

Temporal dynamics of the consistency effect in reading Chinese: an event-related potentials study

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This study aimed to explore the temporal dynamics of the consistency effect in reading Chinese phonograms. High-consistency and low-consistency characters were used in the homophone judgment task, and the event-related potentials were recorded. The data showed that low-consistency characters elicited greater N170 amplitude in the temporal–occipital region and greater P200 amplitude in the frontal region than high-consistency characters, whereas high-consistency characters

showed greater amplitude of the N400 negativity than low-consistency characters. These findings can be interpreted as indicating that low-consistency characters produce a greater activation for the initial analysis of the orthographical and phonological representations, whereas high-consistency characters involve a greater lexical competition in the later stage. *NeuroReport* 18:147–151
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Background

In studies of English, the consistency effect refers to findings that naming responses are faster and more accurate for words that have consistent correspondences between the orthographic body and phonological rime (e.g. -ean in the final position of a word is always pronounced as /in/ as in lean, dean, bean, etc.). In contrast, naming responses are slower and less accurate for inconsistent words that have multiple body–rime correspondences (e.g. -int corresponds to /int/ in mint and to /aint/ in pint) [1]. This effect was observed primarily for words that are low in frequency and was used to support a single mechanism for converting printed words/pseudowords into speech sounds according to the statistical mapping between orthography and phonology. Functional imaging studies have exploited word frequency, lexicality, and spelling-to-sound consistency as probes and posited the left inferior frontal gyrus as the most ubiquitous neuronal structure for spelling-to-sound transformation [2,3]. Other regions, such as the inferior parietal region, supramarginal gyrus, angular gyrus, and temporal–occipital junction in the left hemisphere, have also been shown to be related to this process.

Chinese is characterized as an ideographic writing system that uses characters as the basic writing unit. Unlike English, in which words are composed of letters representing phonemes, Chinese characters are composed of radicals

that cannot correspond to phonological segments to produce or represent the sound of the character. More than 85% of all Chinese characters, however, are phonograms; the phonetic radicals may be used to specify the pronunciation of the whole character. The phonological relationship between phonogram and phonetic radical can be addressed by consistency. This refers to whether the pronunciation of a character agrees with those of its orthographic neighbors which, by definition, contain the same phonetic radical (see Fig. 1). Previous studies have demonstrated the frequency by consistency interaction in naming Chinese phonograms and suggested that phonological information provided by the sublexical unit plays a role in reading Chinese phonograms [4,5]. Our previous event-related functional magnetic resonance imaging (fMRI) study used consistency as the marker and identified a set of neural correlates, including the left inferior frontal gyrus, the left temporo-parietal (inferior parietal gyrus and supramarginal gyrus) region, and the left temporal–occipital junction, involved in Chinese orthography to phonology transformation (OPT) [6]. These are congruent with the findings of researchers using alphabetic scripts, and this implies that the underlying mechanisms for OPT are language universal.

An unsolved problem is whether the consistency effect originates from competition among the phonological representations associated with the phonetic radical at the

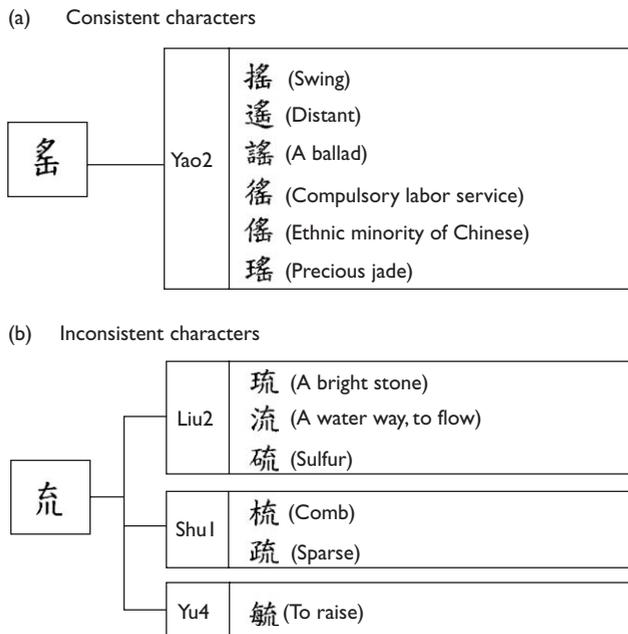


Fig. 1 Examples of consistent and inconsistent Chinese characters. (a) A set of consistent characters containing the same phonetic radical; all are pronounced as yao2. (b) A set of inconsistent characters containing the same phonetic radical but which are pronounced as liu2, shu1, and yu4, respectively. The number following the written pronunciation denotes the tone of the character in Mandarin.

sublexical level or is due to competition among the phonograms that share the same phonetic radical at the lexical level. To probe this question, the present study will use the event-related potentials (ERPs) technique instead of using traditional reaction time measurements. The main reason is that measurement of reaction time reflects the summation of all the steps that elapse before the behavioral response to a language task. In contrast, ERP provides data that reflects processing on a millisecond basis from the onset of language stimuli. More importantly, ERP components can be used to index the different stages of lexical processes [7]. For example, N170 has been associated with word form analysis, and P200 has been used to index mechanisms related to feature detection [8]. Previous studies have also demonstrated the spelling-to-sound regularity effect in P200 and suggested this component may be associated with the extraction of the orthographic and phonological features of words in the early stage of lexical processing [9,10]. N400 is well known for being associated with lexical semantic processing [11]. In addition, this component has been used to index phonological incongruity since studies have found that ERPs elicited by rhyming and nonrhyming words show differences in this component [12].

This study will use these components to index the locus of the consistency effect in reading Chinese. Given that the consistency effect was mainly observed in reading low-frequency characters, the present study manipulates the high-consistency and low-consistency levels within low frequency characters. If the consistency effect is mainly due to postlexical phonological competition, the consistency effect should be found in the later components, such as N400, so that low-consistency characters should generate a greater N400 amplitude than high-consistency characters.

On the other hand, if the consistency effect reflects phonological computation at the sublexical stage, the consistency effect should be found in the earlier components, such as N170 and P200.

Materials and methods

Participants

Twenty-two male college students (aged 18–32 years, mean 22.8 years) were paid for their participation. All participants were right-handed native Chinese speakers with no history of neurological or psychiatric disorders. They learned English since 13 years old in the junior high school. Most of them, however, are not fluent English speakers. They had either normal or corrected-to-normal vision. Written consent was obtained from all participants.

Materials and design

Eighty Chinese phonograms with low-character frequency (less than 100 per 10 million) were selected from the Academia Sinica balanced corpus [13]. All of the characters were configured horizontally with a semantic radical on the left and a phonetic radical on the right. Half of the stimuli were high-consistency characters (mean 0.98, range: 0.9–1.0) and half were low-consistency characters (mean 0.15, range: 0.1–0.2). The statistical analysis showed a significant difference of consistency between these two groups ($P < 0.001$). No difference was found, however, between the high-consistency and low-consistency conditions for their character frequency (mean: 30.7 vs. 24.5, $P = 0.20$), radical combinability (mean: 7.76 vs. 7.25, $P = 0.46$), and subjective familiarity (mean: 3.32 vs. 3.29, $P = 0.77$). The subjective familiarity is based on an unpublished corpus of 5640 Chinese characters. The data were collected from 160 college students by using a 7-point scale for familiarity rating.

Procedure

Participants were seated at a distance of approximately 60 cm in front of a monitor in a dim room. Each participant received 20 trials for practice and 170 randomized experimental trials in four test sessions. Participants could take a break between test sessions, as long as they needed. For each trial, a fixation first appeared at the center of the screen for 300 ms. When the fixation disappeared, a target character was presented in the same place for 200 ms. Participants were asked to name the target character silently. The target character was replaced by a blank for 800 ms and then a probe character was presented. Participants were asked to decide whether the target character and probe character were homophones by pressing a button on the mouse as quickly and as accurately as possible. The index finger indicated 'yes' and the middle finger 'no'. The correctness and reaction time were recorded. This homophone judgment task was used to ensure that participants paid attention to the target characters and processed them for their pronunciations. The probe character remained on the screen until the participant responded or until an interval of 2000 ms had passed. After the disappearance of the probe character, a bold capital letter 'B' was then presented for 500 ms to signal to participants to quickly blink before the next trial if necessary. The screen then turned blank for 300 ms before the start of the next trial. To ensure that participants knew the correct pronunciation of the target character, every target character was followed by a

homophone as a 'yes' trial. Eighty fillers of nonhomophone word pairs were created for 'no' trials.

Event-related potential recording and analysis

The electroencephalogram was recorded from 64 sintered Ag/AgCl electrodes (QuickCap, Neuromedical Supplies, Sterling, Texas, USA) with a common vertex reference and was re-referenced off-line to the average of the right and the left mastoids for off-line analysis. The electroencephalogram was continuously recorded and digitized at a rate of 500 Hz. The signal was amplified by SYNAMPS2 (Neuroscan Inc., El Paso, Texas, USA) with the band-pass set at 0.05–100 Hz. Vertical eye movements were recorded by electrodes placed on the supraorbital and infraorbital ridges of the left eye, and horizontal eye movements by electrodes placed lateral to the outer canthi of the right and left eyes. A ground electrode was placed on the forehead anterior to the FZ electrode. Electrode impedance was kept below 5 k Ω .

For off-line analysis, the continuous wave was segmented into epochs, starting 100 ms before and finishing 800 ms after the target onset, and the 100 ms prestimulus period was used for baseline correction. Trials contaminated by eye movement or with voltage variations larger than 60 μ V were rejected. Data were then band-pass filtered between 0.1 and 25 Hz. ERPs of the target characters with high-consistency and low-consistency were computed for every participant at every electrode site by averaging over corresponding trials.

Results

Figure 2 shows the grand average ERPs for reading high-consistency and low-consistency characters at 11 representative electrodes. All conditions showed the N1–P2 complex followed by a negative deflection that fits with the N400

component. Effects of consistency were assessed via comparisons of mean amplitudes in three temporal windows of interest: N170 (150–210 ms), P200 (180–230 ms), and N400 (300–500 ms). Different repeated measures of analysis of variance (ANOVA) were performed, including factors such as consistency (high and low) and electrodes in the regions of interest. For each ANOVA, the Huynh-Feldt adjustment to the degrees of freedom was applied to correct for violations of sphericity associated with repeated measures. Accordingly, for all F tests with more than one degree of freedom in the numerator, the corrected *P* value is reported. The Tukey test was used for all post-hoc comparisons.

N170

The mean amplitude of N170 was analyzed by a three-way ANOVA with the consistency (high and low), hemisphere (left and right), and electrode (P3/4, P5/6, P7/8, PO5/6, PO7/8) as within-subject factors. The data revealed a significant main effect of consistency [$F(1,4) = 9.66$; $P < 0.01$], which interacted with the hemisphere [$F(1,4) = 6.21$; $P < 0.05$]. Post-hoc comparison indicated the significant consistency effect was found in both left ($P < 0.05$) and right ($P < 0.0001$) electrodes. Planned comparison showed that low-consistency characters revealed greater negativity of N170 than high-consistency characters at all electrodes ($P < 0.0001$).

P200

The analysis of P200 was conducted separately on the data derived from the midline and lateral sites. In the midline analysis, the factors of consistency and electrode (FZ, FCZ, CZ, CPZ, and PZ) were included as within-subject factors.

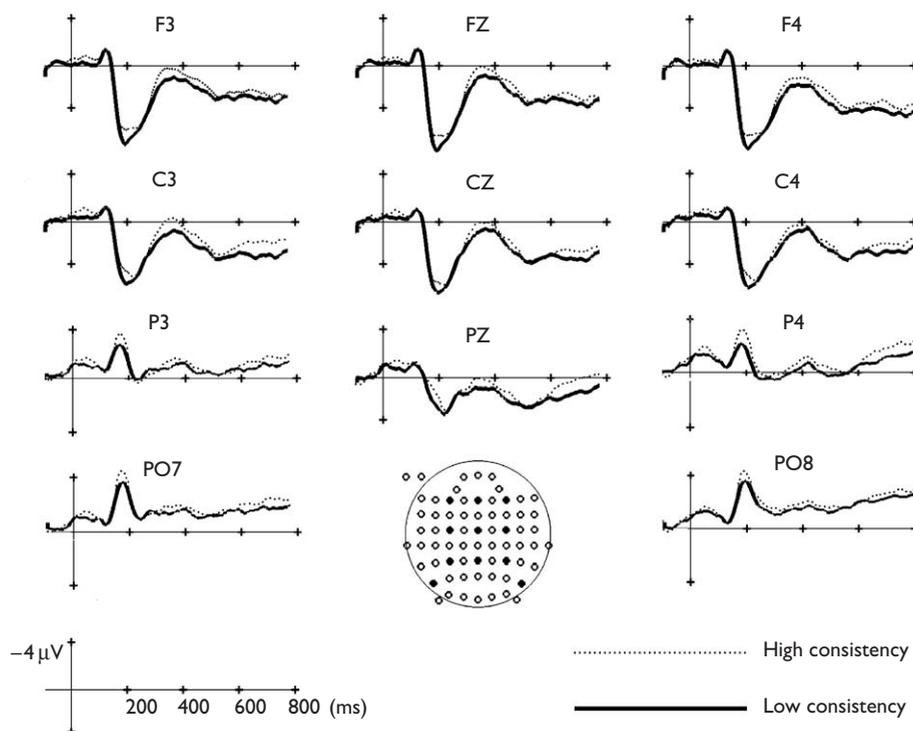


Fig. 2 The grand mean event-related potentials for reading high-consistency and low-consistency characters at representative electrodes.

For the lateral analysis, the factors of consistency (high and low), hemisphere (left and right), and electrode (F3/4, FC3/4, C3/4, and CP3/4) were used as within-subject factors. The midline analysis revealed a significant main effect of consistency [$F(1,4)=5.11$; $P<0.05$]. The lateral analysis showed a significant main effect of consistency [$F(1,3)=11.73$; $P<0.01$], which interacted with the hemisphere and the electrode [$F(1,3)=6.19$; $P<0.001$]. Follow-up comparisons indicated that the low-consistency characters revealed greater positivity of P200 than the high-consistency characters at all electrodes, but this effect was most significant at the left frontal sites (F3, $P<0.0001$).

N400

The analysis of N400 was also conducted separately on the data derived from the midline and lateral sites. In the midline analysis, the consistency and the electrode (FZ, FCZ, CZ, CPZ, and PZ) were used as within-subject factors. For the lateral analysis, the factors of consistency (high and low), hemisphere (left and right), and electrode (F3/4, FC3/4, C3/4, CP3/4, and P3/4) were included. The midline analysis revealed a marginal significance of consistency [$F(1,4)=3.52$; $P<0.074$]. The lateral analysis showed a significant main effect of consistency [$F(1,4)=6.54$; $P<0.05$] and a marginally significant three-way interaction between consistency, hemisphere, and electrode [$F(1,4)=2.38$; $P=0.058$]. Post-hoc comparison revealed that high-consistency characters elicited greater N400 negativity at almost every electrode ($P<0.001$) except for C3 ($P=0.11$), P3 ($P=0.92$), and P4 ($P=0.14$).

Discussion

The present study identified a set of ERP components, including N170, P200, and N400, associated with the consistency effect in reading Chinese characters and suggested that the mapping consistency between orthography and phonology affects lexical processing at different stages. First of all, reading low-consistency characters produced greater negativity of N170 than reading high-consistency characters. A previous study combining fMRI with magnetoencephalography has confirmed that N170 originates predominately from the inferior occipito-temporal regions [14]. This region is typically involved in visual word form identification [15] and has been reported to be related to the phonological processes of reading Chinese and alphabetic languages, although its activity is mainly bilateral for Chinese but more left-lateralized for alphabetic languages [16]. Other studies showed bilateral N170 differences between pseudowords and words in English, in contrast to the typical left-lateralized N170 found in German [17,18]. This language-specific effect in pseudoword processing suggests that different levels of engagement in OPT might explain the variable left-lateralization of N170. Furthermore, our previous fMRI study also reported a consistency effect in the left fusiform gyrus [6]. Taken together, these are congruent with the current findings and suggest that orthography-to-sound mapping influences the early stages of character/word processing.

The present study also demonstrated that low-consistency characters produce a higher positive amplitude at the P200 time window and lower negative amplitude at the N400 time window than high-consistency characters. Previous studies have found that sublexical syllable frequency and

congruency effects occurred in the P200 time window at the frontal region, whereas the lexicality and lexical frequency effects were seen in the later N400 window [19,20]. These findings were used to support the two-stage framework for lexical access by using P200 and N400 to index the sublexical and lexical processing, respectively. Our findings can be considered as further empirical support for this framework. The consistency effect can be interpreted as an early orthographic or phonological activation (indexed by P200), associated with a given phonetic radical at the sublexical level and a late competition (indexed by N400) among those lexical candidates who share the same phonetic radical. To be more specific, in the current study, the number of characters sharing a given phonetic radical (the so-called phonetic combinability) was matched well between high-consistency and low-consistency conditions. The only difference between high-consistency and low-consistency characters is the number of phonological alternatives associated with a given phonetic radical. The phonetic radicals of low-consistency characters were associated with a larger number of phonological candidates than those of high-consistency characters and, thus, resulted in greater activation during the early stage in analyzing the orthographic or phonological representation and showed greater positivity in P200. Later on, the activated lexical candidates should be inhibited via lateral inhibition to identify the correct lexical item. The greater N400 activation for high-consistency characters suggested that a specific phonological representation had been selected in the earlier stage. Given that the phonetic combinability was matched between high-consistency and low-consistency conditions, there were more homophones within a selected phonological subgroup for high-consistency characters than for low-consistency characters. Thus, high-consistency characters led to greater N400 activation due to lexical competition than low-consistency characters.

In conclusion, our data provided evidence for the consistency effect in early and late ERP components. These findings suggest the phonetic radical is a functional sublexical unit for Chinese lexical processing. The validity of a phonetic radical in representing the pronunciation of a character affects lexical processing from the early extraction of orthographic and phonological information to the late lexical competition.

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