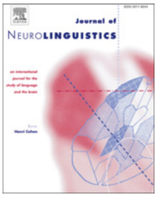
Journal of Neurolinguistics 23 (2010) 416–426

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling



Cultural background influences the liminal perception of Chinese characters: An ERP study

Gang Peng [a,b,*], James W. Minett [a], William S.-Y. Wang [a]

[a] *Language Engineering Laboratory, Department of Electronic Engineering, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong*
[b] *State Key Laboratory of Brain and Cognitive Sciences, The University of Hong Kong, Hong Kong*

A R T I C L E   I N F O

Article history:
Received 4 November 2009
Received in revised form 15 March 2010
Accepted 15 March 2010

Keywords:
ERP
P300
Context updating
Chinese characters
Cultural difference
Liminal perception

A B S T R A C T

The event-related brain potentials elicited by rapid visual presentation of Chinese characters and non-characters were studied for two groups of adult native Chinese speakers: one group of Putonghua speakers, who could read Simplified Chinese characters, and one group of Hong Kong Cantonese speakers, who could read Traditional Chinese characters. For Putonghua participants, but not Hong Kong Cantonese participants, liminally perceived characters were found to elicit significantly greater P300 amplitude than non-characters. Based on the context updating hypothesis, this result indicates that Putonghua participants discriminated stimuli according to their linguistic function (character versus non-character) more easily than Hong Kong Cantonese participants. Putonghua participants were also better able to discriminate characters based on their physical properties (high symmetry character versus low symmetry character). These findings are consistent with the hypothesis that Simplified character readers have greater visual discrimination skill than Traditional character readers. The results also provide the first evidence that cultural background shapes sensitivity in the liminal perception of Chinese characters, an important step toward a general theory of the cognitive processes involved in reading.

* Corresponding author. Language Engineering Laboratory, Department of Electronic Engineering, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong. Tel.: +852 3163 4346; fax: +852 2603 5558.

E-mail addresses: gpeng@ee.cuhk.edu.hk (G. Peng), jminett@ee.cuhk.edu.hk (J.W. Minett), wsywang@ee.cuhk.edu.hk (W.S.-Y. Wang).

0911-6044/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jneuroling.2010.03.004

1. Introduction

Written language makes use of graphemes to encode the corresponding spoken language (Daniels & Bright, 1996). In most cases, languages that differ significantly in their spoken forms also differ significantly in their corresponding written forms. However, the languages of the Sinitic (Chinese) family are unusual in that, although many of them are mutually unintelligible (Cheng, 1996; Tang & van Heuven, 2009), they share essentially the same written language (albeit with two character sets and some lexical differences). Written Chinese uses a logographic script that consists of thousands of characters, each comprising a hierarchical arrangement of strokes (Wang, 1973). Two character sets are commonly used in written Chinese: Traditional characters, which were previously used throughout China, but which are now used in Hong Kong, Macau, Taiwan, and some other Chinese-speaking communities around the world, and Simplified characters, which were adopted in Mainland China in 1956, and are now also used in Singapore and Malaysia. The Simplified characters were designed with fewer strokes than their Traditional counterparts with the aim of making the task of learning the written language easier (Wang, 1973). The two character sets nevertheless share a subset of characters that have identical forms in each set, and which are therefore familiar to all literate Chinese individuals.

In Mainland China, Putonghua (abbreviated here as PTH; i.e., Modern Standard Chinese, also often referred to as Mandarin) is the official language, with Simplified characters as its writing system. From kindergarten, children are taught the pronunciations of characters using the *Pinyin* phonemic coding system (McBride-Chang, Chow, Zhong, Burgess, & Hayward, 2005). PTH is used as the medium of instruction for schooling at all levels except in a few outlying regions where the medium of instruction is the local dialect. In contrast, in Hong Kong, the ‘mother tongue’ is Cantonese (abbreviated here as HKC); Traditional Chinese characters are used for its writing system. Children are typically taught to read characters by rote memorization, with no instruction given using a phonemic coding system, such as *Pinyin*, to aid pronunciation (McBride-Chang et al., 2005). The medium of instruction used in most primary schools is HKC. The medium of instruction adopted in secondary schools, however, has varied. Hong Kong was a British colony for 155 years until its sovereignty returned to China in 1997. Before the return of sovereignty, English was used as the medium of instruction during secondary schooling (Pierson, 1994). Since then, most secondary schools have adopted ‘mother tongue’ instruction in HKC, although English continues to be used as the medium of instruction in about twenty percent of secondary schools (Lai, 2005). Table 1 summarizes the main sociolinguistic differences between native PTH and HKC speakers.

Reading Chinese characters, as well as other logographic scripts, requires a greater involvement of visual processing and memory than does reading alphabetic scripts (Tzeng & Wang, 1983). As a number of studies with child participants have shown, visual processing is a vital component in learning to read Chinese characters proficiently. For example, Huang and Hanley (1994) observed that performance in two tests of visual skill provided a better predictor of Chinese reading ability than did performance in two tests of phonological awareness, both for eight- and nine-year-old HKC-speaking children in Hong Kong and for similarly aged Mandarin-speaking children in Taiwan. In contrast, for eight-year-old English-speaking children in Britain, performance in the phonological tests provided the better predictor of English reading ability. Later, Ho and Bryant (1997) found that performance in the Frostig

Table 1
Sociolinguistic differences between native Putonghua and Hong Kong Cantonese speakers.

	Mother tongue	Character set	Phonemic coding system	Primary school medium of instruction		Secondary school medium of instruction	
				Spoken	Written	Spoken	Written
PTH speakers	Putonghua	Simplified	*Pinyin*	Putonghua	Chinese	Putonghua	Chinese
HKC speakers	Cantonese	Traditional	None[a]	Cantonese	Chinese	Cantonese; some English	Chinese; some English

[a] Note that a phonemic coding system – *The Linguistic Society of Hong Kong Romanization Scheme*, more commonly known as *Jyutping* – for Hong Kong Cantonese does exist, but it is not in widespread use (Lun, S. C. (2008). The road of Jyutping (Cantonese Romanization) in Hong Kong and its social implications and applications. *Sociolinguistics Symposium: Micro and Macro Connections*, Amsterdam, The Netherlands, 3–5 April, 2008).

Developmental Test of Visual Perception (Frostig, Lefever, & Whittlesey, 1963) by three-year-old pre-literate HKC-speaking children significantly predicted subsequent reading ability, emphasizing the importance of visual processing during the initial stages of learning to read Chinese.

McBride-Chang et al. (2005) have since conducted an inter-cultural, longitudinal study in which they contrasted the reading abilities, phonological awareness, and visual skills of two groups of five-year-old Chinese-speaking children: HKC-speaking children in Hong Kong and PTH-speaking children in Xiangtan, Hunan Province, China. Among other results, they found that the PTH group performed significantly better than the HKC group in two tests of visual skill. The Visual Closure test assessed each participant's ability to recognize a visual form from a partial representation of it, a potential predictor of Chinese character recognition ability. The Visual Discrimination test assessed each participant's ability to match a visual form to one of a set of similar forms, a potential predictor of ability to distinguish visually similar characters, such as 大 and 太, which differ orthographically in terms of a single stroke. McBride-Chang et al. (2005) suggest that the visual skill group difference might be due, in part, to the different character sets that the PTH- and HKC-speaking children had learned to read. They argue that, because Simplified characters have fewer visual features by which to discriminate them than the corresponding Traditional characters, there is a greater pressure for Simplified character readers to develop stronger visual skills in order to learn to read Chinese proficiently. In other words, the different sociolinguistic backgrounds of PTH and HKC speakers – namely, their use of Simplified and Traditional characters, respectively – may give rise to behavioral differences in their perception of written Chinese. What then is the impact of such cultural difference on cognition?

Various studies have examined the impact of cultural difference on cognition by measuring the event-related brain potentials (ERPs) elicited from participants with distinct cultural backgrounds. In one line of research, ERPs were elicited from participants in response to presentation of affective images (Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Hot, Saito, Mandai, Kobayashi, & Sequeira, 2006). In the latter study, culture-modulated differences in the ERPs arose from 170 ms after stimulus onset, and were most evident for the parietal Late Positive Component (LPC) within the 255–455 ms time window. In another line of research, the ERPs elicited during music-related tasks revealed significant culture-modulated differences in the perception by musicians trained within different musical cultures (Bischoff Renninger, Granot, & Donchin, 2003) and in the perception of culturally distinct musical styles (Nan, Knösche, & Friederici, 2006) and instruments (Arikan et al., 1999; Zhu et al., 2008). Arikan et al. (1999), for example, found that music played with the *ney*, an instrument with which their Turkish participants were familiar, elicited a larger amplitude centro-parietal P300 component than similar music played on a less familiar instrument, the violincello. Similarly, Zhu et al. (2008) found that music played to Chinese participants with the *guqin*, an instrument of Chinese origin, elicited a stronger amplitude P300 in the 300–500 ms time window than piano music. The authors suggested that participants' differential responses to the *guqin* and piano might be due to the acoustical similarity of the musical tones produced by the *guqin* and the lexical tones of spoken Chinese.

Prior work on the impact of difference in cultural background on the cognitive processing of language has considered the perception of lexical tone by both tone language speakers and non tone language speakers (Xu, Gandour, & Francis, 2006), the perception of reading materials in *different* languages by participants from a *single* sociolinguistic group (Liu, Perfetti, & Wang, 2006; Xue, Jiang, Chen, & Dong, 2008), as well as the perception of reading materials in a *single* language by participants from *different* sociolinguistic groups (Proverbio, Del Zotto, & Zani, 2006). In the latter study (Proverbio et al., 2006), skilled readers (literate Greek participants) and naïve readers (monolingual Italian participants) were exposed to both written Greek words and legal pseudowords. In their analysis, the authors examined the centro-parietal P300 component, using it as an index of lexical and semantic processing as well as task difficulty, finding that its amplitude was modulated both by participants' cultural familiarity with the stimuli and, in the case of skilled readers only, the distinction between word and pseudoword stimuli.

The aforementioned studies on the impact of culture on cognition reveal modulation of late positive parietal ERP components, particularly P300, for participants having different cultural backgrounds. The P300 component (Sutton, Braren, Zubin, & John, 1965) is typically elicited by rare stimuli (deviants) randomly interspersed among frequent, categorically distinct stimuli (standards) in an oddball paradigm (Donchin, Ritter, & McCallum, 1978). According to the context updating hypothesis (Donchin, 1981; Donchin & Coles, 1988), as successive stimuli are presented, the participant builds a mental schema of stimulus context that must be updated whenever stimulus detection engages memory operations (Polich, 2007). Regardless of stimulus modality, such context updating elicits a P300 component whose amplitude is modulated by the participant's overall arousal level and the task difficulty, with greater amplitude P300 elicited by context updates that are processed more easily (Polich, 2007).

The results of McBride-Chang et al. (2005) lead us to expect that PTH-speaking children, who learn to read Simplified Chinese characters, will be better able to discriminate visually similar characters, as well as non-characters, than HKC-speaking children, who learn to read Traditional Chinese characters. Although there is evidence that visual skills become less vital for character recognition as the child learns to recognize more characters (Ho & Bryant, 1997; McBride-Chang & Chang, 1995), the stronger visual discrimination skill of Simplified character readers may persist into adulthood. Using a primed character naming experiment, Perfetti, Liu, and Tan (2005) have provided evidence that in identifying a Chinese character, graphic information is processed before either phonological information or semantic information. Thus, we predict that in the early stages of character perception, the ERPs elicited by rapid presentation of Chinese writing materials will be modulated primarily by participants' visual discrimination skill, and, therefore, that these ERPs will differ for Simplified character readers and Traditional character readers.

In the present study, we aim to assess the impact of sociolinguistic background on the ERPs elicited by rapid visual presentation of Chinese writing materials to literate adult Chinese speakers: one group of PTH-speaking participants, who read Simplified characters, and one group of HKC-speaking participants, who read Traditional characters. The Chinese writing materials that we used as stimuli consisted of characters for which the Simplified and Traditional forms were identical. Non-characters were constructed from the character stimuli either by removing a stroke or by adding a stroke. The ERPs were analyzed in terms of their functional properties (character versus non-character) and, for comparison, in terms of their physical properties (high versus low symmetry character). We sought evidence that the ERPs, particularly the P300 component, elicited by characters and non-characters would differ more for the PTH participants than for the HKC participants, consistent with the hypothesis that the stronger visual discrimination skill of Simplified character readers persists into adulthood, and reflecting the greater proficiency of the PTH participants in distinguishing characters from non-characters.

2. Materials and methods

2.1. Participants

Twenty-one native speakers of PTH and twenty-two native speakers of HKC, all students at The Chinese University of Hong Kong, were paid to participate in this study. Their written consent was obtained. All participants were right-handed, with normal or corrected-to-normal vision, and reported no history of neurological illness. Data from seven participants (3 PTH; 4 HKC) were excluded from the subsequent analysis due to the excessive number of artifacts or poor accuracy (see Section 2.4, EEG recording below, for details). The remaining thirty-six participants comprised eighteen PTH speakers (9 male; mean age = 21.3 years) and eighteen HKC speakers (9 male; mean age = 20.5 years). Approval to conduct this study was obtained from the Survey and Behavioral Research Ethics Committee of The Chinese University of Hong Kong.

2.2. Materials

Chinese characters were selected from Hong Kong, Mainland China & Taiwan: Chinese Character Frequency – A Trans-Regional, Diachronic Survey (Ho & Kwan, 2001), an online database that includes token frequencies for 4844 characters in use in the Simplified Character Set (in Mainland China) and 4628 characters in use in the Traditional Character Set (in Hong Kong). Approximately 80% of Chinese characters (Hsu, Tsai, Lee, & Tzeng, 2009), both Traditional and Simplified, are phonograms (Wang,

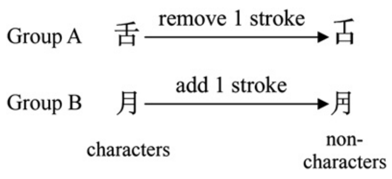


Fig. 1. Examples of characters and the non-characters with which they are paired.

1981), which have a dual structure that consists of a semantic component, indicating some aspects of meaning, and a phonetic component, indicating some aspects of pronunciation. We selected the 60 most frequent 'simple' characters – i.e., non-phonograms – that had identical form in the two character sets. Each character in the list was paired with a non-character, present in neither the Simplified nor the Traditional Character Set, constructed from the character by either removing or adding one stroke, as illustrated in Fig. 1. This method of constructing non-characters ensured that the total numbers of strokes comprising the characters and non-characters were balanced.

The character–non-character pairs formed two groups: Group A, consisting of characters with four to seven strokes (mean = 5.08 strokes) and their paired non-characters, which were constructed by removing a stroke; and Group B, consisting of characters with two to seven strokes (mean = 4.32 strokes) and their paired non-characters, which were constructed by adding a stroke. Fifty distinct pairs were used for testing, as shown in Table 2; a further ten pairs were used for practice. All fifty testing characters are in common use and familiar to literate adults. Their frequencies, averaged across the two character sets, ranged from 1.0% (the character 人) to 0.0011% (the character 乍). No significant difference in frequency distribution across the two sets of testing characters was observed (Wilcoxon signed ranks test: $Z = -0.874$, $p = .382$).

2.3. Procedure

Participants were seated in a quiet room in front of an LCD screen at a viewing distance of 80 cm. Character and non-character stimuli were rendered on-screen using the Songti font (non-characters were adapted from the characters with which they were paired), and subtended a visual angle of 1.07° H × 1.07° W (1.5 cm × 1.5 cm). The procedure for trial presentation is illustrated in Fig. 2. Each trial consisted of a cross fixation for 500 ms, followed by a 500 ms blank, and then presentation of a stimulus for 50 ms. Character and non-character stimuli were presented interspersed with irrelevant distractors ('×' or 'o'). A complex mask (shown in Fig. 2) was then presented for up to 950 ms. The short presentation time of each stimulus and the use of the mask, which reduced participants' residual perception of the stimulus, were chosen so that the stimulus was at the threshold of visibility (cf. Del Cul, Baillet, & Dehaene, 2007; Sergent, Baillet, & Dehaene, 2005) and perceived *liminally* – that is, participants were aware that a stimulus had been presented, but were unable to consciously identify the stimulus.[1] Participants were instructed to attend to the stimuli in order to judge when either of the two distractors appeared, thereby ensuring that they maintained concentration throughout the experiment. They were asked to press the left-most button on a PST Serial Response Box (supplied by Psychology Software Tools, Inc., Pittsburgh, PA, USA) when observing '×' or the right-most button when observing 'o', and to respond as quickly and as accurately as possible. Responses made after the 950 ms mask were treated as no responses. Immediately after the participant responded or the mask had been presented for 950 ms, whichever came first, a blank was presented for 2000 ms.

Each participant was presented with a practice block of 29 trials, consisting of 10 character–non-character pairs plus 9 distractors, in random order. The practice block was repeated up to eight times until the participant attained at least 80% accuracy in identifying the two distractors – all participants were able to achieve this accuracy threshold. The 100 testing symbols, consisting of 50 characters and

[1] A behavioral test on two participants confirmed that characters could not be discriminated consciously from non-characters (identification accuracy 52%).

Table 2
List of testing stimuli. Group A comprises 25 character–non-character pairs for which non-characters were constructed by removing a stroke from the paired character. Group B comprises 25 character–non-character pairs for which the non-characters were constructed by adding a stroke to the paired character.

	Group A		Group B	
	character	non-character	character	non-character
1	舌	[illegible]	人	[illegible]
2	牙	[illegible]	井	[illegible]
3	心	[illegible]	水	[illegible]
4	米	[illegible]	石	[illegible]
5	冬	[illegible]	尺	[illegible]
6	屯	[illegible]	月	[illegible]
7	民	[illegible]	田	[illegible]
8	式	[illegible]	豆	[illegible]
9	史	[illegible]	女	[illegible]
10	西	[illegible]	子	[illegible]
11	卡	[illegible]	夫	[illegible]
12	内	[illegible]	王	[illegible]
13	右	[illegible]	户	[illegible]
14	左	[illegible]	方	[illegible]
15	令	[illegible]	包	[illegible]
16	央	[illegible]	本	[illegible]
17	五	[illegible]	支	[illegible]
18	甩	[illegible]	升	[illegible]
19	立	[illegible]	上	[illegible]
20	老	[illegible]	走	[illegible]
21	吉	[illegible]	古	[illegible]
22	更	[illegible]	又	[illegible]
23	勿	[illegible]	未	[illegible]
24	且	[illegible]	全	[illegible]
25	由	[illegible]	乍	[illegible]

50 non-characters, were then presented to the participant three times in random order over the course of 12 blocks. Each block consisted of 25 testing symbols plus a random number (6–11) of distractors. No testing symbol appeared more than once in any block, and no complete pair of testing symbols (i.e., both a character and its paired non-character) appeared in any single block. Each participant was permitted a break of 1 min between blocks.

2.4. EEG recording

Electroencephalograph (EEG) data were recorded using a Net Amps 200 amplifier (Electrical Geodesics, Inc., Eugene, OR, USA), with 200 MΩ input impedance, and 128-channel Ag/AgCl electrode arrays. EEG data were recorded in NetStation 4.3 (also supplied by Electrical Geodesics, Inc.) continuously at a rate of 1000 Hz, referenced to the vertex, filtered with an analogue band-pass filter

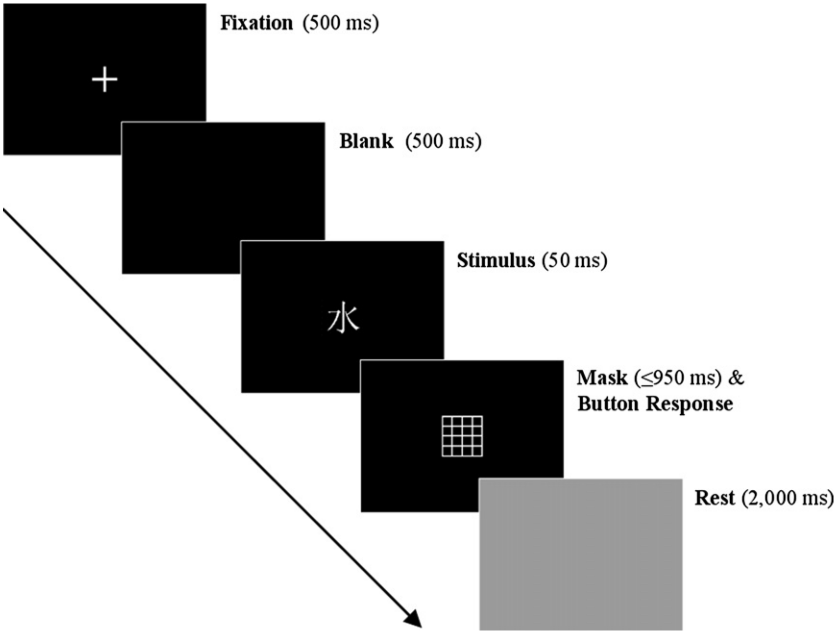


Fig. 2. Illustration of the trial presentation procedure.

(0.1–400 Hz), and digitized using a 16-bit A/D converter. The data from nine electrodes (frontal: Fz, F3, F4; central: Cz, C3, C4; parietal: Pz, P3, P4) were recomputed offline against average-mastoid reference, and low-pass filtered at 40 Hz. Electrode impedances were generally kept below 50 kΩ, considerably below the 200 kΩ threshold that Ferree, Luu, Russell, and Tucker (2001) have found to provide accurate signal acquisition (<0.1% error) from a Net Amps amplifier with 200 MΩ input impedance. Eye movements and blinks were monitored with electrodes placed on the supra- and infraorbital ridges of each eye (vertical eye movement), and near the outer canthus of each eye (horizontal eye movement).

EEG segments for critical stimuli were extracted from 100 ms before stimulus onset to 800 ms after stimulus onset. The mean voltage in the 100 ms interval prior to stimulus onset was used as the baseline in the subsequent ERP derivation. The EEG segments were subjected to artifact detection procedures provided by NetStation. Trials with ocular artifacts were excluded from averaging to ERP. Moreover, if more than 25% of the experimental trials for a particular participant were contaminated by ocular artifacts, the entire EEG recording for that participant was excluded. As a result, the EEG recordings obtained from four participants (1 PTH; 3 HKC) were excluded from further analysis. Recordings from three more participants (2 PTH; 1 HKC) were excluded due to those participants' failure to attain accuracy of 90% in identifying distractors. In addition, trials for which the participant incorrectly identified a character or non-character as a distractor were also excluded (0.68% of trials).

3. Results

3.1. Function – character versus non-character

Fig. 3(a–c) shows the grand average ERPs elicited by characters and non-characters at two representative electrodes (Cz, Pz): (a) for all participants; (b) for PTH participants only; and (c) for HKC participants only. Differences in the ERP waveforms for all participants (see Fig. 3(a)) were apparent at centro-parietal electrodes from about 275 ms after stimulus onset. A repeated measures analysis of variance was conducted to determine the impact of Culture (PTH, HKC) and Function (character, non-

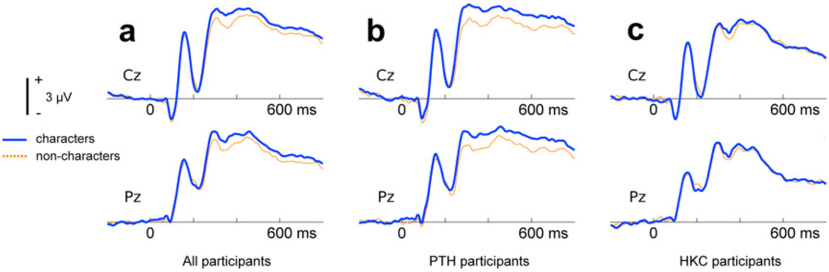


Fig. 3. Grand-averaged ERPs elicited by characters and non-characters at 2 midline electrodes (Cz, Pz) for: (a) all participants; (b) PTH participants only; and (c) HKC participants only.

character) on the mean amplitude of the observed P300 component, which was calculated at each of three central (Cz, C3, C4) and three parietal (Pz, P3, P4) electrode sites over the 275–475 ms time window. Corrections for violations of sphericity were made, where appropriate, using the Greenhouse–Geisser method.

Analysis of the amplitude of the P300 component showed a significant main effect of Function ($F(1,34) = 25.45$, $P < .0001$), with characters eliciting greater amplitude P300 than non-characters (see Fig. 3(a)). The impact of sociolinguistic background was evident in the significant interaction between Function and Culture ($F(1,34) = 6.71$, $P = .014$). Post hoc analysis revealed a significant main effect of Function among PTH participants ($F(1,17) = 24.56$, $P < .001$; see Fig. 3(b)), with characters eliciting the greater P300. A similar trend was observed for HKC participants, but this did not attain significance ($F(1,17) = 3.71$, $P = .071$; see Fig. 3(c)). All other effects were not significant ($P > .05$).

3.2. Character symmetry – low symmetry versus high symmetry

Fig. 4(a–c) shows the grand average ERPs elicited by low and high symmetry characters at three representative electrodes (Fz, Cz, Pz): (a) for all participants; (b) for PTH participants only; and (c) for HKC participants only. Differences in the ERP waveforms for all participants (see Fig. 4(a)) were apparent in the P200 component observed at fronto-central electrodes about 135–185 ms after stimulus onset, and the P300 component observed at centro-parietal electrodes from about 275 ms

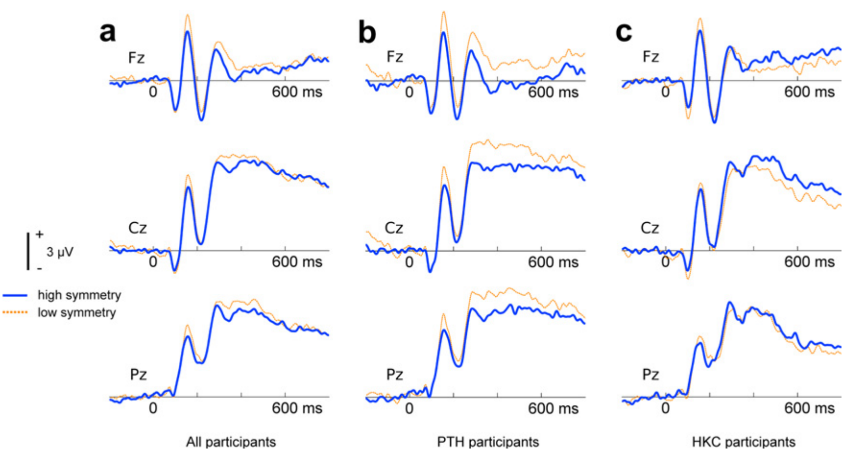


Fig. 4. Grand-averaged ERPs elicited by low and high symmetry characters at 3 midline electrodes (Fz, Cz, Pz) for: (a) all participants; (b) PTH participants only; and (c) HKC participants only.

after stimulus onset. The mean amplitude of the P200 component was calculated at each of six fronto-central electrode sites (Fz, F3, F4, Cz, C3, C4) over the 135–185 ms time window. The mean amplitude of the P300 component was calculated at each of six central-parietal electrode sites (Cz, C3, C4, Pz, P3, P4) over the 275–475 ms time window. Repeated measures analyses of variance were conducted to determine the impact of Culture (PTH, HKC) and Symmetry (low symmetry, high symmetry) on the ERPs elicited by characters. Corrections for violations of sphericity were made, where appropriate, using the Greenhouse–Geisser method.

Analysis of the P200 amplitude showed a significant main effect of symmetry ($F(1,34) = 18.65$, $P < .001$). No other effect was significant ($P > .05$).

Analysis of the P300 amplitude revealed a significant interaction between Symmetry and Culture ($F(1,34) = 6.15$, $P = .018$). In the post hoc analysis, a significant main effect of symmetry was observed for PTH participants ($F(1,17) = 6.63$, $P = .020$; see Fig. 4(b)), with low symmetry characters eliciting the greater amplitude P300, but not for HKC participants ($F(1,17) = 0.55$, $P = .468$; see Fig. 4(c)). All other effects were not significant ($P > .05$).

4. Discussion

For PTH participants, character stimuli elicited a P300 component with significantly greater magnitude than non-character stimuli. According to the context updating hypothesis (Donchin, 1981; Donchin & Coles, 1988), the amplitude of the P300 component indexes attentional resources, with tasks that demand more attentional resources eliciting smaller P300 amplitude (Kahnemann, 1973; Kok, 2001). Based on this hypothesis, we infer that PTH participants were able to process character stimuli with greater ease than non-character stimuli and, therefore, that they could distinguish stimuli liminally according to function (i.e., character or non-character). For HKC participants, however, the trend toward characters eliciting greater amplitude P300 was not significant, providing only weak evidence that HKC participants could distinguish stimuli liminally according to function.

Perfetti et al. (2005) have demonstrated that Chinese character naming is facilitated by graphic priming when the prime is presented 43 ms before the character to be named. With the same prime duration, neither phonological priming nor semantic priming has significant effect on naming latency. However, when the prime duration is extended to 57 ms, graphic priming inhibits character naming, whereas phonological priming facilitates character naming. These findings suggest that in about the first 50 ms of character perception, attentional resources are allocated primarily to graphic processing, rather than to either phonological or semantic processing. Consequently, we expect participants having greater visual discrimination skill to be able to process the stimuli used in the present study with greater ease. Our results are therefore consistent with the hypothesis that PTH participants have better visual discrimination skill – perhaps acquired during childhood as a result of their having learned to read Simplified characters (McBride-Chang et al., 2005) – than HKC participants.

Reanalysis of P300 amplitude in terms of character symmetry revealed that, for PTH participants, low symmetry characters elicited a P300 component with significantly greater amplitude than high symmetry characters. Thus, we infer that PTH participants were able to distinguish characters liminally according to their physical properties (high symmetry or low symmetry). More than 80% of Chinese characters are phonograms, typically with asymmetric structure (Hsu et al., 2009). Characters, therefore, typically have low symmetry, a feature to which PTH participants may be attuned. However, there was no significant evidence that HKC participants were attuned to this feature.

Hsiao and Cottrell (2009) have observed that non-Chinese readers perceive Chinese characters more holistically than native Chinese readers. They also found that Chinese readers exhibit a left-side bias in their perception of characters, and suggest that this left-side bias might be indicative of their greater visual expertise. If these links among visual skill, holistic perception of Chinese characters, and left-side bias generalize to Chinese readers with different sociolinguistic backgrounds, we may predict that Simplified character readers should have a stronger left-side bias than Traditional character readers, and that Traditional character readers perceive Chinese characters more holistically than Simplified character readers, a hypothesis for potential future investigation.

An alternative to the explanation stated above is possible. Each non-character stimulus used in the present experiment was constructed from a character by altering a single visual feature, i.e., by adding or removing one stroke. Contrary to the hypothesis that the fewer visual features of Simplified characters require their readers to develop stronger visual discrimination skills than readers of Traditional characters (McBride-Chang et al., 2005), it is possible that the greater visual complexity of Traditional characters makes it possible for their readers to identify characters based on a subset of the available visual features, thereby reducing their ability to discriminate graphically similar character and non-character stimuli when presented liminally. Indeed, there was no significant difference in the P300 amplitude elicited from HKC participants by character and non-character stimuli. However, for PTH participants, stimulus perception was more difficult for the non-character stimuli. Further research may clarify the extent to which character set complexity is a cause of the observed P300 modulation.

In addition, further studies that include participants with other sociolinguistic backgrounds may serve to confirm whether the observed modulation of P300 amplitude is caused primarily by differences in the processing of visual features of Simplified and Traditional characters, or by other sociolinguistic variables. For example, the ERP responses of PTH participants and HKC participants may be contrasted with those elicited from Taiwan Mandarin speakers, who read using Traditional Chinese characters, Guangzhou Cantonese speakers in Mainland China, who read using Simplified Chinese characters, and Japanese speakers, who read *Kanji*, a logographic script derived from Chinese characters, allowing the relative contributions of spoken language and character set to be assessed.

The present study demonstrates that sociolinguistic background shapes the sensitivity of perception of reading materials at the liminal level. Research on reading has focused mainly on reading at the supraliminal level (e.g., Hsu et al., 2009; Law, Weekes, Wong, & Chiu, 2008; Lee et al., 2007; Liu et al., 2006; Tan, Spinks, Eden, Perfetti, & Siok, 2005; Tzeng, Hung, & Wang, 1977; Tzeng & Wang, 1983; Wang, 1981; Xue et al., 2008). Only limited research has touched upon liminal or subliminal processing in reading (e.g., Heinzel et al., 2008), with little linkage to existing models of reading (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Perfetti et al., 2005; Seidenberg & McClelland, 1989). Understanding the extent and limits of subliminal and liminal processing of reading is an important step toward a fuller understanding of the conscious processing of reading (cf. Kouider & Dehaene, 2007) and the building of a general theory of reading, both for languages that use alphabetic writing systems, such as English, and languages that use logographic writing systems, such as Chinese.

Acknowledgments

The work described in this paper was partially supported by grants from the Shun Hing Institute of Advanced Engineering at The Chinese University of Hong Kong (Project No. BME 8115020) and from the Research Grants Council of the Hong Kong Special Administrative Region, China. We thank the editor and reviewers for their constructive help in improving the paper.

References

Arikan, M. K., Devrim, M., Oran, Ö., Inan, S., Elhih, M., & Demiralp, T. (1999). Music effects on event-related potentials of humans on the basis of cultural environment. *Neuroscience Letters, 268*, 21–24.

Bischoff Renninger, L. A., Granot, R., & Donchin, E. (2003). Absolute pitch and the P300 component of the event-related potential: an exploration of variables that may account for individual differences. *Music Perception, 20*, 357–382.

Cheng, C.-C. (1996). Quantifying dialect mutual intelligibility. In C.-T. J. Huang, & Y.-H. A. Li (Eds.), *New horizons in Chinese linguistics* (pp. 269–292). Boston: Kluwer Academic Publishers.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: dual-route and parallel-distributed-processing approaches. *Psychological Review, 100*, 589–608.

Daniels, P. T., & Bright, W. (1996). *The world's writing systems*. New York: Oxford University Press.

Del Cul, A., Baillet, S., & Dehaene, S. (2007). Brain dynamics underlying the nonlinear threshold for access to consciousness. *PLoS Biology, 5.10*, e260. doi:10.1371/journal.pbio.0050260.

Delplanque, S., Lavoie, M. E., Hot, P., Silvert, L., & Sequeira, H. (2004). Modulation of cognitive processing by emotional valence studied through event-related potentials in humans. *Neuroscience Letters, 356*, 1–4.

Donchin, E. (1981). Surprise! … Surprise? *Psychophysiology, 18*, 493–513.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences, 11*, 357–374.

Donchin, E., Ritter, W., & McCallum, C. (1978). Cognitive psychophysiology: the endogenous components of the ERP. In P. Callaway, P. Tueting, & S. Koslow (Eds.), *Brain-event related potentials in man* (pp. 349–411). New York: Academic Press.

Ferree, T. C., Luu, P., Russell, G. S., & Tucker, D. M. (2001). Scalp electrode impedance, infection risk, and EEG data quality. *Clinical Neurophysiology, 112*, 536–544.

Frostig, M., Lefever, D. W., & Whittlesey, J. R. (1963). *Marianne Frostig developmental test of visual perception*. Palo Alto, CA: Consulting Psychologists Press.
Heinzel, A., Hautzel, H., Poeppel, T. D., Boers, F., Beu, M., & Mueller, H.-W. (2008). Neural correlates of subliminal and supraliminal letter processing – an event-related fMRI study. *Consciousness and Cognition, 17*, 685–699.
Ho, C. S.-H., & Bryant, O. (1997). Phonological skills are important in learning to read Chinese. *Developmental Psychology, 33*, 946–951.
Ho, H.-H., & Kwan, T.-W. (2001). Hong Kong, Mainland China & Taiwan: Chinese character frequency – a trans-regional, diachronic survey. http://arts.cuhk.edu.hk/Lexis/chifreq/.
Hot, P., Saito, Y., Mandai, O., Kobayashi, T., & Sequeira, H. (2006). An ERP investigation of emotional processing in European and Japanese individuals. *Brain Research, 1122*, 171–178.
Hsiao, J. H., & Cottrell, G. W. (2009). Not all visual expertise is holistic, but it may be leftist: the case of Chinese character recognition. *Psychological Science, 20*, 455–463.
Hsu, C. H., Tsai, J. L., Lee, C. Y., & Tzeng, O. J. L. (2009). Orthographic combinability and phonological consistency effects in reading Chinese phonograms: an event-related potential study. *Brain and Language, 108*, 56–66.
Huang, H. S., & Hanley, J. R. (1994). Phonological awareness and visual skills in learning to read Chinese and English. *Cognition, 54*, 73–98.
Kahnemann, D. (1973). *Attention and effort*. Englewood-Cliffs: Prentice Hall.
Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38*, 557–577.
Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review of visual masking. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 362*, 857–875.
Lai, M.-L. (2005). Language attitudes of the first postcolonial generation in Hong Kong secondary schools. *Language in Society, 34*, 363–388.
Law, S. P., Weekes, B. S., Wong, W., & Chiu, K. (2008). Reading aloud non-characters by individuals with acquired dyslexia: evidence for lexically mediated processes in reading Chinese. *Language and Cognitive Processes, 23*, 1–26.
Lee, C. Y., Tsai, J. L., Chan, W. H., Hsu, C. H., Hung, D. L., & Tzeng, O. J. L. (2007). Temporal dynamics of the consistency effect in reading Chinese: an event related potentials study. *NeuroReport, 18*, 147–151.
Liu, Y., Perfetti, C. A., & Wang, M. (2006). Visual analysis and lexical access of Chinese characters by Chinese as second language learners. *Language and Linguistics, 7*, 637–657.
McBride-Chang, C., & Chang, L. (1995). Memory, print exposure, and metacognition: components of reading in Chinese children. *International Journal of Psychology, 30*, 607–616.
McBride-Chang, C., Chow, B. W.-Y., Zhong, Y., Burgess, S., & Hayward, W. G. (2005). Chinese character acquisition and visual skills in two Chinese scripts. *Reading and Writing, 18*, 99–128.
Nan, Y., Knösche, T. R., & Friederici, A. D. (2006). The perception of musical phrase structure: a cross cultural ERP study. *Brain Research, 1094*, 179–191.
Perfetti, C. A., Liu, Y., & Tan, L. H. (2005). The lexical constituency model: some implications of research on Chinese for general theories of reading. *Psychological Review, 112*, 43–59.
Pierson, H. (1994). Ethnolinguistic vitality during a period of decolonisation without independence: perceived vitality in Hong Kong. *International Journal of the Sociology of Language, 108*, 43–61.
Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*, 2128–2148.
Proverbio, A. M., Del Zotto, M., & Zani, A. (2006). Greek language processing in naive and skilled readers: functional properties of the VWFA investigated with ERPs. *Cognitive Neuropsychology, 23*, 355–375.
Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*, 523–568.
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.
Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. *Science, 150*, 1187–1188.
Tan, L. H., Spinks, J. A., Eden, G. F., Perfetti, C. A., & Siok, W. T. (2005). Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences of the United States of America, 102*, 8781–8785.
Tang, C., & van Heuven, V. J. (2009). Mutual intelligibility of Chinese dialects experimentally tested. *Lingua, 119*, 709–732.
Tzeng, O. J. L., Hung, D. L., & Wang, W. S.-Y. (1977). Speech recoding in reading Chinese characters. *Journal of Experimental Psychology: Human Learning and Memory, 3*, 621–630.
Tzeng, O. J. L., & Wang, W. S.-Y. (1983). The first two R's. *American Scientist, 71*, 238–243.
Wang, W. S.-Y. (1973). The Chinese language. *Scientific American, 228*, 50–63.
Wang, W. S.-Y. (1981). Language structure and optimal orthography. In O. J. L. Tzeng, & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 223–236). Hillsdale, NJ: Lawrence Erlbaum.
Xu, Y. S., Gandour, J. T., & Francis, A. L. (2006). Effects of language experience and stimulus complexity on the categorical perception of pitch direction. *Journal of the Acoustical Society of America, 120*, 1063–1074.
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.
Zhu, W.-N., Zhang, J.-J., Liu, H.-W., Ding, X.-J., Ma, Y.-Y., & Zhou, C.-L. (2008). Differential cognitive responses to guqin music and piano music in Chinese subjects: an event-related potential study. *Neuroscience Bulletin, 24*, 21–28.