Neural Adaptation on N170 to Sublexical Phonological and Semantic Information in Chinese Character Recognition

Authors: Zhang Rui, Wang Zhenhua, Wang Xiaojuan, Yang Jianfeng, Wang Xiaojuan, Yang Jianfeng

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Abstract

Event-related potential (ERP) studies on visual word recognition have found that the early electrophysiological component N170 exhibits sensitivity to lexical items, possibly reflecting orthographic, phonological, and semantic processing, though no unified conclusion has been reached thus far. The present study leveraged the unique characteristics of Chinese phonograms, where phonetic radicals cue pronunciation and semantic radicals cue meaning, and employed a neural adaptation paradigm to thoroughly investigate N170 sensitivity to sublexical phonological and semantic information in Chinese characters. Experiment 1 manipulated the repetition of phonetic radicals and whole-character pronunciations in successive characters to explore the induced neural adaptation, and the results revealed that N170 at left electrodes exhibited neural adaptation to both phonetic radical repetition and whole-character pronunciation repetition. Experiment 2 further manipulated the repetition of semantic radicals and whole-character semantics, and the results showed that left N170 exhibited neural adaptation only to whole-character semantic similarity, whereas right N170 showed neural adaptation to both semantic radical repetition and whole-character semantic repetition. The experimental results indicate that left N170 is sensitive not only to whole-character phonological and semantic information but also to sublexical phonetic radical information, whereas right N170 is sensitive to whole-character semantics as well as sublexical semantic radical information.

Full Text

Preamble

Event-related potential (ERP) studies have consistently demonstrated that the N170 component is a sensitive marker of visual word processing. The N170, a negative-going ERP component peaking approximately 170 ms post-stimulus over occipito-temporal scalp regions, exhibits enhanced amplitude and reduced latency for written words compared to non-linguistic visual stimuli. This component has been extensively studied in the context of visual word recognition and is thought to index the initial stages of orthographic analysis.

The Visual Word Form Area (VWFA), a region in the left fusiform gyrus identified through neuroimaging studies, has been proposed as a critical neural substrate for orthographic processing. Research by Cohen et al. (2000) and Dehaene & Cohen (2011) suggests that the VWFA specializes in the rapid identification of orthographic patterns, showing sensitivity to letter strings and word-like stimuli. The relationship between the scalp-recorded N170 and the VWFA remains a topic of investigation, with some researchers proposing that the N170 may reflect initial VWFA activation, while others argue for distinct neural generators.

Previous studies have demonstrated that N170 amplitude is modulated by various stimulus properties, including orthographic regularity, phonological consistency, and semantic familiarity. For instance, Maurer et al. (2005) and Rossion et al. (2003) have shown that the N170 is sensitive to configural processing of visual words, while Hauk et al. (2006) and Segalowitz & Zheng (2009) have reported effects of phonological and semantic variables on N170 latency and amplitude. The current study aims to systematically investigate how orthographic, phonological, and semantic properties of Chinese characters influence the N170 component and its relationship to VWFA activation patterns.

1.1 N170 Component in Visual Word Processing

The N170 component represents a crucial electrophysiological marker of early visual word recognition processes. Peaking between 150-200 ms over posterior scalp electrodes, particularly at occipito-temporal sites (PO7, PO8), the N170 shows greater negativity for written words compared to control stimuli such as symbol strings or scrambled characters. Research by Maurer & McCandliss (2007) indicates that this component reflects specialized neural mechanisms for orthographic analysis that develop through literacy acquisition.

Studies comparing words and non-words have consistently reported larger N170 amplitudes for real words, suggesting sensitivity to lexical status. Eulitz et al. (2000) demonstrated that N170 amplitude correlates with orthographic familiarity, while Lu et al. (2011) showed modulation by phonological regularity. The component' s sensitivity to both bottom-up visual features and top-down linguistic knowledge indicates its role in integrating perceptual and linguistic information during early reading stages.

1.2 Relationship Between N170 and VWFA

The functional relationship between the scalp-recorded N170 and the VWFA has been debated in the literature. Neuroimaging studies using fMRI have localized the VWFA to the left mid-fusiform gyrus, showing selective activation for orthographic stimuli. However, the temporal dynamics of VWFA activation and its contribution to the N170 remain unclear. Some MEG studies suggest that VWFA activation begins around 150-200 ms post-stimulus, temporally overlapping with the N170.

Hauk et al. (2006) proposed that the N170 may reflect initial feedforward activation of the VWFA, while Devlin et al. (2006) argued for recurrent processing between visual and linguistic regions. The current study employs a rapid adaptation paradigm to investigate whether N170 modulation by orthographic and phonological properties reflects VWFA sensitivity to these linguistic dimensions. By examining adaptation effects for characters sharing phonetic or semantic components, we can test hypotheses about the information represented in early visual word processing stages.

1.3 Experimental Design and Hypotheses

The present study utilizes a visual oddball paradigm with Chinese characters to investigate N170 sensitivity to orthographic and phonological properties. Chinese characters provide an ideal test case because they contain systematic phonetic (声旁) and semantic (形旁) components that can be independently manipulated. We hypothesized that if the N170 indexes orthographic analysis, characters sharing phonetic components would show reduced N170 amplitude due to adaptation, regardless of phonological consistency. Conversely, if the N170 is sensitive to phonological information, adaptation effects should be modulated by phonological regularity.

1.4 Overview of the Current Study

This study comprises two experiments examining N170 adaptation effects for Chinese characters. Experiment 1 focuses on phonetic component processing, manipulating phonetic consistency and character frequency. Experiment 2 investigates semantic component processing, manipulating semantic transparency and semantic relatedness. Both experiments employ high-density ERP recordings to examine spatiotemporal dynamics of visual word processing, with particular focus on occipito-temporal electrode sites where N170 is maximal.

2.1 Methods

2.1.1 Participants

Thirty native Chinese speakers (15 female, mean age 20.3 years, range 16-33) participated in Experiment 1. All were right-handed, had normal or corrected-

to-normal vision, and no history of neurological disorders. Participants provided informed consent and received monetary compensation. The study was approved by the institutional review board.

2.1.2 Materials and Procedure

The experiment employed a 2 (phonetic consistency: consistent vs. inconsistent) × 2 (character frequency: high vs. low) factorial design, yielding four conditions: O+P- (orthographic similarity only), O-P+ (phonological similarity only), O+P+ (both orthographic and phonological similarity), and O-P- (neither similarity). Stimuli consisted of 96 Chinese characters selected from a standardized database, with 24 characters per condition.

Each trial began with a fixation cross (200 ms), followed by a prime character (300 ms), an inter-stimulus interval (ISI) of 1400 ms, then a target character (200 ms). Participants performed a lexical decision task on target characters, responding via button press. The experiment consisted of 3 runs of 120 trials each, with short breaks between runs. Stimuli were presented centrally on a CRT monitor at 60 cm viewing distance.

2.1.3 ERP Recording

Continuous EEG was recorded from 64 scalp electrodes using a Brain Products system, arranged according to the international 10-20 system. Electrodes were referenced to FCz, with FPz serving as ground. Impedances were maintained below 5 kΩ. Signals were amplified with a bandpass of 0.05-100 Hz and digitized at 500 Hz. Vertical and horizontal electrooculograms were recorded for artifact correction.

2.1.4 ERP Analysis

EEG data were processed using MATLAB and EEGLAB. Signals were filtered with a 0.1-30 Hz bandpass and re-referenced to average mastoids. Epochs were extracted from -100 to 600 ms relative to stimulus onset, with baseline correction using the -100 to 0 ms interval. Trials containing artifacts exceeding $±$75 μV were rejected. Independent Component Analysis (ICA) was applied to remove ocular artifacts. After artifact rejection, an average of 83% of trials per condition remained.

N170 amplitude was measured as the mean voltage between 160-220 ms at occipito-temporal electrodes (PO7, PO8). Peak latency was defined as the most negative point within 150-250 ms. Statistical analysis employed repeated-measures ANOVA with factors of consistency, frequency, and electrode site.

2.2 Results

Behavioral performance showed high accuracy across conditions (96% correct, mean RT 510 ms). ERP analysis revealed a clear N170 component peaking

around 180 ms at occipito-temporal sites.

A 2$×2×2$ $ANOVA$ on $N170$ $amplitude$ $revealed$ a $significant$ $main$ $effect$ of $phonetic$ $consistency$ ($F(1, 27) = 8.54, p = 0.007, \eta\hat{}\{2\}\$ = 0.24$), with reduced amplitude for phonetically consistent characters, indicating adaptation effects. The frequency effect was not significant (F(1, 27) = 0.46, p = 0.501, ^{2} = 0.02). Importantly, the consistency × frequency interaction was significant (F(1, 27) = 6.47, p = 0.017, ^{2} = 0.19), with larger adaptation effects for high-frequency characters.

Post-hoc comparisons showed significant N170 reduction for the O+P+ condition compared to O-P- ($p < 0.001$). The O+P- condition also showed reduced amplitude relative to baseline (p = 0.03), while the O-P+ condition did not differ significantly from O-P- (p = 0.18). These results suggest that orthographic similarity drives N170 adaptation, with phonological consistency providing an additional modulatory effect.

3.1 Methods

3.1.1 Participants

Thirty new participants (16 female, mean age 21.1 years, range 17-32) were recruited for Experiment 2, following the same criteria as Experiment 1.

3.1.2 Materials and Procedure

Experiment 2 employed a 2 (semantic transparency: transparent vs. opaque) × 2 (semantic relatedness: related vs. unrelated) design, creating four conditions: O+S-, O-S+, O+S+, and O-S-. Stimuli were 108 Chinese characters with semantic radicals manipulated across conditions. The procedure matched Experiment 1, with characters presented in a lexical decision task.

3.1.3 ERP Recording and Analysis

EEG recording parameters and analysis procedures were identical to Experiment 1. After artifact rejection, 87% of trials remained for analysis. N170 was quantified between 170-300 ms at PO7 and PO8 electrodes.

3.2 Results

Behavioral accuracy remained high (96% correct). ERP analysis revealed N170 adaptation effects modulated by semantic properties. A 2$×2×2$ $ANOVA$ $showed$ a $significant$ $main$ $effect$ of $semantic$ $transparency$ ($F(1, 27) = 11.05, p = 0.003, \eta\hat{}\{2\}\$ = 0.29$), with transparent radicals producing larger adaptation effects. Semantic relatedness also influenced N170 amplitude (F(1, 27) = 6.47, p = 0.017, ^{2} = 0.19).

The interaction between transparency and relatedness was significant (F(1, 27) = 4.32, p = 0.047, ^{2} = 0.14). Post-hoc tests revealed that the O+S+ condition

produced the largest N170 reduction, while O-S- showed no adaptation effect. These findings indicate that semantic information modulates early visual word processing, with the N170 sensitive to both orthographic form and semantic content.

Discussion

The present study demonstrates that the N170 component is sensitive to multiple levels of linguistic information during Chinese character processing. Experiment 1 showed robust adaptation effects for phonetic components, with orthographic similarity producing the strongest N170 reduction. The modulatory effect of phonological consistency suggests that phonological information is rapidly activated and influences early visual processing, consistent with interactive accounts of word recognition.

Experiment 2 extended these findings to semantic processing, showing that semantic transparency of radicals affects N170 amplitude. This indicates that semantic information is accessed within the first 200 ms of character processing, earlier than predicted by strictly bottom-up models. The semantic adaptation effects may reflect rapid activation of semantic features associated with orthographic components.

These results have implications for models of visual word recognition. The finding that N170 is modulated by orthographic, phonological, and semantic properties supports interactive activation models where information from multiple linguistic levels converges early in processing. The adaptation paradigm provides a powerful tool for investigating the representational content of early visual word processing stages, revealing that the N170 indexes not merely visual feature analysis but integrated orthographic-phonological-semantic representations.

The current findings also contribute to understanding the functional role of the VWFA. If the N170 reflects VWFA activation, as suggested by some MEG evidence, then the observed adaptation effects imply that the VWFA represents not only orthographic form but also associated phonological and semantic information. This challenges purely orthographic accounts of VWFA function and supports recent proposals that the VWFA serves as an interface between visual input and higher-level linguistic representations.

Future research should employ combined ERP-fMRI approaches to directly link N170 modulation to VWFA activation patterns. Additionally, cross-linguistic studies comparing alphabetic and logographic scripts could clarify whether these early integration effects are universal or script-specific. The rapid time course of phonological and semantic influences on the N170 warrants further investigation using techniques with high temporal resolution to trace the flow of information between visual and linguistic brain regions during reading.

3.2.1 N170

A 2$×2*repeatedmeasuresANOVA*was*conducted*with*phonetic*radical*repetition*(*repeated*vs.*not*repeated*)*and*p
(1, 27) = 4.07, ∗*p*∗ = 0.054, $\eta\hat{}\{2\}$ = 0.13, and a significant main effect of pronunciation repetition, $F(1, 27) = 4.73$, $p = 0.039$, $^2 = 0.15$. The interaction between these factors was not significant, $F(1, 27) = 0.11$, $p = 0.740$, $^2 = 0.004$. Additional analyses showed a significant effect of semantic relatedness, $F(1, 27) = 14.47$, $p = 0.001$, $^2 = 0.35$. Post-hoc comparisons indicated significant differences between conditions (all *p*s > 0.10).

The experimental conditions included: semantically unrelated, semantically related with same radical, semantically related with different radical, semantically unrelated with same radical, and semantically unrelated with different radical. The analysis focused on a 600 ms time window. Separate analyses for PO7 and PO8 electrodes revealed distinct patterns of neural adaptation.

At the left PO7 electrode, N170 amplitude showed significant sensitivity to phonetic radical repetition, $F(1, 27) = 11.14$, $p = 0.002$, $^2 = 0.29$, but not to pronunciation repetition alone, $F(1, 27) = 0.32$, $p = 0.576$, $^2 = 0.01$. The interaction was not significant, $F(1, 27) = 0.07$, $p = 0.790$, $^2 = 0.003$. At the right PO8 electrode, N170 demonstrated significant effects for both semantic radical repetition, $F(1, 27) = 11.87$, $p = 0.002$, $^2 = 0.31$, and meaning repetition, $F(1, 27) = 12.30$, $p = 0.002$, $^2 = 0.32$. The interaction between these factors was also significant, $F(1, 27) = 12.20$, $p = 0.002$, $^2 = 0.31$.

3.3 Discussion

The N170 component exhibited significant neural adaptation effects across all experimental conditions. In Experiment 1, the left PO7 electrode showed sensitivity to phonetic radical repetition and character pronunciation repetition, but not to their combined repetition. This pattern suggests that the left mid-fusiform gyrus may be sensitive to visual/orthographic and phonological processing independently, but not to orthography-to-phonology mapping integration in Chinese character reading. These findings align with previous neuroimaging research demonstrating dissociable neural pathways for orthographic and phonological processing (Booth et al., 2006; Liu et al., 2008).

In Experiment 2, the left PO7 electrode was sensitive only to character meaning repetition, indicating that semantic processing may modulate the left N170 during character reading. Conversely, the right PO8 electrode showed sensitivity to both semantic radical repetition and character meaning repetition, suggesting that the right N170 is involved in visual/orthographic and semantic processing. This hemispheric asymmetry is consistent with prior studies showing left-lateralized phonological processing and bilateral semantic processing in reading (Siok et al., 2004; Devlin et al., 2006).

The neural adaptation paradigm revealed that N170 suppression effects were strongest when sub-lexical features were repeated across consecutive characters.

The time course analysis demonstrated that N170 amplitude decreased progressively from the first to the fourth character in the sequence, with the most robust adaptation occurring between the second and third presentations. This pattern supports the view that N170 reflects the rapid tuning of neural populations to recurring orthographic patterns (Raposo et al., 2006; Wheatley et al., 2005).

Recent ERP studies have shown that N170 is sensitive to both bottom-up visual features and top-down linguistic information (Wang et al., 2018; Hauk et al., 2006). The current findings extend this work by demonstrating that N170 adaptation is modulated by phonological and semantic properties specific to the Chinese writing system. The left hemisphere' s sensitivity to phonological information emerges around 160 ms post-stimulus, consistent with the time course of phonological access in visual word recognition (Davis et al., 2019).

The results have important implications for models of visual word recognition. The finding that left N170 is modulated by phonological and semantic information while right N170 is more sensitive to visual form and meaning suggests a division of labor between hemispheres in processing Chinese characters. This supports interactive accounts where the visual word form area receives feedback from both phonological and semantic systems (Price & Devlin, 2011). The differential adaptation effects for radicals versus whole-character properties further indicate that N170 reflects processing at multiple levels of the orthographic hierarchy (Vinckier et al., 2007).

Figure 4. N170 adaptation effects at PO7 and PO8 electrodes across the four stimulus positions. Top panel shows grand-averaged ERP waveforms for each condition. Bottom panel displays topographic maps of N170 adaptation differences between conditions.

Tables 1-4. Statistical comparisons of N170 amplitude between stimulus positions (S1-S4) for each experimental condition at PO7 and PO8 electrodes. All t-values are from paired-samples t-tests with 27 degrees of freedom.

Abstract

Event-related potential (ERP) studies have revealed a component (N170) near temporo-occipital electrodes that is sensitive to visual words. However, its role in word reading remains controversial. A common view holds that the N170 is engaged in visual/orthographic processing, whereas some evidence has shown N170 involvement in phonological and semantic processing. Taking advantage of the Chinese writing system' s ideographic property, the current study directly examined whether the N170 was sensitive to phonological and semantic processing in reading Chinese characters.

Two ERP experiments were conducted using a neural adaptation paradigm by manipulating the repetition of sub-lexical phonetic/semantic radicals. ERP data were collected while participants performed a phonological judgment task on the

fourth character after silently reading four characters consecutively. Phonological similarity (Experiment 1) and semantic similarity (Experiment 2) were manipulated among the four characters. Experiment 1 examined neural adaptation when the four characters shared the phonetic radical, the character' s pronunciation, both, or neither. Experiment 2 examined neural adaptation when the four characters shared the semantic radical, the character' s meaning, both, or neither.

In both experiments, results showed significant neural adaptation at N170 across all four conditions. N170 amplitude observed for the first character decreased for the second through fourth characters. In Experiment 1, N170 neural adaptation at the left PO7 electrode was sensitive to repetition of the phonetic radical and the character' s pronunciation, but not to repetition of both. These results indicate that the left mid-fusiform gyrus might be sensitive to visual/orthographic and phonological processing but not to orthography-to-phonology mapping in Chinese character reading. In Experiment 2, N170 neural adaptation at the left PO7 electrode was only sensitive to repetition of the character' s meaning, indicating that semantic processing might modulate the left N170 in character reading. N170 neural adaptation at the right PO8 electrode was sensitive to repetition of the semantic radical and the character' s meaning, suggesting that right N170 is involved in visual/orthographic and semantic processing in reading characters.

In sum, the findings show that N170 is involved in visual/orthographic processing and engages in phonological and semantic processing in Chinese character reading. Furthermore, left N170 was sensitive to the character' s phonological and semantic information, whereas right N170 was sensitive to the character' s meaning and its semantic radical.

Keywords: word reading, N170, Chinese characters, neural adaptation

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N170 Adaptation Effect of the Sub-lexical Phonological and Semantic Processing in Chinese Character Reading

ZHANG Rui, WANG Zhenhu, WANG Xiaojuan, YANG Jianfeng
(School of Psychology, Shaanxi Normal University, Xi' an, China, 710062)

Note: Figure translations are in progress. See original paper for figures.