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# It's a word: Early electrophysiological response to the character likeness of pictographs

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**Abstract**

Using unfamiliar and meaningless pictographs that varied in their degree of similarity to Chinese characters, the current study tested whether the early electrophysiological response was modulated by character likeness. We measured P100 and N170 while 20 native Chinese speakers were viewing Chinese characters, drawings of objects, and pictographs. Comparisons across the three categories of stimuli showed that pictographs elicited a smaller N170 amplitude than did Chinese characters and a stronger N170 amplitude than did objects, but did not differ in the P100 amplitude from the other two categories. Within the category of pictographs, stimuli with a higher degree of character likeness elicited larger N170 amplitudes and shorter N170 peak latencies, and this effect was again not observed in P100. These results suggest that N170 is sensitive to visual stimuli's character likeness even though they are unfamiliar pictographs with no meanings or sounds.

**Descriptors:** Early electrophysiological response, P100, N170, Category, Character likeness, Pictographs

The initial important stage of reading is visual word recognition that occurs within 200 ms. Neurophysiological research has identified two typical reading-related components, P100 and N170 (also known as P1 and N1) at the occipital and occipito-temporal electrodes, which peak at about 100 ms and 170 ms (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Brem et al., 2006; Simon, Bernard, Lalonde, & Rebai, 2006). N170 has been deemed a category-specific component because of its consistent differences in amplitude and lateralization across words, faces, and other objects (Rossion, Joyce, Cottrell, & Tarr, 2003). Specifically, this component is stronger for faces and words than for other objects, and it is left lateralized for words and right lateralized for faces but bilateral for other objects (Maurer, Rossion, & McCandliss, 2008; Maurer, Zevin, & McCandliss, 2008; Mercure, Dick, Halit, Kaufman, & Johnson, 2008; Rossion et al., 2003). Like N170, P100 has also been found in several studies to show category specificity, but researchers have attributed this effect to category-specific low-level physical features rather than high-level categorical properties (Brem et al., 2006; Halgren, Raij, Marinkovic, Jousmaki, & Hari, 2000; Itier & Taylor, 2002).

The prevailing perspective about the N170 component is that it indexes perceptual expertise, because a stronger N170 could be elicited in bird experts when they processed pictures of birds and in car experts when they processed pictures of cars (Gauthier, Curran, Curby, & Collins, 2003; Tanaka & Curran, 2001). Moreover, extensive training with novel objects (e.g., greebles) would lead to a stronger N170 response to the trained objects (Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002; Scott, Tanaka, Sheinberg, & Curran, 2006). Given such evidence, the visual word-specific N170 has been argued to reflect the human brain's expertise in reading visual words as a result of years of reading experience. Supporting that perspective, developmental studies have found that N170 shows developmental changes (i.e., children showed no word-specific N170 before learning to read but showed a stronger response to words than symbols after they learned to read; Brem et al., 2006; Maurer et al., 2006). Moreover, the amplitudes of N170 have been found to be correlated positively with reading performance (Brem et al., 2006; Maurer et al., 2006).

Although much evidence has supported the idea that N170 is elicited by familiar words (i.e., expertise with processing words that are encountered frequently), it is less clear to what specific properties of familiar words it actually responds. Many researchers have labeled N170 as a visuo-orthographic component, because N170 has been found to be larger for orthographic stimuli (i.e., words, pseudowords, and consonant strings) than for nonorthographic stimuli (i.e., symbols; Bentin et al., 1999; Pylkkanen & Marantz, 2003; Simon, Bernard, Largy, Lalonde, & Rebai, 2004). Moreover, researchers have shown that N170 is

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sensitive to the grapheme–phoneme correspondence (GPC) rules of orthographic stimuli. Words in languages that are expected to favor the use of the GPC rules (e.g., French) elicited a stronger N170 than those in other languages (e.g., Arabic; Simon et al., 2006). Within the same language, words that have a higher level of phonetic combinability elicited a greater N170 than did the low-combinability ones (Hsu, Tsai, Lee, & Tzeng, 2009). Finally, N170 differed between words and pseudowords for deep orthographies (i.e, languages such as English that have complex and inconsistent mapping of graphemes to phonemes), but it did not differ between words and pseudowords for shallow orthographies (i.e., languages such as German that have consistent grapheme–phoneme correspondence; Maurer, Brandeis, & McCandliss, 2005; Wydell, Vuorinen, Helenius, & Salmelin, 2003). In summary, there is strong and consistent evidence that N170 is sensitive to orthography, especially the GPC rules.

However, written texts are complex and multidimensional stimuli (Barton, Fox, Sekunova, & Iaria, 2010). In addition to orthography and the GPC rules, several studies have found that N170 is modulated by other linguistic (e.g., semantics and phonology) and nonlinguistic factors (e.g., stimulus duration and task demands; Montalan et al., 2008; Xue, Jiang, Chen, & Dong, 2008). No study thus far has examined whether the early electrophysiological responses are sensitive to the character likeness of stimuli that are novel and meaningless. Strictly speaking, if the visuo-orthographic expertise perspective is correct, such a property (character likeness) should show no specialization of N170 response because the novel and meaningless materials have no orthography. On the other hand, the prevailing neuron response models would predict that visual character likeness (a form of extension of expertise) should affect the word-specific N170 response.

According to the neuron response models, "neurons' response to a stimulus is suggested as a function of the similarity between the neurons' optimal stimulus and the incoming stimulus" (Grill-Spector & Witthoft, 2009, p. 161). It is the result of "selectivity" of the neurons in the ventral pathway formed by the process of discrimination and memorization of specific objects (Riesenhuber & Poggio, 2002). In the low-level visual system, neural selectivity varies depending on the physical properties such as arcs, intersecting lines, and non-Cartesian gratings (Hegde & Van Essen, 2000). In the highly specialized object-perception domain, neurons are tuned to a dictionary of features at different levels of complexity (Tsunoda, Yamane, Nishizaki, & Tanifuji, 2001). After specific neurons repeatedly and selectively respond to given objects, these objects are represented by their similarity to stored views of prototypes created (Palmeri, Wong, & Gauthier, 2004). On the basis of these models, word- or letter-specific neurons would be sensitive to word or letter likeness, with stronger responses to those stimuli that are more like words or letters.

Nevertheless, because N170 is sensitive to letters as well as words (Wong, Gauthier, Woroch, DeBuse, & Curran, 2005) and their linguistic and nonlinguistic features (Xue et al., 2008), it is difficult to disentangle their respective contributions when they are integral to the experimental stimuli. This is a common problem for most of the previous studies that used real words, pseudowords, letter strings, and false fonts (Bentin et al., 1999; Brem et al., 2006; Martin, Nazir, Thierry, Paulignan, & Demonet, 2006; Maurer et al., 2006), native and foreign words or letters (Liu & Perfetti, 2003; Wong et al., 2005), and different writing systems (Maurer, Zevin, et al., 2008; Simon et al., 2006). The present study aimed to eliminate some of the confounding factors by using logographic novel writings that vary in their character likeness to study the early electrophysiological responses (N170 and P100) to such writings. The novel pictographs (or their integral components) used in this study had never been seen before by the subjects, had no linguistic (semantic, phonological) information for them, and were selected to vary in a continuum of character likeness (ranging from low to high similarity to Chinese characters based on the evaluations by the subjects themselves and an independent sample). We hypothesized that early ERP components (especially N170) would be modulated by the level of character likeness of these stimuli. Chinese characters and simple drawings of common objects were used as comparisons.

## Methods

### *Participants*

Twenty-two undergraduate volunteers were recruited from Beijing Normal University for this study. All participants were right-handed and had normal eyesight in both eyes. Two participants were removed from the analysis because of substantial eyeblink artifacts or signal drift. The remaining 20 participants (10 men, 10 women) had a mean age of 22 years (ranging from 20 to 25 years). They did not know any pictographs used in the present study based on a postexperiment interview (see Procedure below). Participants gave their written informed consent before the experiment.

### *Stimuli*

Thirty-six images of objects, 36 images of Chinese characters, and 108 images of pictographs were used in the present study (Figure 1). All stimuli were presented in white color on a black background. Objects were simple line drawings of either natural or manmade objects (Wang, Xue, Chen, Xue, & Dong, 2007). Of the 36 Chinese characters, 9 were high-frequency (higher than 800 per million according to the Chinese word frequency dictionary) and complex (8 to 12 strokes), 9 were high-frequency and simple (3 to 6 strokes), 9 were low-frequency (lower than 200 per million) and complex, and 9 were low-frequency and simple. The pictographs consisted of three kinds of ancient Chinese characters (36 images each of Dongba, Jiagu, and Xiaozhuan pictographs). Because these pictographs are not regularly structured to allow for a simple count of strokes, their visual complexity was assessed with a procedure used in vision research (Majaj, Pelli, Kurshan, & Palomares, 2002; Zhang, Zhang, Xue, Liu, & Yu, 2007). Each pictograph was sliced four times (horizontally, vertically, and diagonally in two orientations), each time using four straight, parallel, and equally spaced lines. An index based on the


**Figure 1.** Examples of three different types of stimuli.

number of strokes that cross into two neighboring slices was used as the measure of complexity of the pictographs (Majaj et al., 2002; Zhang et al., 2007). Based on this index, the mean complexity of the three levels of character-like pictographs did not differ.

### *Procedure*

During the collection of ERP data, subjects were seated 105 cm away from the computer screen in a dimly lit, sound-attenuated room. A passive-viewing task was adopted to minimize the differences in task demands for the processing of familiar and unfamiliar stimuli. All stimuli were presented visually in white against a black background at the center of the screen. Each stimulus (198 $\times$ 198 pixels) was randomly presented four times, 750 ms each time, followed by a blank screen varying randomly from 1050 ms to 1450 ms (mean = 1250 ms) to reduce the effect of expectation. To avoid the priming effect of characters and objects on pictographs, the three kinds of materials (pictographs, objects, and Chinese characters) were presented in separate sessions. The session for pictographs was randomly divided into three blocks (144 trials for each block) and presented first. Then the sessions of objects (144 trials) and Chinese characters (144 trials) were presented. To guarantee subjects' attention on the tasks, target trials were added (accounting for 12.5% of the trials). During these trials, a circle filled with either blue or orange color was presented and subjects were required to press the button "C" when they saw the blue circle and "M" when they saw the orange circle.

After the ERP portion of the study, subjects had a brief rest and were then asked to evaluate 250 images of pictographs (108 of them were used in the ERP study). They were asked to press the button "1," "2," "3," "4," "5," "6," or "7" based on the degree of character likeness of each stimulus, where 1 = *it looks totally like a picture* and 7 = *it looks totally like a character*. Each stimulus (198 $\times$ 198 pixels) was presented in the center of the screen until subjects pressed the button. To further corroborate the subjects' evaluations of character likeness, an independent sample of 10 additional subjects was asked to evaluate character likeness of the stimuli before the experiment.

Subjects were also asked to complete a brief questionnaire about whether they had experience with the pictographs before. There were three options in the questionnaire ("I have had no experience with the stimuli," "I have seen the stimuli before," and "I am familiar with the stimuli"). All subjects chose the option "I have had no experience with the stimuli."

### *Electroencephalogram (EEG) Recording and Analysis*

Scalp voltages were recorded by a Neuroscan system, using a 64-channel Quick-cap with silver chloride electrodes (Neurosoft, Inc., Sterling, VA). The impedance of all electrodes was kept below 5 k$\Omega$. Electroencephalogram was physically referenced to the left mastoid and was then re-referenced off-line to the average of the left and right mastoids. Two channels were placed at the outer canthi of both eyes to record the horizontal electrooculogram (HEOG) and another two channels above and below the left eye for vertical electrooculogram (VEOG). EEG was amplified with a band pass of 0.1 to 40 Hz, digitized online at a sampling rate of 1000 Hz.

The continuous EEG was transformed to the average reference (Lehmann & Skrandies, 1980). Trials contaminated by eyeblinks, eye movements, or muscle potentials exceeding $\pm$ 75 $\mu$V at any electrode were excluded from the ERP averages, resulting in exclusion of about 16% of the trials from the average, with the valid trials used for averaging being 345, 128, and 131 for pictographs, Chinese characters, and objects, respectively. The continuous EEG data were segmented into epochs from 200 ms prestimulus until 600 ms poststimulus. The 200-ms prestimulus served as the baseline, which had been subtracted out before grand average. Averaged waveforms were filtered with a low-pass filter of 30 Hz (zero-phase, 12 dB/octave). The grand average was obtained by averaging across subjects' averages separately for each type of stimuli. Scalp topographies were visualized with EEGLAB (http://sccn.ucsd.edu/eeglab/).

### *P100 and N170 Quantification and Statistical Analysis*

Based on previous research, we focused on the two typical components (P100 and N170) of the posterior hemispheres that occurred within the first 200 ms. Peak latency values of N170 (peaking around 160 ms) were extracted automatically at the maximum (negative) amplitude value between 130 and 190 ms at the occipito-temporal electrode sites in the left and right hemispheres (PO7 and PO8), where the component peaked maximally in all conditions and were suggested as the source of N170 in previous studies (Bentin et al., 1999; Brem et al., 2006; Maurer, Brandeis, et al., 2005). Because the preceding positivity (P100, peaking around 100 ms) also peaked maximally at these sites (PO7 and PO8), the peak latency value of P100 was also extracted (70–130 ms) at these sites as well at the occipital sites (O1 and O2), which were regarded as the source of P100 (Brem et al., 2006; Itier & Taylor, 2002; Rossion et al., 2003).

Two separate sets of repeated-measures analyses of variance (ANOVAs) were conducted to examine (a) the effects of Category (Chinese characters, objects, and pictographs) $\times$ Hemisphere and (b) the effects of Character Likeness (three levels according to the averaged evaluations of the pictographs) $\times$ Hemisphere on peak amplitudes and latencies of the P100 and N170. Greenhouse–Geisser adjustments were carried out. Post hoc $t$ tests were performed when necessary and considered significant at $p < .05$. To match the trials of the three categories and to avoid the adaptation effect (neural activity decreased as novel stimuli were repeated; Barton et al., 2010; Simon et al., 2006), we chose the first block of pictographs to examine the Category $\times$ Hemisphere effect. In addition, to guarantee the validity of the results, we performed the Character Likeness $\times$ Hemisphere ANOVA twice, once with the evaluation data (of character likeness) from the subjects themselves and the second time with evaluation data from the 10 independent raters.

## Results

### *Behavioral Data*

The average evaluation value of pictographs by the 10 independent raters ranged from 1.1 to 5.8. Three levels of character likeness were created based on these data: the low level of 1.1 to 2.8 (mean = 1.8), the medium level of 2.8 to 4.3 (mean = 3.4), and the high level of 4.3 to 5.8 (mean = 5.1). Mean ratings by the subjects themselves ranged from 2.1 to 5.3, with mean values for the three character-likeness levels being 2.6, 3.5, and 4.3, respectively. The Cronbach's $\alpha$s for the evaluations by subjects themselves and the independent sample were 0.88 and 0.77, respectively. The correlation of the character-likeness ratings between independent raters and subjects was .82 ($p < .001$).

The accuracy rates of the target trials were high (89.7%, 92.2%, and 97.5% for the three blocks of pictographs, 98.4% for objects, and 96.7% for characters), indicating that subjects were attending to the stimuli in the ERP experiment.

### *ERP Data*

*P100 and N170 amplitudes*. For P100, no effects were significant at the sites of O1 and O2, perhaps due to the weak signals at these two sites. We then focused on the sites of PO7 and PO8. The analysis of Category × Hemisphere effects revealed a marginally significant main effect of category, $F(2,38) = 3.086$, $p = .066$, due to a larger P100 for objects as compared to characters ($p < .01$). No significant differences were observed between characters and pictographs or between pictographs and objects. The main effect of hemisphere and its interaction with category were not significant. For the analysis on Character Likeness × Hemisphere effects, no main or interactive effects were significant, regardless of whether character likeness was based on the subjects' own evaluations or those by the independent sample.

In terms of N170, the analysis of Category × Hemisphere effects revealed significant main effect of category, $F(2,38) = 9.484$, $p < .001$, and interaction between category and hemisphere, $F(2,38) = 4.918$, $p < .05$. Further simple effects analysis showed that the effect of category was significant only in the left hemisphere ($p < .001$), due to a larger N170 elicited by characters than pictographs ($p < .001$) and objects ($p < .001$) and a stronger N170 for pictographs than objects ($p < .05$). A marginally significant effect of hemisphere was observed only in the category of objects with a stronger N170 elicited by PO8 than PO7 ($p = .073$). For the analysis of Character Likeness × Hemisphere effects, there was a main effect of character likeness based on the evaluation data from the independent sample, $F(2,38) = 5.583$, $p < .01$: A larger N170 was elicited by the high level of character likeness as compared to the low ($p < .05$) and medium levels ($p < .01$). Based on the evaluation data by subjects themselves, there was a marginally significant effect of character likeness, $F(2,38) = 5.583$, $p = .064$, with a larger N170 for the high level of character likeness as compared to the low level ($p = .079$) and the medium level ($p < .05$). There were neither significant main effects of hemisphere nor its interaction with character likeness, regardless of whether character likeness was based on the subjects' own evaluations or those by the independent sample.

*P100 and N170 latencies*. For P100, there were few significant effects. At the sites of O1 and O2, only a marginally significant main effect of hemisphere (slightly shorter latency at O2 than O1) was observed for the analysis of Character Likeness × Hemisphere based on subjects' own evaluations. At the sites of PO7 and PO8, based on the subjects' evaluation data, there was a significant effect of hemisphere (shorter latency at the site of PO8 than PO7) for the low level of character likeness ($p < .01$) due to a significant interaction effect between character likeness and hemisphere ($p < .05$). No other main or interactive effects were significant.

In terms of N170, the analysis of Category × Hemisphere effects revealed no significant effects. For the analysis of Character Likeness × Hemisphere, results showed a marginally significant main effect of character likeness as evaluated by the independent sample, $F(2,38) = 3.232$, $p = .059$, with shorter latency for the high level than for the low and medium levels of character likeness ($p < .05$ in both comparisons). No significant effects of hemisphere or two-way interaction were observed. In addition, the main effect of character likeness was also marginally significant when we used evaluation data of subjects themselves, $F(2,38) = 2.558$, $p = .113$, due to marginally shorter latencies for the high level as compared to the low level of character likeness ($p = .098$). However, this effect was qualified by a marginally significant interaction effect ($p = .094$) in that the effect of character likeness was marginally significant only in the left hemisphere ($p = .052$). The main effect of hemisphere was not significant when we used subjects' own evaluations of character likeness.

### *Summary of the Results*

The main results are illustrated in Figures 2 to 6. In terms of the amplitudes, results showed category differences for both P100 and N170. As shown in Figure 3, characters elicited a smaller P100 than did objects. In terms of the N170, characters elicted a larger amplitude than did pictographs, which in turn elicited a larger N170 amplitude than did objects. The category effect of N170 existed only in the left hemisphere. Character likeness (as assessed by either subjects or an independent sample) did not influence the amplitudes of P100, but affected N170 (the more character likeness, the stronger N170; Figures 4 to 6).

In terms of latencies, results showed no category differences for either P100 or N170. The effect of hemisphere was evident only for P100, with shorter latencies in the right hemisphere than in the left hemisphere of the low level of character likeness based on evaluation data from subjects themselves (Figures 4a and 5). Character likeness had no effect on P100 latencies, but affected N170 latencies (i.e., greater character likeness based on the evaluations by either subjects themselves or an independent sample led to shorter latencies; Figures 4 to 6).

## Discussion

The main goal of the present study was to examine the effect of character likeness on early potentials. The results contributed to our understandings of early electrophysiological responses to visual stimuli in several ways. First, unlike many previous

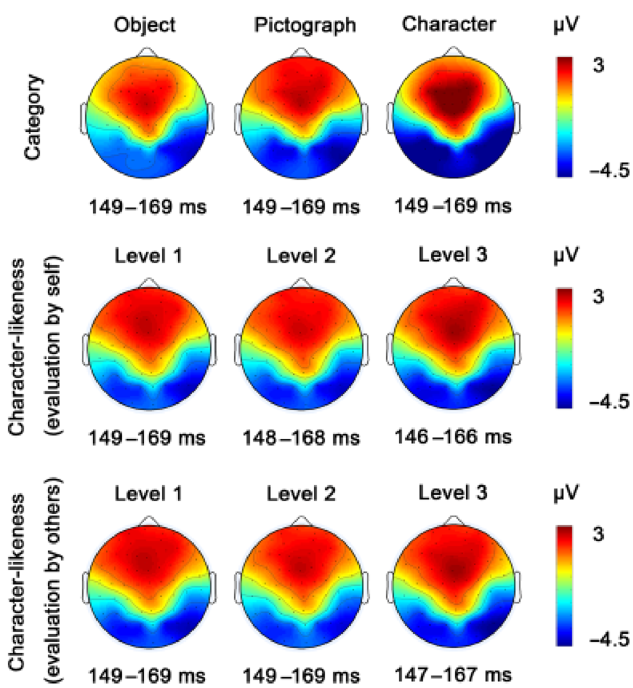


**Figure 2.** Topographic distribution of N170 response over a time window of ± 10 ms around the peak of N170 for different conditions.

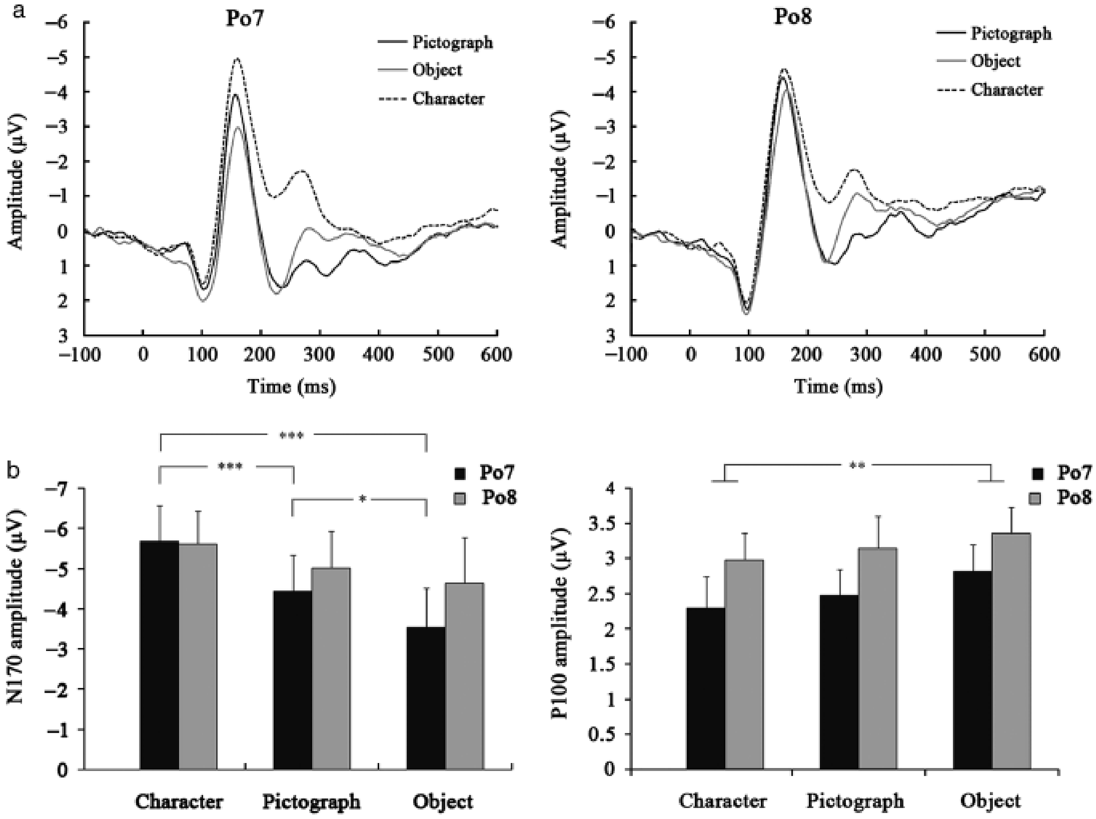


**Figure 3.** Grand average ERPs (a) and peak amplitudes (b) for the three categories of stimuli at the left and right occipito-temporal sites (PO7 and PO8). *$p < .05$, **$p < .01$, ***$p < .001$.

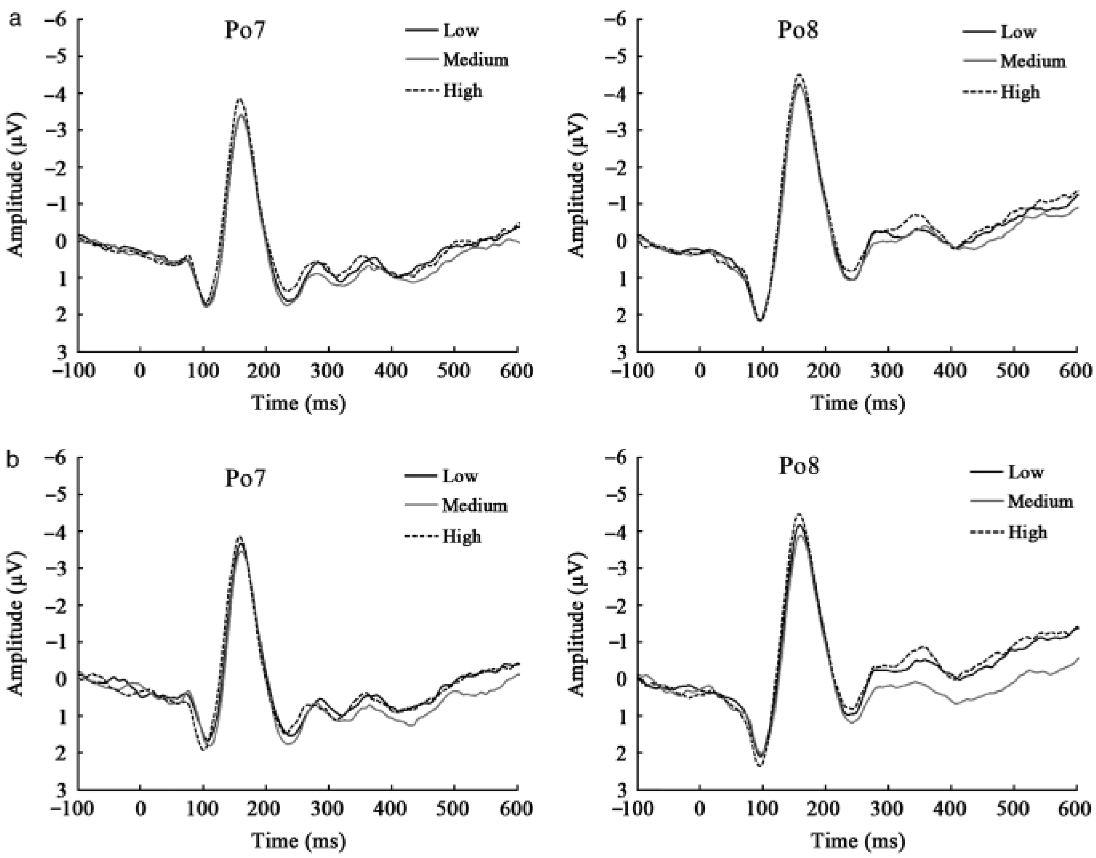


**Figure 4.** Grand average ERPs for the three levels of character likeness based on participants' own evaluations (a) and the evaluations by an independent sample (b).

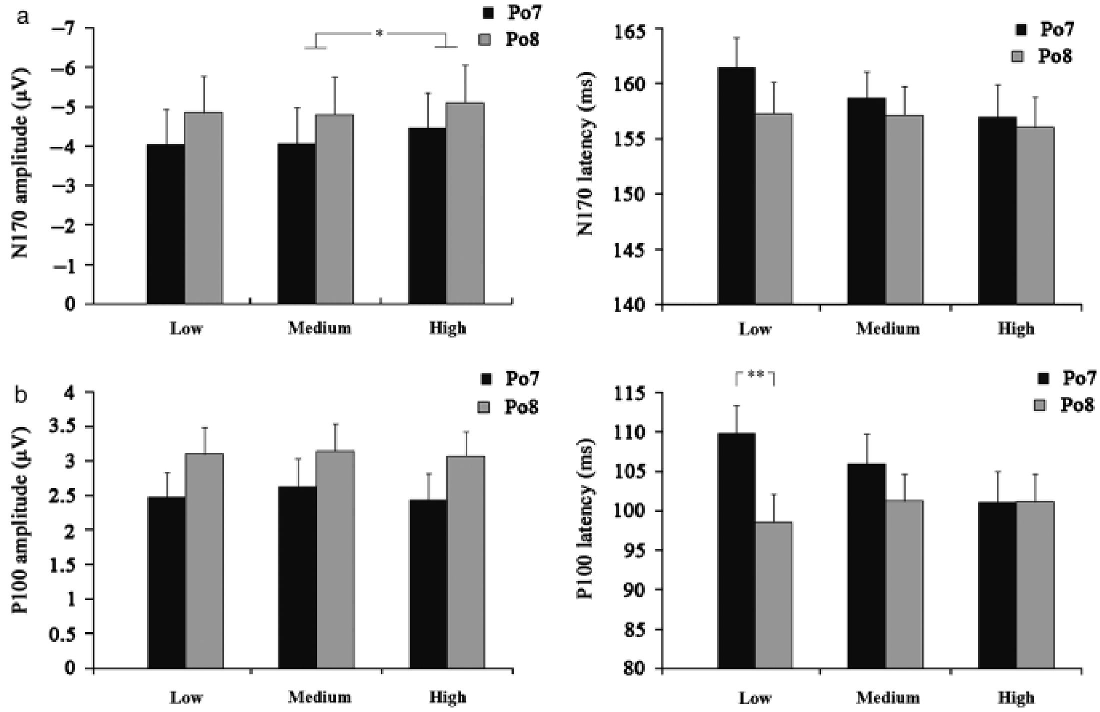


**Figure 5.** Peak amplitudes and latencies of N170 (a) and P100 (b) for the three levels of character likeness based on the participants' own evaluations (PO7 and PO8). $^*p<.05$, $^{**}p<.01$, $^{***}p<.001$.

studies that relied on words and pseudowords (both of which contain letters that can elicit N170), this is the first study to adopt character-like stimuli that are novel (in terms of both characters as a whole and their components) and have no linguistic information such as phonology or semantics. We found significant differences in the amplitudes of N170 elicited by those stimuli as compared to the amplitudes of N170 elicited by words and objects. Second, we further relied on variations in character like-

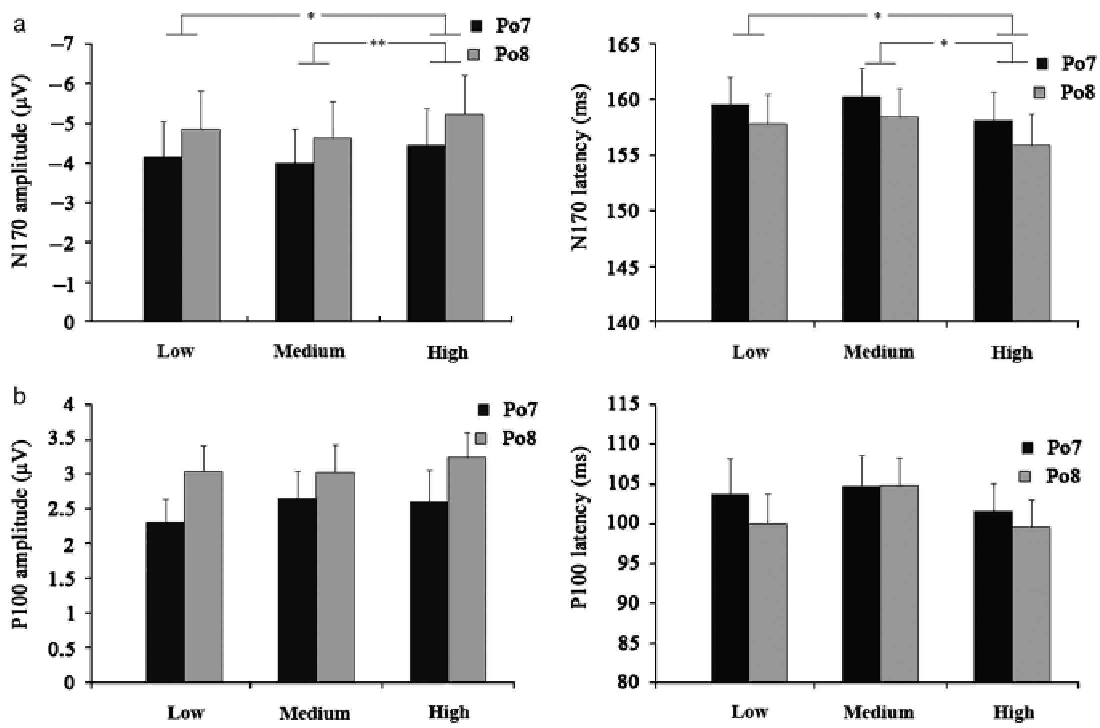


**Figure 6.** Peak amplitudes and latencies of N170 (a) and P100 (b) for the three levels of character likeness based on evaluations by an independent sample (PO7 and PO8). $^*p<.05$, $^{**}p<.01$, $^{***}p<.001$.

ness of these novel pictographs and found that greater character likeness elicited larger amplitudes and shorter latencies of N170. Another strength of the present study was that the evaluations of character likeness were made not only by the subjects themselves but also by an independent sample. The results were consistent across both sets of evaluation data, indicating that the N170 may not be modulated by subjective sensation alone (Sergent, Baillet, & Dehaene, 2005).

In the following paragraphs, we first discuss the category (characters, pictographs, and objects) effects on electrophysiological response patterns. We then focus on the neural responses to the pictographs based on the three levels of character likeness. Finally, we discuss the implications of our results to N170 response patterns and visual word recognition.

### *Early Electrophysiological Response Pattern to Characters, Pictographs, and Objects*

Consistent with previous studies of visual stimulus recognition (Brem et al., 2006; Jacques & Rossion, 2007; Rossion, Kung, & Tarr, 2004; Wong et al., 2005), a positive P100 followed by a negative N170 was evoked around the occipito-temporal area by all three kinds of stimuli used in the present study. In terms of P100, we found a larger amplitude elicited by objects than those by words, but we found no latency differences among the three categories of stimuli. Many previous studies that focused on this component also showed a smaller P100 of words than other objects (Brem et al., 2006; Rossion et al., 2003). As this component is correlated with physical but not category information (Jemel et al., 2003; Tanskanen, Nasanen, Montez, Paallysaho, & Hari, 2005), this early amplitude effect was suggested to be related to low-level physical-feature differences (Halgren et al., 2000; Itier & Taylor, 2002; Jacques & Rossion, 2007; Wydell et al., 2003). Objects are believed to involve more detailed local feature analysis than are words (Han, Liu, Yund, & Woods, 2000). Interestingly, no significant differences in P100 amplitude were observed between pictographs and the other two categories, perhaps suggesting that the physical features of pictographs and the other two categories of stimuli were similar enough so as not to evoke different P100 amplitudes.

More important evidence came from the response pattern of N170. First, we found that the amplitudes of N170 were strongest in response to words, and that character-like pictographs elicited a slightly larger N170 than did objects. As a word-specific component, N170 has been observed in many studies to show a stronger response to words than to objects (Bentin et al., 1999; Maurer, Brem, Bucher, & Brandeis, 2005; Maurer et al., 2006), false fonts (Eulitz et al., 2000), or symbols (Maurer, Brandeis, et al., 2005; Maurer, Brem, et al., 2005; Maurer et al., 2006). This specificity probably reflects neural specialization for linguistic versus nonlinguistic properties shaped by reading experience. Our study documented that N170 also responded to pictographs. These stimuli are different from nonwords (consonant strings) and pseudo-words used in previous studies (Bentin et al., 1999; Martin et al., 2006; Wydell et al., 2003) because these unfamiliar pictographs do not contain any linguistic information. They are also different from false fonts or symbols because of their character-like shapes.

Second, the amplitude difference of N170 occurred only at the left hemisphere. Notably, Chinese characters were found to elicit bilateral N170 in the present study, which was consistent with results of several previous studies focusing on Chinese and other logographic scripts (e.g., Japanese; Kim, Yoon, & Park, 2004; Koyama, Kakigi, Hoshiyama, & Kitamura, 1998). This was in contrast with the typical left lateralization of N170 for alphabetic scripts (Maurer, Brandeis, et al., 2005; Proverbio, Cok, & Zani, 2002; Rossion et al., 2003). Not all studies, however, showed consistent results. For example, Wong et al. (2005) reported a left-lateralized response for Chinese words. In another study, native Japanese speakers showed a left-lateralized response, whereas monolingual English speakers showed a bilateral N170 to three types of Japanese scripts (logographic Kanji characters and syllabic scripts hiragana and katakana), suggesting a possible role of familiarity of visual words in lateralization (Maurer, Zevin, et al., 2008). Similar to Chinese characters, pictographs elicited bilateral N170. We also observed a tendency of right-lateral N170 for objects. Previous studies have not shown consistent results on the lateralization of N170 for objects, which might have been caused by differences in materials. For example, Rossion et al. (2003) found bilateral N170 for objects (cars), whereas some other studies reported right lateralization of N170 for objects (chairs and houses; Boutsen, Humphreys, Praamstra, & Warbrick, 2006; Itier, Latinus, & Taylor, 2006).

In summary, the evidence from the early electrophysiological responses to three categories of images showed dissociation between the amplitude of P100 and that of N170. This is consistent with a previous claim that P100 may reflect a neural response to low-level physical features whereas N170 probably reflects a neural response to category information (Itier & Taylor, 2002; Rossion et al., 2003).

### *Tuning of N170 to Character Likeness*

The main goal of the present study was to test whether and how character likeness would affect early electrophysiological responses. Although the comparison of ERPs elicited by the three categories provided important evidence, potential confounds were introduced because they cannot be matched in familiarity, physical properties, and linguistic information. Using variations in character likeness within the category of pictographs would allow for better control of potential confounding factors such as familiarity, complexity, and linguistic information (all pictographs are unfamiliar, meaningless, and nonpronounceable).

First, we found that the amplitude of N170, but not P100, was sensitive to character likeness, paralleling our results based on comparisons across categories of materials. This finding clarifies the nature of N170. Researchers have argued that orthographic expertise (i.e., familiarity with particular written words) is responsible for word specificity in N170 (Brem et al., 2006), but that perspective does not explain why this visual system responds differently to the same words in different fonts and why words and handwriting showed different repetition-suppression patterns in this system (Barton et al., 2010; Simon, Petit, Bernard, & Rebai, 2007). The results of our current study suggest that such expertise is not specific to (familiar) words but, rather, is generalizable to similar visual stimuli that do not have linguistic information. More importantly, the extent of generalization depended on character likeness. Just as a larger N170 was elicited by objects when viewed by experts of those objects as compared to when viewed by nonexperts (Rossion et al., 2002; Tanaka & Curran, 2001), the stronger N170 evoked by more character-like stimuli may be the result of neurons' selective response to the stimuli more similar to their expertise "prototype" formed by prior visual word experience. Moreover, some studies suggested that this stage represented "holistic perception" (Gauthier et al., 2003) and "shape analysis" processing (Pernet et al., 2003; Pernet, Celsis, & Demonet, 2005). Thus, at the stage of N170, more neurons' involvement in a higher degree of character-like stimuli may be due to the need of more elaborate holistic shape analysis. It is worth mentioning that previous studies documented the word specificity of N170 in the left hemisphere; we found the sensitivity of N170 to character likeness in both hemispheres, which indicated that the property of character likeness would not modulate the lateralization. One explanation, as mentioned earlier, is that pictographs elicited bilateral activations, which reflected the greater visuospatial analysis, because of years of experience in processing Chinese characters (a script that relies on visuospatial analysis and consequently recruits the right hemisphere; Liu, Dunlap, Fiez, & Perfetti, 2007; Tan, Laird, Li, & Fox, 2005; Tan et al., 2000).

Second, the present study found that the latencies of N170, but not P100, were also tuned to character likeness with shorter latencies to more character-like stimuli, although the results were not entirely consistent across the two hemispheres and across the two types of evaluation data of character likeness. Previous research has not paid sufficient attention to latency differences in N170, and the reported differences also appeared to be inconsistent. Some studies did not find latency differences between orthographic and nonorthographic stimuli (Bentin et al., 1999) or words and other categories (Eulitz et al., 2000) whereas others reported a shorter latency for words than letter strings (Maurer, Brem, et al., 2005) and other categories such as cars and faces (Rossion et al., 2003). Some studies even showed a shorter latency in the left hemisphere than the right hemisphere in visual word processing (Bentin et al., 1999; Wong et al., 2005). It is not clear what factors contribute to the N170 latency differences. Some researchers suggested the N170 latency was also associated with reading expertise, as supported by evidence of a shorter latency for a more familiar language than a less familiar language (Maurer, Zevin, et al., 2008). One developmental study supported this suggestion with the evidence that N170 latencies were shorter for adults than for adolescents for words but not for control stimuli (Brem et al., 2006). The current study showed faster latencies for more character-like stimuli, indicating that the property of character likeness affected both strength and speed of the neural response.

Third, the tuning of N170 amplitude and latency to character likeness was observed with the evaluation data from both subjects themselves and an independent sample. These results not only showed convergent validity of the evaluation data, but also suggested that the N170 response was not merely a result of subjective interpretations of the stimuli (Sergent et al., 2005), but was instead based on some kind of consensual "character prototype" developed by all adults. It should be noted that the stimuli with low and medium levels of character likeness did not elicit significantly different N170 responses. Many factors may have contributed to this nonsignificant finding between the two finely differentiated groups (or categories). Such factors include signal-to-noise ratio, individual differences, and task sensitivity, as well as the distribution of character likeness of the materials. Future research should, for example, increase the differentiation of character likeness of the materials.

In summary, we found dissociation between P100 and N170 (in both amplitude and latency) in response to character likeness. N170, but not P100, was tuned to character likeness, with a stronger and faster N170 response to more character-like stimuli. This finding extends previous visuo-orthographic expertise theory (McCandliss, Cohen, & Dehaene, 2003) to a generalized expertise perspective based on neuron response models, to which we now turn.

***Visual Word Recognition: Also Expertise for Character Likeness?***
Reading is an important and unique human activity. The expertise theory proposed by McCandliss et al. (2003) suggested the brain developed a specialized response to visual words as a result of years of reading those words. Previous research has localized this function to the left mid-fusiform area and linked its function to N170. This perspective remains controversial in terms of the exclusive specificity of the mid-fusiform's functions (Mei et al., 2010; Price & Devlin, 2003; Price, Winterburn, Giraud, Moore, & Noppeney, 2003; Xue, Chen, Jin, & Dong, 2006). Furthermore, it is also not clear to what specific properties of words the mid-fusiform gyrus (and N170) responds, because experimental materials used in previous studies had multiple features. One set of studies showed that its sensitivity to visual words is independent of changes in case, font, size, and location (Dehaene et al., 2001, 2004; Polk & Farah, 2002) but is dependent on orthographic regularity and GPC rules (Bentin et al., 1999; Fiebach, Friederici, Muller, & von Cramon, 2002; Hsu et al., 2009). Based on such evidence, several researchers suggested that N170's specialization was orthography (Binder, Medler, Westbury, Liebenthal, & Buchanan, 2006; Vinckier et al., 2007).

Other studies, however, showed that N170 responded to factors beyond orthography or GPC rules. Other linguistic (e.g., semantics, phonology) and nonlinguistic properties (presentation duration) of words may also shape this neural response (Goswami & Ziegler, 2006; Xue et al., 2008). In the current study, we tested the effect of character likeness on the early neural responses and found evidence of tuning of N170 to character likeness. This result has important implications to our understanding of visual word recognition.

Different from previous research that mainly focused on the orthography or the GPC rules of visual words, the current result indicates that the component of N170 is also involved in the analysis of visual stimulus' character likeness. It seems that the expertise for orthography (or GPC rules) and character likeness show a similar time course. Furthermore, N170 for character likeness was bilateral, just as was N170 for Chinese and other logographic words in this and previous studies (Liu et al., 2007; Tan et al., 2000, 2005). Both were in contrast with the left-lateralized orthographic and GPC effects on N170 based on alphabetic languages (Bentin et al., 1999; Binder et al., 2006; Simon et al., 2006; Vinckier et al., 2007).

***Conclusion***
Visual word recognition is a very important stage for reading and is modulated by many factors. Most previous studies emphasized the influence of orthographic information (especially the GPC rules) on the word-specific ERP component N170. Our study used a special kind of material (unfamiliar pictographs) varying continuously in their degree of character likeness and found that these stimuli elicited a weaker N170 than Chinese characters but a stronger N170 than objects. More importantly, the results showed a faster and stronger N170 response to those pictographs with a higher degree of character likeness. This result suggests that N170 (and associated neural functions) tuned by visual words has a generalized sensitivity to unfamiliar stimuli that show similarity to characters.

## REFERENCES


Barton, J. J., Fox, C. J., Sekunova, A., & Iaria, G. (2010). Encoding in the visual word form area: An fMRI adaptation study of words versus handwriting. *Journal of Cognitive Neuroscience*, *22*, 1649–1661.

Bentin, S., Mouchetant-Rostaing, Y., Giard, M. H., Echallier, J. F., & Pernier, J. (1999). ERP manifestations of processing printed words at different psycholinguistic levels: Time course and scalp distribution. *Journal of Cognitive Neuroscience*, *11*, 235–260.

Binder, J. R., Medler, D. A., Westbury, C. F., Liebenthal, E., & Buchanan, L. (2006). Tuning of the human left fusiform gyrus to sublexical orthographic structure. *NeuroImage*, *33*, 739–748.

Boutsen, L., Humphreys, G. W., Praamstra, P., & Warbrick, T. (2006). Comparing neural correlates of configural processing in faces and objects: An ERP study of the Thatcher illusion. *NeuroImage*, *32*, 352–367.

Brem, S., Bucher, K., Halder, P., Summers, P., Dietrich, T., Martin, E., et al. (2006). Evidence for developmental changes in the visual word processing network beyond adolescence. *NeuroImage*, *29*, 822–837.

Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J. B., Le Bihan, D., et al. (2004). Letter binding and invariant recognition of masked words: Behavioral and neuroimaging evidence. *Psychological Science*, *15*, 307–313.

Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J. F., Poline, J. B., et al. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience*, *4*, 752–758.

Eulitz, C., Eulitz, H., Maess, B., Cohen, R., Pantev, C., & Elbert, T. (2000). Magnetic brain activity evoked and induced by visually presented words and nonverbal stimuli. *Psychophysiology*, *37*, 447–455.

Fiebach, C. J., Friederici, A. D., Muller, K., & von Cramon, D. Y. (2002). fMRI evidence for dual routes to the mental lexicon in visual word recognition. *Journal of Cognitive Neuroscience*, *14*, 11–23.

Gauthier, I., Curran, T., Curby, K. M., & Collins, D. (2003). Perceptual interference supports a non-modular account of face processing. *Nature Neuroscience*, *6*, 428–432.

Goswami, U., & Ziegler, J. C. (2006). A developmental perspective on the neural code for written words. *Trends in Cognitive Sciences*, *10*, 142–143.

Grill-Spector, K., & Witthoft, N. (2009). Deos the bairn not raed ervey lteter by istlef, but the wrod as a wlohe? *Neuron*, *62*, 161–162.

Halgren, E., Raij, T., Marinkovic, K., Jousmaki, V., & Hari, R. (2000). Cognitive response profile of the human fusiform face area as determined by MEG. *Cerebral Cortex*, *10*, 69–81.

Han, S., Liu, W., Yund, E. W., & Woods, D. L. (2000). Interactions between spatial attention and global/local feature selection: An ERP study. *NeuroReport*, *11*, 2753–2758.

Hegde, J., & Van Essen, D. C. (2000). Selectivity for complex shapes in primate visual area V2. *Journal of Neuroscience*, *20*, RC61.

Hsu, C. H., Tsai, J. L., Lee, C. Y., & Tzeng, O. J. (2009). Orthographic combinability and phonological consistency effects in reading Chinese phonograms: An event-related potential study. *Brain and Language*, *108*, 56–66.

Itier, R. J., Latinus, M., & Taylor, M. J. (2006). Face, eye and object early processing: What is the face specificity? *NeuroImage*, *29*, 667–676.

Itier, R. J., & Taylor, M. J. (2002). Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *NeuroImage*, *15*, 353–372.

Jacques, C., & Rossion, B. (2007). Early electrophysiological responses to multiple face orientations correlate with individual discrimination performance in humans. *NeuroImage*, *36*, 863–876.

Jemel, B., Schuller, A. M., Cheref-Khan, Y., Goffaux, V., Crommelinck, M., & Bruyer, R. (2003). Stepwise emergence of the face-sensitive N170 event-related potential component. *NeuroReport*, *14*, 2035–2039.

Kim, K. H., Yoon, H. W., & Park, H. W. (2004). Spatiotemporal brain activation pattern during word/picture perception by native Koreans. *NeuroReport*, *15*, 1099–1103.

Koyama, S., Kakigi, R., Hoshiyama, M., & Kitamura, Y. (1998). Reading of Japanese Kanji (morphograms) and Kana (syllabograms): A magnetoencephalographic study. *Neuropsychologia*, *36*, 83–98.

Lehmann, D., & Skrandies, W. (1980). Reference-free identification of components of checkerboard-evoked multichannel potential fields. *Electroencephalography and Clinical Neurophysiology*, *48*, 609–621.

Liu, Y., Dunlap, S., Fiez, J., & Perfetti, C. (2007). Evidence for neural accommodation to a writing system following learning. *Human Brain Mapping*, *28*, 1223–1234.

Liu, Y., & Perfetti, C. A. (2003). The time course of brain activity in reading English and Chinese: An ERP study of Chinese bilinguals. *Human Brain Mapping*, *18*, 167–175.

Majaj, N. J., Pelli, D. G., Kurshan, P., & Palomares, M. (2002). The role of spatial frequency channels in letter identification. *Vision Research*, *42*, 1165–1184.

Martin, C. D., Nazir, T., Thierry, G., Paulignan, Y., & Demonet, J. F. (2006). Perceptual and lexical effects in letter identification: An event-related potential study of the word superiority effect. *Brain Research*, *1098*, 153–160.

Maurer, U., Brandeis, D., & McCandliss, B. D. (2005). Fast, visual specialization for reading in English revealed by the topography of the N170 ERP response. *Behavioral and Brain Functions*, *1*, 13.

Maurer, U., Brem, S., Bucher, K., & Brandeis, D. (2005). Emerging neurophysiological specialization for letter strings. *Journal of Cognitive Neuroscience*, *17*, 1532–1552.

Maurer, U., Brem, S., Kranz, F., Bucher, K., Benz, R., Halder, P., et al. (2006). Coarse neural tuning for print peaks when children learn to read. *NeuroImage*, *33*, 749–758.

Maurer, U., Rossion, B., & McCandliss, B. D. (2008). Category specificity in early perception: Face and word N170 responses differ in both lateralization and habituation properties. *Frontiers in Human Neuroscience*, *2*, 18.

Maurer, U., Zevin, J. D., & McCandliss, B. D. (2008). Left-lateralized N170 effects of visual expertise in reading: Evidence from Japanese syllabic and logographic scripts. *Journal of Cognitive Neuroscience*, *20*, 1878–1891.

McCandliss, B. D., Cohen, L., & Dehaene, S. (2003). The visual word form area: Expertise for reading in the fusiform gyrus. *Trends in Cognitive Sciences*, *7*, 293–299.

Mei, L., Xue, G., Chen, C., Xue, F., Zhang, M., & Dong, Q. (2010). The "visual word form area" is involved in successful memory encoding of both words and faces. *NeuroImage*, *52*, 371–378.

Mercure, E., Dick, F., Halit, H., Kaufman, J., & Johnson, M. H. (2008). Differential lateralization for words and faces: Category or psychophysics? *Journal of Cognitive Neuroscience*, *20*, 2070–2087.

Montalan, B., Caharel, S., Personnaz, B., Le Dantec, C., Germain, R., Bernard, C., et al. (2008). Sensitivity of N170 and late positive components to social categorization and emotional valence. *Brain Research*, *1233*, 120–128.

Palmeri, T. J., Wong, A. C., & Gauthier, I. (2004). Computational approaches to the development of perceptual expertise. *Trends in Cognitive Sciences*, *8*, 378–386.

Pernet, C., Basan, S., Doyon, B., Cardebat, D., Demonet, J. F., & Celsis, P. (2003). Neural timing of visual implicit categorization. *Brain Research. Cognitive Brain Research*, *17*, 327–338.

Pernet, C., Celsis, P., & Demonet, J. F. (2005). Selective response to letter categorization within the left fusiform gyrus. *NeuroImage*, *28*, 738–744.

Polk, T. A., & Farah, M. J. (2002). Functional MRI evidence for an abstract, not perceptual, word-form area. *Journal of Experimental Psychology. General*, *131*, 65–72.

Price, C. J., & Devlin, J. T. (2003). The myth of the visual word form area. *NeuroImage*, *19*, 473–481.

Price, C. J., Winterburn, D., Giraud, A. L., Moore, C. J., & Noppeney, U. (2003). Cortical localisation of the visual and auditory word form areas: A reconsideration of the evidence. *Brain and Language*, *86*, 272–286.

Proverbio, A. M., Cok, B., & Zani, A. (2002). Electrophysiological measures of language processing in bilinguals. *Journal of Cognitive Neuroscience*, *14*, 994–1017.

Pylkkanen, L., & Marantz, A. (2003). Tracking the time course of word recognition with MEG. *Trends in Cognitive Sciences*, *7*, 187–189.

Riesenhuber, M., & Poggio, T. (2002). Neural mechanisms of object recognition. *Current Opinion in Neurobiology*, *12*, 162–168.

Rossion, B., Gauthier, I., Goffaux, V., Tarr, M. J., & Crommelinck, M. (2002). Expertise training with novel objects leads to left-lateralized facelike electrophysiological responses. *Psychological Science*, *13*, 250–257.

Rossion, B., Joyce, C. A., Cottrell, G. W., & Tarr, M. J. (2003). Early lateralization and orientation tuning for face, word, and object processing in the visual cortex. *NeuroImage*, *20*, 1609–1624.

Rossion, B., Kung, C. C., & Tarr, M. J. (2004). Visual expertise with nonface objects leads to competition with the early perceptual

processing of faces in the human occipitotemporal cortex. *Proceedings of the National Academy of Sciences, USA*, *101*, 14521–14526.
Scott, L. S., Tanaka, J. W., Sheinberg, D. L., & Curran, T. (2006). A reevaluation of the electrophysiological correlates of expert object processing. *Journal of Cognitive Neuroscience*, *18*, 1453–1465.
Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature Neuroscience*, *8*, 1391–1400.
Simon, G., Bernard, C., Lalonde, R., & Rebai, M. (2006). Orthographic transparency and grapheme–phoneme conversion: An ERP study in Arabic and French readers. *Brain Research*, *1104*, 141–152.
Simon, G., Bernard, C., Largy, P., Lalonde, R., & Rebai, M. (2004). Chronometry of visual word recognition during passive and lexical decision tasks: An ERP investigation. *International Journal of Neuroscience*, *114*, 1401–1432.
Simon, G., Petit, L., Bernard, C., & Rebai, M. (2007). N170 ERPs could represent a logographic processing strategy in visual word recognition. *Behavioral and Brain Functions*, *3*, 21.
Tan, L. H., Laird, A. R., Li, K., & Fox, P. T. (2005). Neuroanatomical correlates of phonological processing of Chinese characters and alphabetic words: A meta-analysis. *Human Brain Mapping*, *25*, 83–91.
Tan, L. H., Spinks, J. A., Gao, J. H., Liu, H. L., Perfetti, C. A., Xiong, J., et al. (2000). Brain activation in the processing of Chinese characters and words: A functional MRI study. *Human Brain Mapping*, *10*, 16–27.
Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science*, *12*, 43–47.
Tanskanen, T., Nasanen, R., Montez, T., Paallysaho, J., & Hari, R. (2005). Face recognition and cortical responses show similar sensitivity to noise spatial frequency. *Cerebral Cortex*, *15*, 526–534.
Tsunoda, K., Yamane, Y., Nishizaki, M., & Tanifuji, M. (2001). Complex objects are represented in macaque inferotemporal cortex by the combination of feature columns. *Nature Neuroscience*, *4*, 832–838.
Vinckier, F., Dehaene, S., Jobert, A., Dubus, J. P., Sigman, M., & Cohen, L. (2007). Hierarchical coding of letter strings in the ventral stream: Dissecting the inner organization of the visual word-form system. *Neuron*, *55*, 143–156.
Wang, Y., Xue, G., Chen, C., Xue, F., & Dong, Q. (2007). Neural bases of asymmetric language switching in second-language learners: An ER-fMRI study. *NeuroImage*, *35*, 862–870.
Wong, A. C., Gauthier, I., Woroch, B., DeBuse, C., & Curran, T. (2005). An early electrophysiological response associated with expertise in letter perception. *Cognitive, Affective and Behavioral Neuroscience*, *5*, 306–318.
Wydell, T. N., Vuorinen, T., Helenius, P., & Salmelin, R. (2003). Neural correlates of letter-string length and lexicality during reading in a regular orthography. *Journal of Cognitive Neuroscience*, *15*, 1052–1062.
Xue, G., Chen, C., Jin, Z., & Dong, Q. (2006). Language experience shapes fusiform activation when processing a logographic artificial language: An fMRI training study. *NeuroImage*, *31*, 1315–1326.
Xue, G., Jiang, T., Chen, C., & Dong, Q. (2008). Language experience shapes early electrophysiological responses to visual stimuli: The effects of writing system, stimulus length, and presentation duration. *NeuroImage*, *39*, 2025–2037.
Zhang, J. Y., Zhang, T., Xue, F., Liu, L., & Yu, C. (2007). Legibility variations of Chinese characters and implications for visual acuity measurement in Chinese reading population. *Investigative Ophthalmology and Visual Science*, *48*, 2383–2390.

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