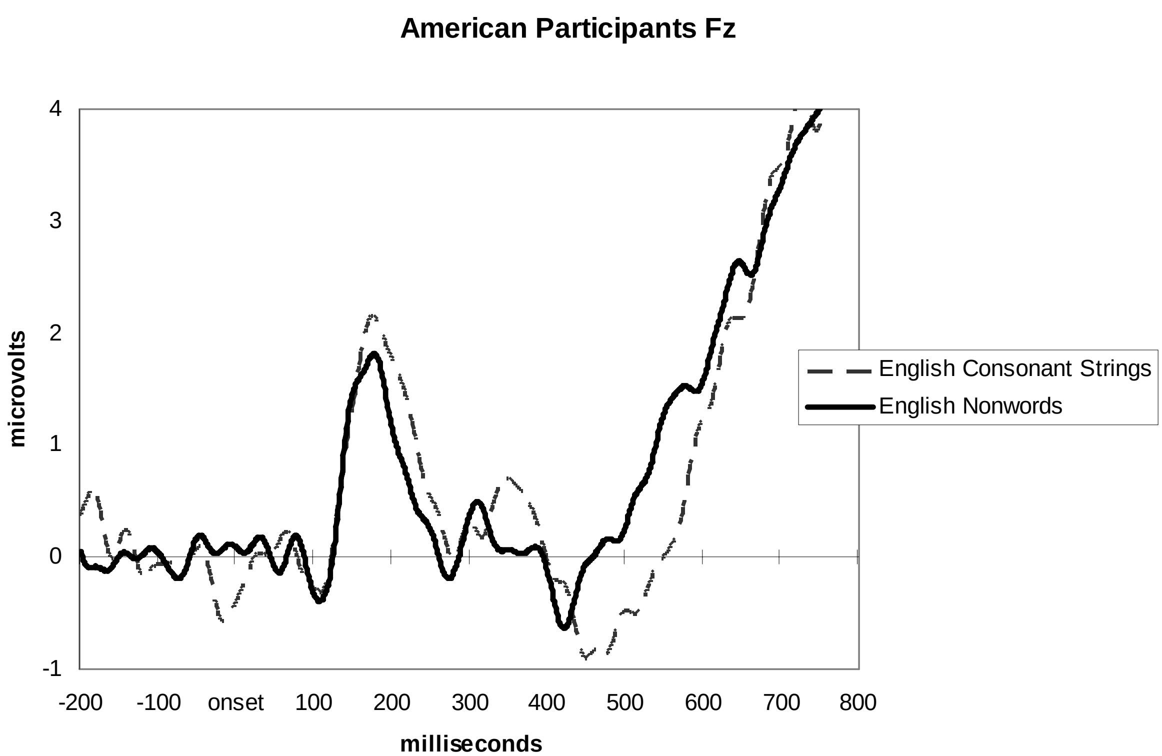


Figure 11. American participants L1 nonwords versus consonant strings

The following comparisons showed no significant effects:

- Chinese participants L1 high-frequency versus low-frequency
- Chinese participants L1 real versus pseudocharacters
- Chinese participants L2 high-frequency versus low-frequency
- Chinese participants L2 real versus nonwords
- American participants L0 real versus pseudocharacters
- American participants L1 high-frequency versus low-frequency

4.3.7 Summary of ERP results

ERP results from the present study are summarized in Table 3. Referring back to predicted results in Table 1, we found two results consistent with predictions made based on previous research (highlighted in italics in Table 3). First, Chinese-English bilinguals did show earlier processing of L1 relative to L2, when comparing latencies of N225 components elicited by high-frequency real words from each language. Second, American participants showed no difference between real and pseudocharacters in Chinese, as would be anticipated for an unknown language (L0).

However, we also found several ERP results other than expected. Both groups showed latency differences between pronounceable nonwords and nonpronounceable consonant strings in English—with the Chinese participants showing this effect earlier (P150) than the American participants (N225 and N400). The American participants also showed sensitivity to differences between English items and Chinese items, and between Chinese high- and low-frequency items, between 200 and 500 ms post-stimulus. In English, the American participants showed N400 latency differences between real words and consonant strings.

Surprisingly, no significant effects of frequency or lexicality were found for Chinese participants in their first or second language. Also, no significant effects of frequency were found for American participants in their first language. As expected, no significant effects of lexicality were found for American participants in their unknown language.

Table 3. ERP results summary

	Chinese Participants	American Participants
1. Chinese Real vs. English Real	*EARLIER RECOGNITION OF L1* N225 L1 earlier latency and more negative adaptive mean than L2 at frontal, central, and parietal sites	N225 L0 HF greater mean amplitude than L1 HF at left frontal site (F3) N225 and N400 L0 LF greater mean amplitude than L1 LF at right frontal site (F4) P225 L0 greater adaptive mean than L1 at left and right occipital sites (O1 & O2)
2. Chinese High vs. Low Frequency	no differences	N400 HF greater mean amplitude than LF at frontal, central, and parietal sites
3. Chinese Real vs. Pseudocharacters	no differences	*NO DIFFERENCES*
4. English High vs. Low Frequency	no differences	no differences
5. English Real vs. Consonant Strings	no differences	N400 real earlier latency than CS at occipital and temporal sites
6. English Nonword vs. Consonant Strings	P150 NW earlier latency than CS at temporal sites (T7 & T8)	N225 NW earlier latency than CS at right temporal site (T8) N400 NW earlier latency than CS at frontal, central, and parietal sites

5.0 DISCUSSION

5.1 BEHAVIORAL—TRIANGLE SEARCH TASK

Performance on the triangle search was not affected by stimulus language. Familiarity with a language neither enhanced nor interfered with target detection. Because accuracy rates were at ceiling, the task was simple enough to perform regardless of the stimulus language. There were no differences within or between groups on the triangle search accuracy or response times. We can take this to mean that the two participant groups were both performing the task as instructed, and we can confidently compare their ERP data.

5.2 BEHAVIORAL—RECOGNITION TEST

The triangle search task did not require participants to attend to the words, and recognition memory for items was not expected to be high. Recognition sensitivity measures (d' scores) ranged from .26 to 1.89. In general, participants were significantly better at remembering items from L1 relative to L2 or L0. The data suggest that participants were indeed attending to and reading the words, at least incidentally, even thought the triangle search task did not require it. This means that incidentally viewed language stimuli achieve processing sufficient to produce modest levels of subsequent recognition. Thus we can be more confident that the ERP results reflected some reading processes.

5.3 ERP TASK

As predicted, Chinese participants showed early orthographic sensitivity for items in their native language compared to their L2. However, they did not show sensitivity to frequency or lexicality for items in either L1 or L2. This is puzzling because they knew both languages, and automatic reading should have occurred for all real items. Previous studies have found reading-related components with groups of native Chinese speakers (Liu & Perfetti, 2003; Liu, Perfetti, & Hart, 2003), but they used language tasks that required some lexical processing of items. Recall that in a delayed naming task, Chinese-English bilinguals exhibited an N250 effect of language, such that Chinese items elicited greater amplitude than English items for left frontal, right frontal, and left central electrodes (Liu & Perfetti, 2003). In the present study, we purposely chose a passive viewing task to see if automatic reading occurred nonetheless. For Chinese participants, we can say that incidental reading may involve lower level visual processing, enough to detect orthographic differences between writing systems, but not deeper lexical processing, enough to exhibit effects of lexicality or frequency.

The American participants also had unexpected patterns of results. For Chinese items, with which they should not have been familiar, they showed N400 effects of frequency. The norming data did not suggest detectable differences in the stimuli, but it is possible that there were still some subtle differences that the naïve reader may have detected. So again it is perplexing why people who do not have any knowledge of the orthography, phonology, and semantics of Chinese characters would have differential brain activity when viewing high- versus low-frequency items in that language. The American participants also exhibited orthographic sensitivity when we compared L1 to L0, but these effects were later (N225 and N400) and usually more anterior (left and right frontal) than might be expected. For our American participants, the Chinese stimuli were essentially meaningless shapes, similar to those used in the previously described French study, which found an N170 effect at occipital and temporal sites (Bentin et al., 1999). Our data also showed a P225 effect at left and right occipital sites. Again, this is later than the N170.

Both native and nonnative speakers processed more wordlike letter strings faster than nonpronounceable consonant strings in English. These effects showed up earlier (P150) in nonnative speakers and at temporal sites, suggesting they were doing a quick orthographic check then dismissing the items as nonwords. Native speakers showed effects later (N225 and N400) and at more widespread sites (temporal, frontal, central, parietal) suggesting they were making more of an attempt to continue processing items as words. This might suggest that familiarity with a language encourages further processing. Yet, the latency-to-peak differences between nonwords and consonant strings were small (10-23 ms) and may not translate to a meaningful advantage in cognitive processing or in behavioral measures.

5.4 RESEARCH QUESTIONS REVISITED

1. Will the ERP components found in explicit reading tasks also be observed in our incidental reading task?

We found some ERP components that were related to lexical characteristics (i.e., pronounceability, orthographic familiarity). However, many of the predicted reading-related components were not found, particularly frequency effects in L1 for both groups. When the task does not require reading, it seems that the incidental reading which does occur is not as robust as purposeful reading. In a Stroop task, Repovš (2004) found greater interference from automatic word reading when a verbal response rather than a manual response was used. This suggests that task characteristics or instructions do indeed influence the extent to which experimental items are processed.

2. Does familiarity with the language facilitate automatic word reading?

When comparing stimuli from two different languages, both participant groups showed some differential ERP responses. However, finer-grained manipulations at the level of frequency and lexicality within a language type did not have much effect. Only the American participants showed N400 effects of lexicality, and these were more posterior than a typical reading-related N400.

It is possible that our ERP signal was reflecting other processes besides incidental reading. Although we removed the potential noise from naming and lexical decision-type responses, we may have introduced another source of noise with the triangle search task. Participants had to monitor the items and keep track of the number of triangles they saw as the trials progressed. We might have unwittingly introduced other nonreading cognitive process—

searching for the triangle; having an "aha" effect after detecting a triangle; maintaining or updating the count of 0, 1, or 2 after each item in a run until the response probe; anticipating the appearance of the response probe; trying to sustain attention throughout the task; and visually recognizing the stimuli as they appear on the computer monitor. Rudell and colleagues (Rudell & Hu, 1999; 2001; Rudell & Hua, 1995; 1996; 1997) have identified an ERP component they termed the recognition potential (RP). It is an early component, usually occurring 100 to 200 ms post-stimulus, that is related to a participant visually recognizing the presence of a stimulus. The RP is difficult to distinguish from a P100 and other early visual components. Thus, it may be the case that the P150 and N225 components we reported may be reflecting some recognition processes as well. However, this still does not account for the N400 frequency effect we found for American participants viewing Chinese characters.

In conclusion, the passive viewing task did not seem to elicit reading to the same degree that other language tasks, such as naming and lexical decision tasks, have done. We found some ERP effects of orthography, lexicality, and pronounceability, but no effects of frequency. This suggests that automatic word reading does occur in a passive viewing task, such that orthographic and perhaps some phonological information are processed. Frequency effects disappeared in a passive viewing task. Our ERP results may also be reflecting other cognitive processes involved in the triangle search task, which was designed to ensure participants paid attention to items on the screen. Future studies could take this into consideration and utilize a task that better minimizes all decision-related components.

APPENDIX A

EXPERIMENTAL STIMULI

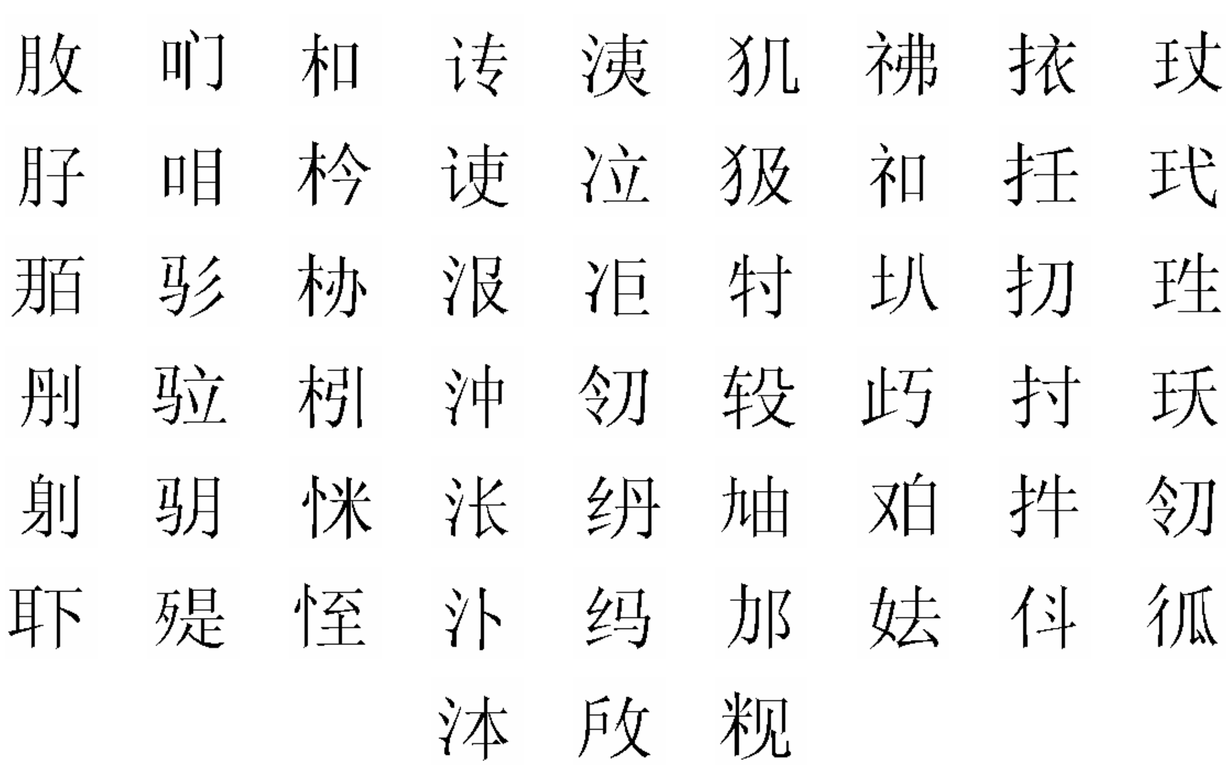
Chinese High-Frequency Characters

那	相	利	没	组	加	体	此	情
取	根	和	法	级	放	任	政	性
明	林	种	油	线	们	代	如	领
时	极	物	活	理	他	位	好	所
的	样	转	流	现	使	很	对	切
形	机	制	决	报	件	地	观	提
			料	把	作			

Chinese Low-Frequency Characters

肽	咦	鸣	杖	沁	狸	拒	袄	侄
肿	哦	叽	枉	淮	犸	扶	祀	仿
胁	吲	骇	轩	汀	狭	抒	轩	坍
肘	呤	驭	铱	沂	玖	扑	籽	巧
胀	咪	驮	讶	泣	珀	拂	邯	弛
豚	吓	躬	诫	纫	琥	鸠	殃	姥
			彤	陌	孤			

Chinese Pseudocharacters



English High-Frequency Words			English Low-Frequency Words		
book	build	bridge	ache	beige	bruise
cold	dance	bright	brag	chalk	chrome
door	eight	caught	coax	geese	clique
each	floor	choice	eave	haunt	dearth
game	heart	course	flex	joust	fright
hand	house	friend	harp	knack	groove
just	known	ground	iced	lathe	hushed
keep	large	growth	jade	noose	inched
left	month	health	knob	ounce	morgue
much	north	length	lint	plaid	quench
note	peace	raised	math	quake	scrape
once	point	school	noun	rhyme	splash
park	quite	should	pawn	shred	spouse
road	range	source	quiz	sieve	starve
stay	teeth	spread	rein	vault	stitch
true	three	square	rink	weave	thirst
used	voice	street	swan	yacht	thrash
wish	wrong	strong	vine	yearn	trance
year	young	weight	yawn	zoned	writhe

English Nonwords			English Consonant Strings		
balse	hotch	slurk	bnpltr	htrncw	qlfgt
blarns	knoods	smod	bnshf	jldnrb	qrdkls
bolk	korgue	splaks	crtgh	jrctnk	rdfs
booch	lerg	sprin	dcrhkl	kfrhb	rfsht
bunge	lish	stirk	dhlpt	klsth	rgml
clinge	lurb	strusk	dqcl	lfwtc	rlvsk
crowse	phod	swen	dtnlw	lnfhtv	slrnth
deach	plirst	tremps	dtnrb	lnpf	sngdlq
drigs	poif	trooch	fchtl	lrhft	spcwhv
drocks	proils	vash	fdtkc	lrth	tcdn
feep	scorte	veeds	fphkl	lthm	tdgh
filge	scrabe	vooled	ftdkrn	mhls	tdhw
flasp	scrink	walf	glhnsr	mrsg	tdrkf
fotch	shipes	wrelse	gmhk	ngwl	tghw
geeves	sholk	yace	gtbn	nhtf	tphc
glamp	skess	yeet	hcdft	nsrlm	vstl
glat	slale	yibe	hgtlv	ntlhf	xlgntd
glaw	sloin	zafe	hlnr	pnwhc	xrhcst
hish	slume	zigh	hmtwc	psntw	zrhlwb

APPENDIX B

TARGET ITEMS IN THE TRIANGLE SEARCH TASK

Chinese

High-Frequency

Low-Frequency

Pseudocharacters

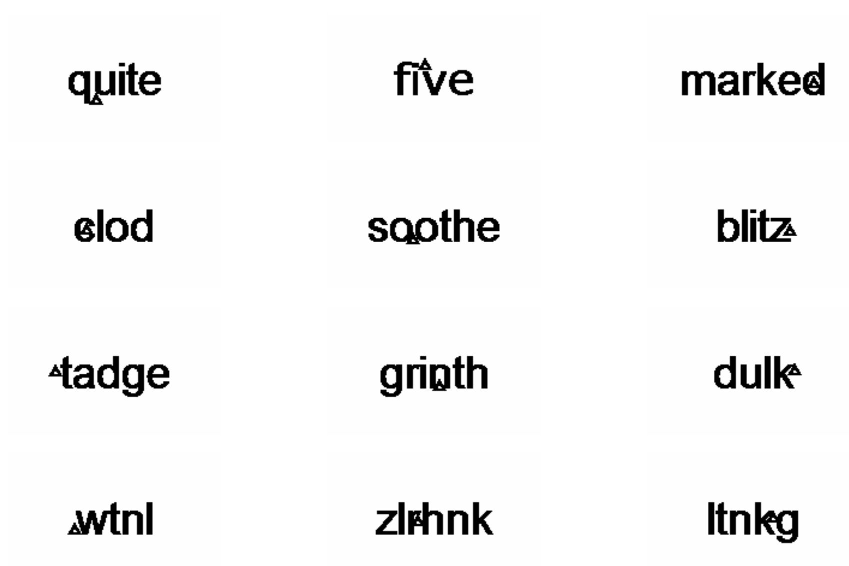
English

High-Frequency

Low-Frequency

Nonwords

Consonant Strings



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