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Chinese characters elicit face-like N170 inversion effects

Man-Ying Wang [a,*], Bo-Cheng Kuo [b,c], Shih-Kuen Cheng [d]

[a] *Department of Psychology, Soochow University, Taiwan*
[b] *Department of Psychology, National Chengchi University, Taiwan*
[c] *Department of Psychology, National Taiwan University, Taiwan*
[d] *Institute of Cognitive Neuroscience, National Central University, Taiwan*

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ABSTRACT

Recognition of both faces and Chinese characters is commonly believed to rely on configural information. While faces typically exhibit behavioral and N170 inversion effects that differ from non-face stimuli (Rossion, Joyce, Cottrell, & Tarr, 2003), the current study examined whether a similar reliance on configural processing may result in similar inversion effects for faces and Chinese characters. Participants were engaged in an orientation judgment task (Experiment 1) and a one-back identity matching task (Experiment 2). Across two experiments, the N170 was delayed and enhanced in magnitude for upside-down faces and compound Chinese characters, compared to upright stimuli. The inversion effects for these two stimulus categories were bilateral for latency and right-lateralized for amplitudes. For simple Chinese characters, only the latency inversion effects were significant. Moreover, the size of the right-hemisphere inversion effects in N170 amplitude was larger for faces than Chinese characters. These findings show the N170 inversion effects from non-face stimuli closely parallel effects seen with faces. Face-like N170 inversion effects elicited by Chinese compound characters were attributed to the difficulty of part-whole integration as well as the disrupted regularity in relational information due to inversion. Hemispheric difference in Chinese character processing is also discussed.

1. Introduction

Visual recognition is accomplished with astonishing speed and accuracy even when the visual input is minimal and ambiguous (Biederman, 1987; Macé, Delorme, Richard, & Fabre-thorpe, 2010; Thorpe, Fize, & Marlot, 1996). The understanding of the underlying mechanisms of this puzzling phenomenon have been gradually unfolding from behavioral and neuroscientific studies of object and face recognition (Peissig & Tarr, 2007). The current study focused on the electrophysiological correlates in the recognition of faces and Chinese characters that are both highly efficient and reliant on configural properties (Diamond & Carey, 1986; Liu, Tian, Li, Gong, & Lee, 2009).

An early event-related brain potential (ERP) associated with the presentation of visual objects is the N170 (Bentin, Allison, Puce, & Perez, 1996; Rossion et al., 2000, 2003). It peaks at around 130–200 ms after stimulus presentation over bilateral occipito-temporal electrode sites. The N170 responded consistently, but not exclusively, to faces (Bentin et al., 1996; Itier, Latinus, & Taylor, 2006; Rossion et al., 2000). Objects elicited N170 (Botzel, Schulze, & Stodieck, 1995; Rossion et al., 2003) and vertex positive potential (VPP) (Jeffreys, 1989, 1993) that were smaller than faces. Significant N170 has also been recorded in response to English words (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Rossion et al., 2003). In contrast to the right-lateralized N170 for faces, the N170 for words was left-lateralized (Mercure, Dick, Halit, Kaufman, & Johnson, 2008). When recording from the right hemisphere, the N170 amplitude has been found to be larger for faces compared to words while its amplitude was equivalent for faces and words in the left hemisphere (Rossion et al., 2003).

The N170 has been shown to be larger in amplitude (Kim et al., 2004; Linkenkaer-Hansen et al., 1998; Rossion et al., 1999) and delayed in latency (Bentin et al., 1996; Jeffreys, 1993, for VPP) when faces were inverted. N170 inversion effects for non-face stimulus categories were much less common (Busey & Vanderkolk, 2005; Minnebusch, Suchan, & Daum, 2009; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002). When the N170 inversion effect was significantly found for non-face stimuli, the effect was bilateral or left-lateralized, rather than right-lateralized as was typically found for faces (Busey & Vanderkolk, 2005; Rossion, Curran, & Gauthier, 2002; Rossion et al., 2003). Discrepancy in stimulus processing between faces and non-face objects are not only evident from their differences in the N170, but behavioral performance also shows that the impairment due to inversion is greater for faces compared to objects (Diamond & Carey, 1986; Farah, Wilson, Drain, & Tanaka, 1995; Valentine, 1988; Yin, 1969). The evidence

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* Corresponding author. Address: Department of Psychology, Soochow University, 70 Lin-Shi Rd., Taipei, Taiwan. Fax: +886 2 28810379.
E-mail address: mywang@scu.edu.tw (M.-Y. Wang).

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that the effect of inversion is asymmetric with respect to faces and non-face stimuli led to this phenomenon being coined the *face inversion effect*.

While the cause(s) of the N170 and the behavioral face inversion effect is still debated (Jacques & Rossion, 2010), the disruption of holistic/configural processing has been identified to be at least partly responsible for the variation in N170 amplitude and latency due to stimulus inversion (Bentin et al., 1996; Sagiv & Bentin, 2001). In fact, other manipulations that are believed to disrupt holistic/configural processing have resulted in similar enhanced and delayed N170 effects as inversion (George, Evans, Fiori, & Davidoff, 1996; Jacques & Rossion, 2010; Milivojevic, Johnson, Hamm, & Corballis, 2003). Letourneau and Mitchell (2008), for example, disrupted the holistic processing of faces by spatially misaligning face halves. Misaligned faces elicited effects in line with face inversion, i.e., a larger and delayed N170 compared to intact faces.

If the disruption of holistic/configural processing is indeed crucial in causing the inversion effects, then any non-face stimuli that rely on configural information for recognition should also result in face-like inversion effects. The current study tested this claim by examining the inversion effects for Chinese characters whose recognition has also been suggested to heavily rely on configural processing (Liu et al., 2009). Although the Chinese orthography is considered logographic and the Chinese characters picturesque, Chinese characters appear to be very different from faces upon first examination. The face configuration is highly constrained so that eyes, nose, mouth are arranged at approximately similar locations within any faces. Chinese characters, in contrast, are composed of multiple strokes that are unlikely to be constrained in any conspicuous way. Then, in what sense is a Chinese character as configural as a face?

Multiple senses of configural properties have been defined in the face literature (Maurer, Grand, & Mondloch, 2002; Rossion & Gauthier, 2002). We suggest in the following that the various types of configural information face recognition relies on are also important for the recognition of Chinese characters. The Chinese character is hierarchically organized that each character is composed by *radicals*, which, in turn, consists of multiple *strokes* (Ding, Peng, & Taft, 2004; Huang & Wang, 1992) (see Fig. 1a for examples). The *stroke* represents the feature level in Chinese character processing (Ding et al., 2004) and plays specific roles in Chinese character perception (Li & Yeh, 2003; Tse & Cavanagh, 2000). The *radical* is composed by multiple strokes and is considered the basic orthographic unit. Chinese character is configural in the sense that its visual pattern is represented as an undifferentiated whole and this holistic property has been shown to facilitate identification (Chua, 1999a, 1999b; Yeh & Li, 2002). An important piece of holistic information concerns the spatial structure by which components are aligned. Face parts are arranged in a T-shaped spatial structure within a face while character components are arranged in horizontal or vertical structures within about 80% of Chinese characters (Gao & Kao, 2002; Yeh, Li, & Chen, 1997). This structural information is available relatively early in the visual processing of Chinese characters that affected visual search and radical detection performance (Wang, 2002; Yeh & Li, 2002) and is dependent on one's reading experience (Yeh, Li, Takeuchi, Sun, & Liu, 2003).

The alternative type of configural information that Chinese character recognition relies on emphasizes the spatial relationships between local components or features in qualitative (i.e., the first-order relational) or quantitative (i.e., the second-order relational) terms (Diamond & Carey, 1986; Leder & Bruce, 2000). For faces, the first-order relational information concerns the relative locations of different face parts within the T-region of a face. For characters, however, this information refers to the relative locations of character components within the horizontal or vertical character structures (see Fig. 1b). The first order relational information is highly constrained in faces, so is it in Chinese characters. The location of a radical in a character is not arbitrary but depends considerably on the type of the radical (i.e., *semantic* vs. *phonetic*) so that, for example, the phonetic radical is more likely to appear on the right and the semantic radical on the left of a horizontal character (Hsiao & Shillcock, 2006) (see Fig. 1a). These constraints as well as the first-order relational information itself contribute to the recognition of Chinese characters (Ding et al., 2004; Wang & Ching, 2009).

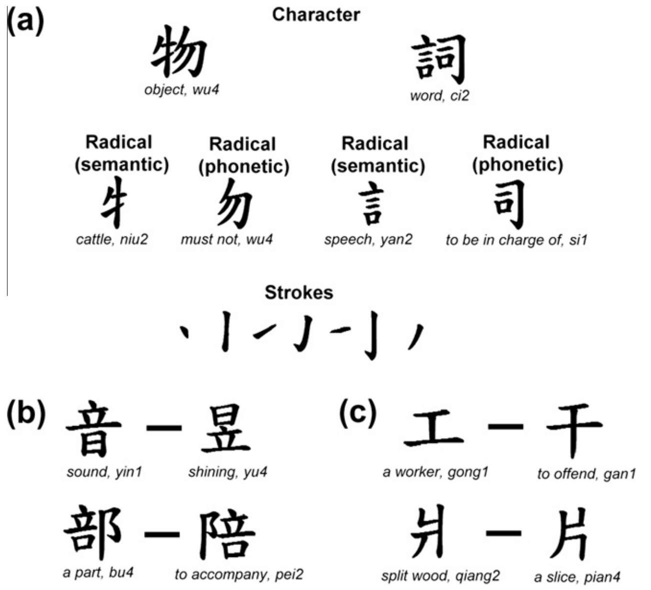

Fig. 1. (a) The Chinese character is hierarchically represented at the stroke, radical, and character levels. (b) The two characters in each pair differ by the relative locations of their composing radicals, i.e., the first-order relational information. (c) The two characters (radicals) in each pair differ by the metric properties of stroke relations, i.e., the second-order relational information.

The second-order relational information for Chinese characters is more discriminating at the stroke level. Modifying the relative length and distances between strokes may result in different radicals (see Fig. 1c). Since the number of candidate radicals is more than 500 (Han, 1994), this spatial and metric information of stroke arrangements is critical in resolving radical identity. The computing of this second-order relational information could be more demanding in characters composed by multiple radicals (*compound* characters) than characters composed by only one radical (*simple* characters).

The above discussion explicitly explains what the various types of configural information are in a Chinese character and why they are important in Chinese character recognition. This reliance on configural information leads directly to the prediction that we will observe face-like inversion effects for Chinese characters. Although inversion may not disrupt the holistic structure of a horizontal or vertical character, it could impact seriously on the processing of first- and second-order relational information within a Chinese character. In an upside-down character, the first-order relational information concerning locations of radicals is disrupted. For example, a phonetic radical is located to the right of a semantic radical in an upright horizontal character. Their relative location will be reversed when the character is upside-down. Inversion also disrupts the second-order relational information in terms of the spatial relationship between strokes. Since the disrupted first-order and second-order relational information are indispensible for deriving the orthographic representation of a Chinese character, the effect of inversion is expected to be evident on both behavioral and neural (in terms of the N170 inversion effects) levels. The results of the current experiments should provide evidence for parallel mechanisms governing the visual processing of Chinese characters and faces.

In two experiments, the effects of inversion on behavioral and N170 performance in Chinese characters are compared to those in faces to determine how closely the former mimics the latter. Participants will perform an orientation judgment task in Experiment 1 and a one-back identity matching task in Experiment 2. Additional comparisons on the inversion effect will be made between simple and compound characters. Compared to simple characters, inversion in compound characters may result in greater disruption of configural information that includes the first-order relational information for radicals as well as more second-order relational information from the greater numbers of strokes. We aim to determine whether simple and compound Chinese characters consistently elicit face-like behavioral and electrophysiological responses to inversion and if the behavioral and N170 inversion effects differ between them.

2. Experiment 1

In Experiment 1, the effects of inversion on N170 amplitudes and latency were examined for faces and Chinese characters in an orientation judgment task (Itier et al., 2006; Rossion et al., 2000, 2003). Effects of inversion on N170 amplitude and latency were expected for both faces and Chinese characters. Since non-face stimuli rarely exhibited N170 inversion effect and when they did the lateralization of the effect was not right-lateralized as typically found for faces, the lateralization pattern of the inversion effect for Chinese characters constitutes another criterion in judging how closely this effect mimics that of faces. It is also of interest to compare the N170 inversion effects for simple and compound Chinese characters as they may differ in the configural processing required for recognition.

2.1. Methods

2.1.1. Participants

All participants in this experiment were right-handed, according to the Edinburgh handedness inventory (Oldfield, 1971). Thirty participants were recruited. They had normal or corrected-to-normal visual acuity and were financially reimbursed for their time. All participants reported themselves as being healthy, without any neurological or psychiatric history and not on any medication known to affect the central nervous system. Informed written consent was obtained from all participants prior to the study. Data from 5 participants were excluded, due to poor performance on the task (<60% correct trials) or too few trials remaining after EEG artifact rejection (<14 trials). The behavioral and ERP analyses were performed on the remaining 25 participants (15 females, age range 18–31 years, mean age = 20.84). All experimental methods received approval from the local ethics committee.

2.1.2. Design and stimuli

The task and stimuli are illustrated in Fig. 2. The within-subject factors consisted of orientation (upright and inverted) and stimulus types (faces, simple Chinese characters and compound Chinese characters). For Chinese characters, character frequency (high- vs. low-frequency) served as an additional within-subjects factor.

The stimuli consisted of 32 grayscale images of faces, 64 simple Chinese characters, and 64 compound Chinese characters. Face images were front-on views of 16 females and 16 males in neutral expressions with hair, clothing, and background removed. In both compound and simple characters, half of the characters were of high frequency (averaging 105.59 and 2234.21 per million occurrences for compound and simple characters, respectively) and the other half were of low frequency (with 9.56 and 9.04 per million occurrences for compound and simple, respectively) (National-Languages-Committee, 2000). Character complexity (number of strokes) was matched across frequency conditions. Mean numbers of strokes were 10.59 and 10.28 for high- and low-frequency compound characters, respectively. The mean numbers of strokes for high- and low-frequency simple characters was 4.74 and 4.28, respectively[1].

The three types of stimuli were presented in separate blocks and the order of the blocks was counterbalanced across participants. Upright and inverted stimuli were randomly presented within each block. Face stimuli were repeated four times, twice upright and twice inverted. Character stimuli were repeated twice, once upright and once inverted. The total number of trials was 384.

Simple and compound Chinese characters were presented in black, DFKai font on an otherwise white background. Faces, simple characters, and compound characters subtended approximately 6° (width) × 8° (height), 2.2–3.6° × 1.8–3.5° and 3.6–4.0° × 3.3–3.5° of visual angle, respectively. Inverted versions of all stimuli were created by rotating them 180°.

2.1.3. Procedure

Participants were comfortably seated in a dimly illuminated room, 67 cm in front of a computer monitor. Participants were given written and verbal instructions to maintain fixation on a small dot at the center of the monitor during the active parts of the experiment. They were asked to minimize blinking/eye movements, keep their eyes fixed at the center of the screen during the experiment and to respond with their right hand as accurately and quickly as possible.

2.1.4. Task

Participants were instructed to judge whether the presented stimulus was upright or inverted (Fig. 2). Each trial began with a centrally displayed cross (1000 ms) which was replaced by the stimulus (800 ms). Participants pressed the left mouse button to indicate that the stimulus was "upright" and the right mouse button to indicate that it was "inverted". Inter-trial intervals varied randomly between 1500 ms and 2000 ms. Twelve practice trials were completed prior to the actual experiment.

2.1.5. EEG recording and processing

EEG was recorded continuously during the entire duration of each experimental run using NuAmp amplifiers (Neuroscan, Inc.). Brain activity was recorded with 37 Ag/AgCl electrodes positioned according to the 10–20 international system (AEEGS, 1991) on an elastic cap. The montage included six midline sites (FZ, FCZ, CZ, CPZ, PZ, and OZ) and twelve sites over each hemisphere (FP1/FP2, F3/F4, F7/F8, FC3/FC4, FT7/FT8, C3/C4, T3/T4, CP3/CP4, TP7/TP8, P3/P4, T5/T6, and O1/O2). Vertical eye movements were recorded by electrodes placed on the supraorbital and infraorbital ridges of the right eye [vertical electro-oculogram (VEOG)], and horizontal eye movements by electrodes placed on the outer canthi of the right and left eyes [horizontal electro-oculogram (HEOG)]. Additional electrodes were used as ground and reference sites. Electrodes were referenced to the right mastoid site (A2) during recording. The electrode between FPZ and FZ (AFZ) on the midline served as the ground electrode. Electrode impedances were kept

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[1] Although the mean frequency count of simple characters matched that of compound characters in the low-frequency condition, it was higher in the high-frequency condition. This reflects the fact that simple characters generally have higher word frequency, and they are few in number to allow for a better frequency match.

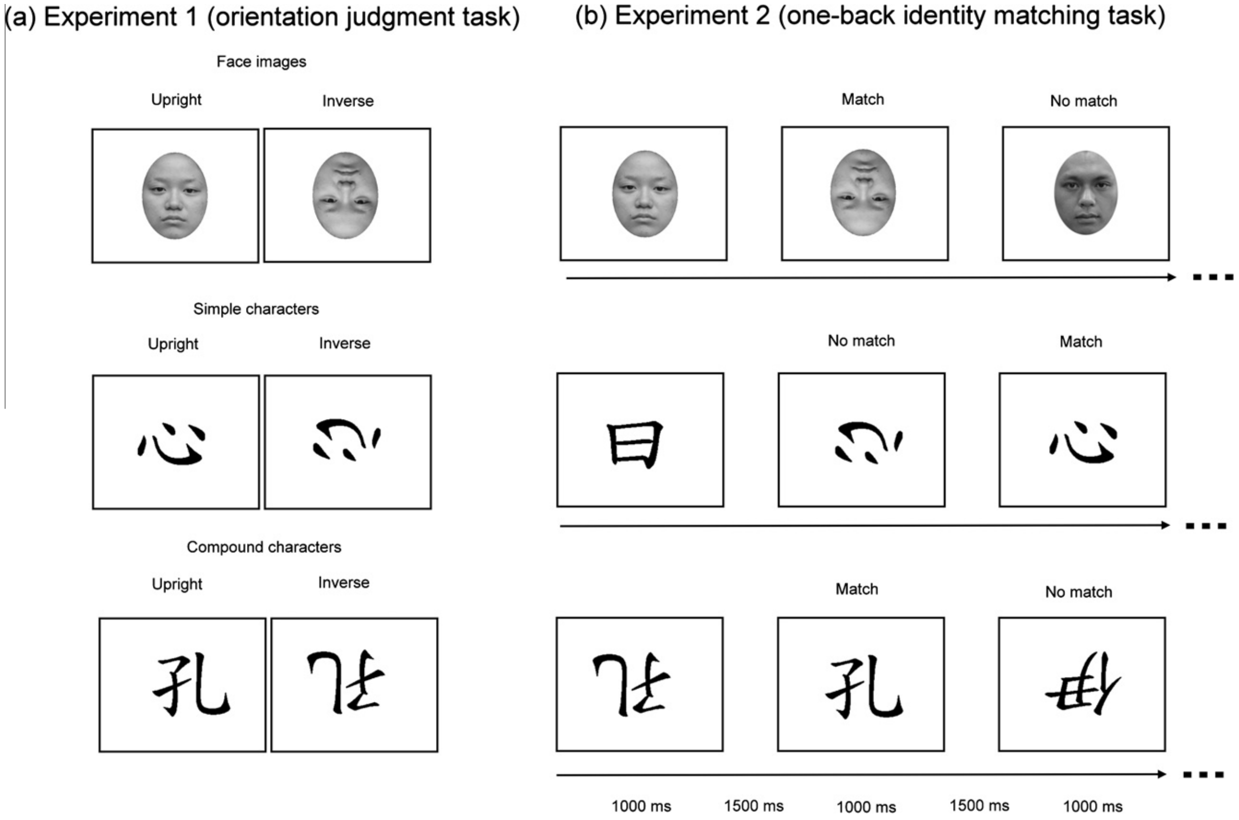

Fig. 2. Illustration of stimuli and tasks adopted in (a) Experiment 1 and (b) Experiment 2.

below 5 k. The ongoing brain activity at each electrode site was sampled every 1 ms (1000-Hz analogue-to-digital sampling rate). Activity was filtered with a low-pass filter of 300 Hz, and no high-pass filter was used.

For offline analysis, the EEG was re-referenced using a common average reference to maximally capture categorical and hemispheric differences at the time period of the N170 (Joyce & Rossion, 2005). Bipolar EOG signals were derived by computing the difference between the voltages at electrodes placed to the side of each eye (HEOG) and above and below the left eye (VEOG). The re-referenced and transformed continuous data were then low-pass filtered (40 Hz) to exclude high-frequency noise.

The continuous EEG was then segmented into epochs starting 100 ms before and ending 500 ms after the onset of each stimulus. The EEG epochs were baseline-corrected with the 100 ms pre-stimulus period. Epochs containing excessive noise or drift (±100 μV) at any electrode or with eye-movement artifacts (blinks or saccades) were excluded. Blinks were identified as large deflections (±50 μV) in the HEOG or VEOG electrodes. Saccades were identified by visually inspecting the HEOG traces individually. Finally, epochs were averaged according to stimulus type and orientation.

2.1.6. Data analysis

Two-way repeated-measures ANOVAs were performed on behavioral data (mean reaction time and accuracy) to test the effect of stimulus types (faces vs. simple characters vs. compound characters) and orientation (upright vs. inverted). Reaction times that were less than 100 ms or over 1000 ms were treated as outliers and excluded from the analysis (.45% excluded).

For the ERP, two important visual potentials time-locked to the onset of each stimulus were analysed: the P1 (using a time window of 90–130 ms) and the N170 (using a time window of 150–190 ms). Within these time windows, mean amplitudes were computed. The peak latencies of individual waveforms were extracted at the maximum amplitude value in the P1 time window and at the minimum amplitude value in the N170 time window. These measures were taken at the left and right lateral occipital–temporal electrode pairs (T5 and T6) where the most prominent N170 potential was observed in all conditions (also see Rossion & Jacques, 2008). Two sets of ANOVAs were conducted on both mean amplitude and peak latency for the P1 and the N170, respectively. The "stimulus type" analysis examined differences in inversion effects across the three types of stimuli in a stimulus type (face vs. simple character vs. compound character) × orientation (upright vs. inverted) × hemisphere (left vs. right) repeated measures ANOVA. The "character frequency" analysis focused on the effect of character frequency (that was varied only in the Chinese characters) with four-way repeated measures ANOVAs, testing the effects of character frequency (low vs. high), character type (simple vs. compound), orientation, and hemisphere.

We also tested whether the scalp distributions differed among stimulus types and whether the scalp distributions of stimulus types interacted with posterior electrodes. The voltage differences between upright and inverted stimuli were computed for posterior electrodes pairs (O1/O2, TP7/8 and T5/6). The differential voltage was then normalized over these electrodes in each condition for each participant (McCarthy & Wood, 1985). A three-way repeated-measures ANOVA [stimulus type (3) × electrode pairs (3) × hemisphere (2)] was conducted to test for the differential distribution of the normalized N170. The Greenhouse-Geisser epsilon correction for non-sphericity was applied to all analyses where appropriate (Jennings & Wood, 1976).

Finally, we analyzed correlation pattern and the time course of the N170 inversion effect. N170 amplitude or latency difference between upright and inverted stimuli was used as the dependent measure. Correlations between faces and Chinese characters were computed separately for the left and the right hemispheres. We also examined the timing of the right-lateralized N170 inversion effects for faces, simple and compound Chinese characters. The difference waves (inverted–upright) were analyzed separately for the left hemisphere (T5) and the right hemisphere (T6) using a short time window (20 ms), sliding every 10 ms, between 120 and 220 ms after stimulus onset. The significance of the effect of hemisphere on the inversion effect was then assessed using standard repeated measures ANOVA. The first significant interaction ($p < .05$) was taken to mark the onset of the right-lateralized effect.

2.2. Results

Effects were significant at $p < .05$ (or lower). All other effects were not significant, $p > .05$ (or higher).

2.2.1. Behavioral performance analysis

The behavioral results are summarized in Table 1. Inverted stimuli were processed more slowly than upright ones [$F(1,24) = 4.10$, $p = .05$, $\eta_p^2 = .15$]. This RT inversion effect did not interact with stimulus type [$p > .1$, $\eta_p^2 = .001$]. In accuracy data, orientation interacted with stimulus type [$F(2,48) = 3.96$, $p = .025$, $\eta_p^2 = .14$]. Accuracy did not differ significantly between inverted and upright stimuli for compound Chinese characters ($p > .1$) and faces ($p = .056$). Inverted simple characters were more accurate than upright ones ($p = .044$). The significant main effect of stimulus type on RTs [$F(2,48) = 24.36$, $p < .001$, $\eta_p^2 = .50$] and accuracy [$F(2,48) = 12.41$, $p < .001$, $\eta_p^2 = .34$] showed that responses to simple Chinese characters were slower and less accurate than those for faces and compound characters.

2.2.2. ERP results – P1

2.2.2.1. Stimulus type.

2.2.2.1.1. Amplitude. The main effects of hemisphere was significant [$F(1,24) = 10.29$, $p = .004$, $\eta_p^2 = .30$], showing a stronger P1 for the right compared to the left hemisphere (see Fig. 3 and Table 2).

2.2.2.1.2. Latency. The significant effect of stimulus type [$F(1.51,36.23) = 20.21$, $p < .001$, $\eta_p^2 = .46$] was due to the P1 being more delayed for faces than for simple and compound characters ($ps < .001$) and that the P1 was more delayed for simple characters compared to compound characters ($p = .05$).

2.2.2.2. Character frequency.

2.2.2.2.1. Amplitude. Character frequency did not result in any significant effect and the only significant effect was that of hemisphere [$F(1,24) = 8.35$, $p = .008$, $\eta_p^2 = .26$], showing a larger P1 on the right than the left hemisphere.

2.2.2.2.2. Latency. The only significant effect involving character frequency was the three-way interaction between character frequency, orientation and hemisphere [$F(1,24) = 4.64$, $p = .041$, $\eta_p^2 = .16$]. The P1 was relatively delayed for low-frequency compared to high-frequency characters in the left hemisphere ($p = .052$). The effect of character type [$F(1,24) = 19.96$, $p < .001$, $\eta_p^2 = .45$] was also significant due to a greater delay in the P1in for simple compared to compound characters.

2.2.3. ERP results – N170

2.2.3.1. Stimulus type.

2.2.3.1.1. Amplitude. There was an overall inversion effect [$F(1,24) = 13.21$, $p = .001$, $\eta_p^2 = .36$], due to a larger N170 for inverted compared to upright stimuli. The effects of hemisphere [$F(1,24) = 9.60$, $p = .005$, $\eta_p^2 = .29$] and the interaction between orientation and hemisphere [$F(1,24) = 22.57$, $p < .001$, $\eta_p^2 = .49$] showed a larger N170 in the right hemisphere as well as evidence for an N170 inversion effect in the right hemisphere ($p < .005$) but not in the left hemisphere ($p > .1$) (see Fig. 3 and Table 3).

Stimulus orientation also interacted with stimulus type [$F(1.99,47.87) = 4.46$, $p = .017$, $\eta_p^2 = .16$], indicating that the significant overall inversion effect was mainly driven by faces and compound characters ($ps < .05$) and not by simple characters ($p > .1$). Follow-up comparisons also showed that the inversion effect for faces is greater than that for compound characters [$t(24) = 2.13$, $p < .05$]. Orientation and stimulus type did not further interact with hemisphere [$p > .1$, $\eta_p^2 = .03$]. These amplitude results of the N170 revealed a similar pattern of inversion effect for faces and Chinese characters although the size of the face inversion effect was larger than that of Chinese characters (see Fig. 4).

2.2.3.1.2. Latency. There was also a significant overall inversion effect on the measures of latency [$F(1,24) = 47.35$, $p < .001$, $\eta_p^2 = .66$], showing a delayed N170 for inverted stimuli. The orientation by stimulus type interaction was not significant ($p > .1$, $\eta_p^2 = .08$). *The significant main effect of stimulus type [$F(1.56,37.53) = 17.60$, $p < .001$, $\eta_p^2 = .42$] showed that an earlier N170 was observed for faces compared to both simple and compound Chinese characters ($ps < .01$) and for compound compared to simple characters ($p < .05$).*

2.2.3.2. Character frequency.

2.2.3.2.1. Amplitude. Character frequency resulted in a significant main effect [$F(1,24) = 5.38$, $p = .029$, $\eta_p^2 = .18$], showing stronger N170 for low-frequency compared to high-frequency characters. Other significant effects included that of orientation [$F(1,24) = 4.37$, $p = .047$, $\eta_p^2 = .15$], *hemisphere [$F(1,24) = 5.84$, $p = .024$, $\eta_p^2 = .20$], and the interaction between orientation and hemisphere [$F(1,24) = 20.64$, $p < .001$, $\eta_p^2 = .46$].*

2.2.3.2.2. Latency. The N170 was delayed in low-frequency compared to high-frequency characters [$F(1,24) = 4.74$, $p = .039$, $\eta_p^2 = .17$]. It was also delayed by inversion [$F(1,24) = 14.92$, $p = .001$, $\eta_p^2 = .38$] and in simple compared to compound characters [$F(1,24) = 20.70$, $p < .001$, $\eta_p^2 = .46$].

2.2.3.3. Scalp distribution. Analyses using normalized differences in voltage between inverted and upright stimuli did not show any

Table 1
Mean reaction times (ms) and mean accuracy (% correct) (±SD) as the function of stimulus types and orientation.

		Faces	Simple characters	Compound characters
Experiment 1				
RT	Upright	473.22 ± 59.95	504.22 ± 72.24	471.09 ± 67.95
	Inverted	480.96 ± 62.52	513.21 ± 68.20	480.17 ± 64.04
Accuracy	Upright	98.00 ± 2.04	95.31 ± 4.23	98.00 ± 1.78
	Inverted	96.81 ± 2.87	96.56 ± 2.16	98.13 ± 2.16
Experiment 2				
RT	Upright	632.58 ± 79.88	545.52 ± 79.65	546.02 ± 66.53
	Inverted	684.65 ± 79.75	565.34 ± 80.04	578.72 ± 65.89
Accuracy	Upright	83.69 ± 5.41	95.70 ± 3.22	96.34 ± 3.85
	Inverted	80.76 ± 8.00	96.05 ± 2.72	95.27 ± 3.82

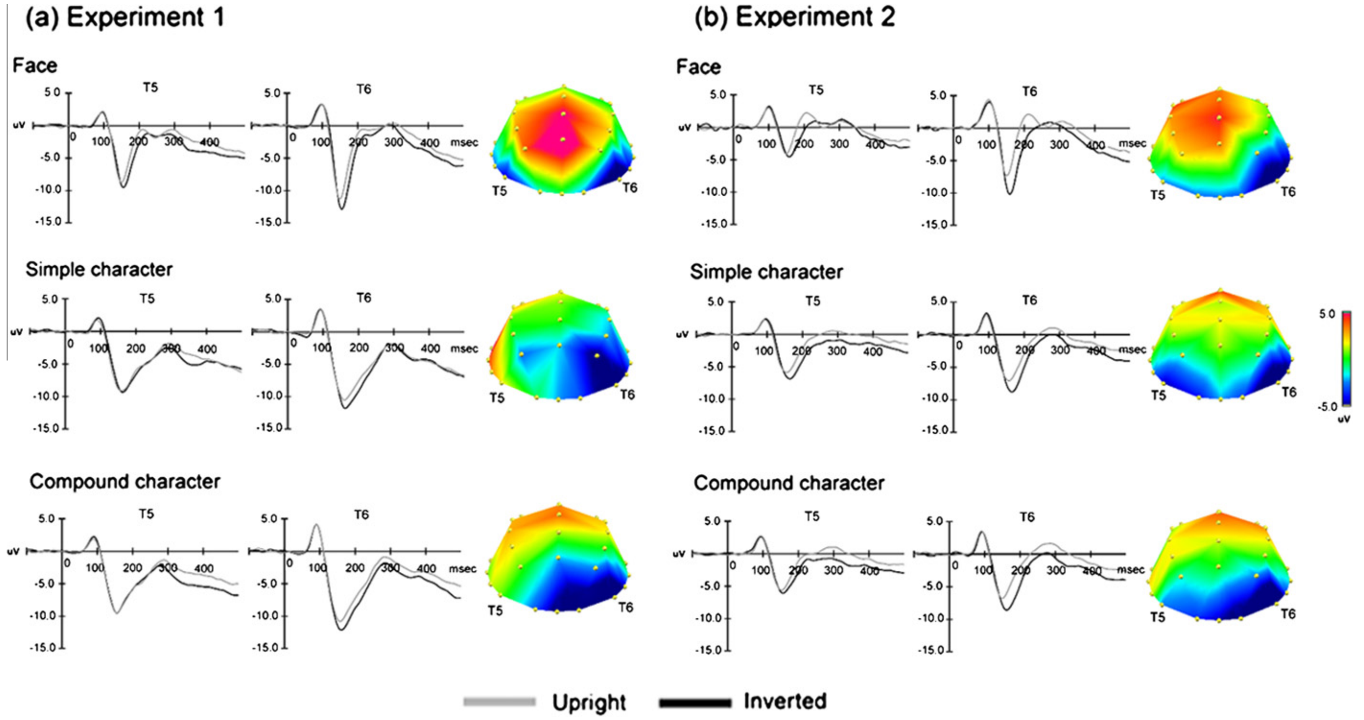

Fig. 3. The N170 as the function of stimulus orientation and stimulus type recorded at T5 and T6 electrodes in (a) Experiment 1 and (b) Experiment 2. Note the enhanced (Experiments 1 and 2) and delayed (Experiment 2) N170 for inverted (solid lines) compared to upright stimuli (dashed lines), especially at right hemisphere electrode T6 (left panel, grand-averaged waveforms). Topographical maps plotted next to each waveform reflected the differential activity between upright and inverted stimuli of the three stimulus types in each experiment (right panel, red: positive responses; blue: negative responses). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 2

Mean amplitude (μV) and peak latency (ms) (±SD) of P1 (90–130 ms) as the function of stimulus types and orientation at lateral occipital–temporal electrode (T5 – left; T6 – right).

		Faces		Simple characters		Compound characters	
		Left	Right	Left	Right	Left	Right
Experiment 1							
Amplitude	Upright	1.46 ± 1.71	2.19 ± 2.48	0.88 ± 1.28	1.98 ± 1.71	0.88 ± 1.51	2.45 ± 2.32
	Inverted	1.27 ± 1.70	2.48 ± 1.87	1.34 ± 1.24	2.22 ± 1.97	1.17 ± 1.59	2.39 ± 2.19
Latency	Upright	112.12 ± 9.50	114.56 ± 7.07	109.60 ± 9.53	109.34 6.47±	106.18 ± 8.75	107.10 ± 5.97
	Inverted	112.36 ± 8.94	113.60 ± 11.21	110.48 ± 9.09	108.78 ± 7.81	105.22 ± 8.42	106.92 ± 5.87
Experiment 2							
Amplitude	Upright	2.27 ± 1.41	3.49 ± 1.82	1.67 ± 1.65	1.80 ± 1.77	1.82 ± 2.01	2.22 ± 2.00
	Inverted	2.46 ± 1.78	3.16 ± 1.77	1.82 ± 1.45	2.26 ± 1.88	2.02 ± 1.82	2.30 ± 1.93
Latency	Upright	113.81 ± 10.51	115.31 ± 9.64	111.53 ± 9.23	111.31 ± 9.09	110.09 ± 9.61	108.56 ± 7.60
	Inverted	117.50 ± 9.80	115.06 ± 10.91	112.31 ± 9.60	112.28 ± 9.31	109.34 ± 7.48	109.94 ± 9.36

Table 3

Mean amplitude (μV) and peak latency (ms) (±SD) of N170 (150–190 ms) as the function of stimulus types and orientation at lateral occipital–temporal electrode (T5 – left; T6 – right).

		Faces		Simple characters		Compound characters	
		Left	Right	Left	Right	Left	Right
Experiment 1							
Amplitude	Upright	−7.38 ± 2.89	−9.46 ± 3.59	−8.55 ± 3.12	−9.65 ± 4.27	−8.78 ± 3.76	−10.04 ± 4.66
	Inverted	−8.27 ± 2.89	−11.08 ± 3.93	−8.36 ± 2.97	−10.50 ± 4.27	−8.69 ± 3.48	−11.21 ± 4.48
Latency	Upright	166.56 ± 9.35	166.20 ± 9.01	174.40 ± 12.14	175.10 ± 10.69	169.38 ± 11.86	172.54 ± 11.41
	Inverted	171.44 ± 10.60	171.24 ± 9.36	176.54 ± 10.17	178.66 ± 9.34	171.26 ± 10.85	176.10 ± 10.33
Experiment 2							
Amplitude	Upright	−3.10 ± 1.99	−6.21 ± 4.07	−5.37 ± 2.58	−6.89 ± 4.11	−5.05 ± 2.47	−6.45 ± 3.63
	Inverted	−3.48 ± 3.10	−8.75 ± 4.37	−6.02 ± 2.53	−7.97 ± 4.33	−5.44 ± 2.69	−8.05 ± 3.83
Latency	Upright	168.19 ± 10.38	167.94 ± 8.79	170.84 ± 11.38	172.22 ± 10.95	168.72 ± 10.58	168.06 ± 11.45
	Inverted	173.94 ± 10.09	175.00 ± 1.78	176.34 ± 10.88	179.41 ± 8.68	173.31 ± 12.39	177.34 ± 7.70

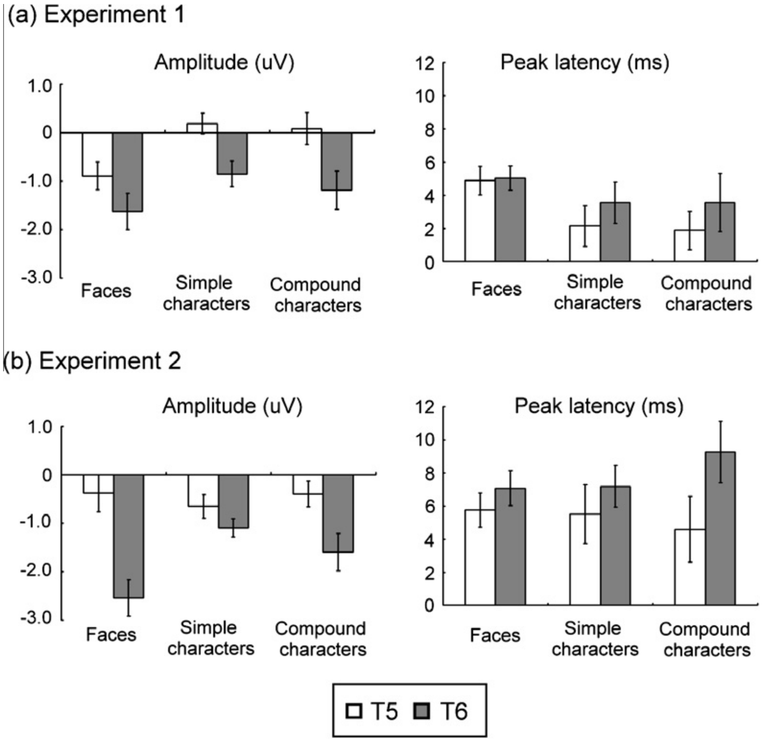

Fig. 4. The difference between upright and inverted stimuli on N170 mean amplitude (μV) and peak latency (ms) (inverted minus upright) at T5 and T6 for faces, simple Chinese characters and compound Chinese characters in (a) Experiment 1 and (b) Experiment 2.

significant effect of stimulus type ($p > .1$, $\eta_p^2 = .01$) and the interaction of stimulus type and electrodes ($p > .1$, $\eta_p^2 = .07$) in the topographical distribution of the N170 inversion effect. These results suggested that there was no significant difference in scalp distribution among stimulus types during the N170 time window.

2.2.3.4. ERPs correlation. For the inversion effects of faces and Chinese characters (on N170 amplitudes and latency), Pearson correlation coefficients (r) were computed and listed in Table 4. The only significant correlation was that between faces and compound Chinese characters on N170 amplitude in the right hemisphere ($r = .47$, $p = .01$).

2.2.3.5. Time course of N170 interaction effect. Fig. 5 illustrated the time course of the interaction effect between stimulus orientation and hemisphere. Significant right-lateralized inversion effects were observed around 140 ms after stimulus onset for compound characters and around 160 ms after stimulus onset for faces and simple characters. The interaction effect of simple and compound characters persisted somewhat longer (until 230 ms) than that of faces (until 190 ms).

Table 4
Pearson correlations (r) between faces and Chinese characters on N170 amplitude and latency inversion effect (inverted-upright).

	Hemisphere	Simple characters		Compound characters	
		r	*p*-Value	*r*	*p*-Value
Experiment 1					
Amplitude	Left	.08	.69	.06	.78
	Right	.10	.62	.47	.01
Latency	Left	−.30	.15	−.07	.73
	Right	.10	.64	−.33	.11
Experiment 2					
Amplitude	Left	−.42	.11	.11	.67
	Right	.55	.03	.28	.30
Latency	Left	.00	1.00	−.00	1.00
	Right	.16	.56	.24	.36

2.3. Discussion

To summarize, effects of inversion on behavioral and N170 measures were found for faces and Chinese characters. Inversion significantly increased reaction times and N170 latency and these effects did not differ among faces, simple and compound Chinese characters. The N170 amplitude effect was overall right-lateralized and significant for faces and compound characters, but not simple characters. In other words, delayed and enhanced N170 inversion effects were clearly found in faces and compound Chinese characters. This effect was larger in faces than in compound Chinese characters. Simple characters differed from faces and compound characters in that their orientation judgments were more difficult (slowest and least accurate) and the N170 inversion effect on amplitude was not significant. The inversion effects related to Chinese characters were not modulated by character frequency, although character frequency itself affected N170 amplitude and latency. Finally, the P1 was sensitive to stimulus type, but not inversion.

It is not immediately clear why orientation judgment was difficult for simple, compared to compound Chinese characters. The average frequency counts for simple characters were actually higher than compound characters. One possibility was that the orientation decision could be, at least, partly based on the presence of atypical stroke/radical orientations and locations for inverted characters. The redundancy gain resulting from the greater numbers of strokes and radicals in compound than simple characters was likely responsible for the better judgment performance for compound characters. Orientation judgments were relatively easy for faces since the decision could be solely based on disrupted first-order relational information, e.g., eyes to the bottom of the mouth

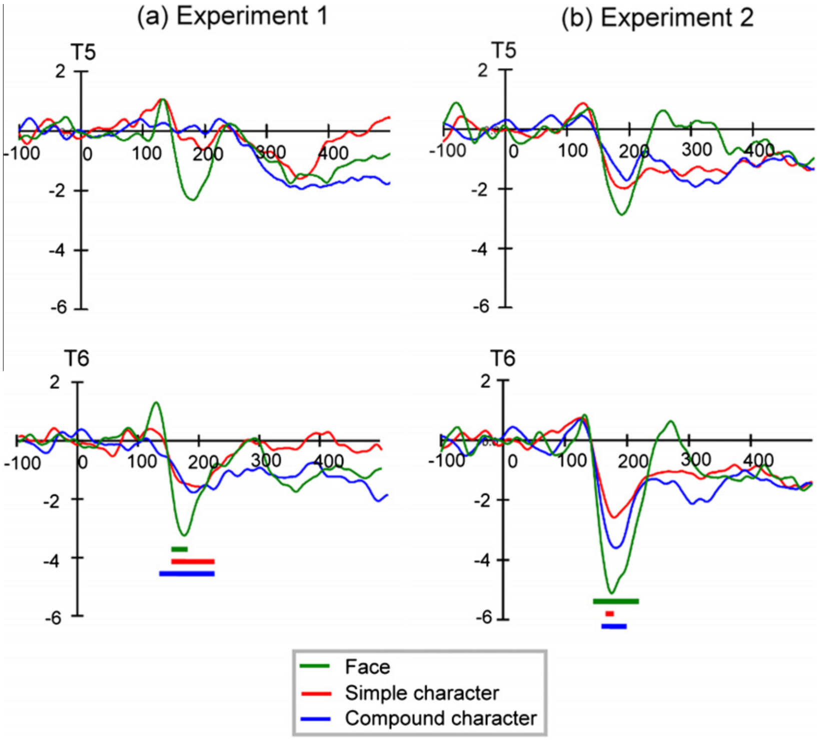

Fig. 5. The time course of ERP difference waves (upright minus inverted) for faces, simple Chinese characters and compound Chinese characters as recorded at T5 and T6 in (a) Experiment 1 and (b) Experiment 2. Interaction effects between inversion and hemispheres were computed for each 20-minisecond time windows, sliding every 10 ms. Color bars marked the start of the first and the last significant interactions between 120 and 220 ms after stimulus onset.

signals an upside-down face. These interpretations, however, suggest that the stimuli in Experiment 1 may have not been processed to the level of individual identification. Experiment 2 was thus conducted using a different task.

3. Experiment 2

Results of Experiment 1 are consistent with the expectation that Chinese characters (especially compound characters) exhibit face-like inversion effects due to a shared reliance on configural processing. Findings in expertise-related effects on the N170 suggested that the N170 for faces or objects of one's expertise is associated with exemplar individuation (Rossion et al., 2002). The nature of the task used in Experiment 1 raised the question of whether the type of configural processing regularly involved in recognizing individual faces and Chinese characters is invoked in the context of orientation judgment. Since orientation judgment could be accomplished by processing visual information diagnostic of stimulus orientation rather than stimulus identity, Experiment 2 was conducted using a one-back identity matching task that more cogently ensures individuated processing (Maurer, Rossion, & McCandliss, 2008; Wong, Gauthier, Woroch, DeBuse, & Curran, 2005). Participants matched the identity of the current stimuli with the previous one regardless of orientation. We expected to observe N170 inversion effects for faces and Chinese characters alike and replicated the basic findings of Experiment 1.

3.1. Methods

Methods were largely similar to Experiment 1. Only differences between the two are reported below.

3.1.1. Participants

Out of 19 volunteers, 16 were included (7 females and 9 males, age range 20–27 years, mean age = 22.06) for data analysis. Data from three participants were excluded, owing to too few trials remaining after EEG artifact rejection (<15 trials). All participants were right-handed, with normal or corrected-to-normal visual acuity and financially reimbursed for their time. They reported themselves as being healthy, without any neurological or psychiatric history and not on any medication known to affect the central nervous system. Informed written consent was obtained from all participants prior to the study. All experimental methods received approval from the local ethics committee.

3.1.2. Design and stimuli

In Experiment 1, the number of repetitions per item was greater for faces than Chinese characters. To exclude the possibility that this difference of within-experiment familiarity may contribute to the main findings of Experiment 1, the numbers of item repetition was matched across different stimulus types. Each item was repeated four times, twice upright, twice inverted, regardless of the stimulus type.

3.1.3. Procedure

Stimuli were presented in blocks of ten trials each. The first two trials within each block were fillers that required no responses. The remaining eight trials were evenly divided into match-upright, match-inverted, mismatch-upright, and mismatch-inverted trials and were presented in random orders. There were 16 such blocks for faces and 32 blocks for simple and compound characters respectively. The total number of trials was 640. At the beginning of experiment, there were also four practice blocks.

3.1.4. Task

Participants judged if the current stimulus was the same as the previous one, irrespective of stimulus orientation (Fig. 1b). A centrally displayed cross (1500 ms) initiated each block of ten trials. A stimulus was presented for 1000 ms with an inter-stimulus interval of 1500 ms. Participants pressed the left mouse button to indicate “match” and the right button for “no match” with their right hand.

3.2. Results

All effects reported were significant at $p < .05$ (or lower) or were theoretically important if they were not significant. All other effects were not significant, $p > .05$ (or higher).

3.2.1. Behavioral performance analysis

Results were consistent with those of Experiment 1. As expected, participants responded to inverted stimuli more slowly than upright ones [$F(1,15) = 73.11$, $p < .001$, $\eta_p^2 = .83$]. The interaction between orientation and stimulus type [$F(2,30) = 11.55$, $p < .001$, $\eta_p^2 = .44$] indicated that inversion reliably slowed RT for all three types of stimuli (all $ps < .001$). Follow-up comparisons showed that the inversion effect was more evident for faces than for simple characters [$t(15) = 4.14$, $p < .005$] and compound characters [$t(15) = 2.63$, $p < .05$]. Stimulus type affected both RT and accuracy [RT: $F(2,30) = 35.19$, $p < .001$, $\eta_p^2 = .70$; accuracy: $F(2,30) = 105.36$, $p < .001$, $\eta_p^2 = .88$]. Participants were slower and less accurate in responding to faces than to Chinese characters.

3.2.2. ERP results – P1

3.2.2.1. Stimulus type.

3.2.2.1.1. Amplitude. We observed a significant effect of stimulus type [$F(1.66,24.94) = 11.91$, $p < .001$, $\eta_p^2 = .44$], indicating a larger P1 for faces than for both simple and compound characters (Fig. 2 and Table 2).

3.2.2.1.2. Latency. A significant main effect of stimulus type [$F(1.28,19.21) = 7.54$, $p = .009$, $\eta_p^2 = .34$] showed that P1 was more delayed for faces compared to Chinese simple and compound characters.

3.2.2.2. Character frequency.

3.2.2.2.1. Amplitude. None of the effects were significant.

3.2.2.2.2. Latency. There was a significant interaction between character frequency and character type [$F(1,15) = 4.84$, $p = .044$, $\eta_p^2 = .24$]. This effect showed that the P1 was delayed for simple compared to compound characters ($p = .002$) when the characters were in high frequency. The main effect of character type was also significant [$F(1,15) = 7.83$, $p = .014$, $\eta_p^2 = .34$].

3.2.3. ERP results – N170

3.2.3.1. Stimulus type.

3.2.3.1.1. Amplitude. In accordance with Experiment 1, we observed significant main effects of orientation [$F(1,15) = 62.57$, $p < .001$, $\eta_p^2 = .81$] and hemisphere [$F(1,15) = 12.58$, $p = .003$, $\eta_p^2 = .46$]. These results reflected, on average, a larger N170 for inverted compared to upright stimuli, and for the right compared to the left hemisphere. The three-way interaction between orientation, hemisphere and stimulus type was significant [$F(1.45,21.76) = 4.21$, $p = .039$, $\eta_p^2 = .22$]. *Right-lateralized N170 inversion effects were obtained for faces ($p < .001$) and compound Chinese characters ($p = .011$) but not for simple Chinese characters ($p > .1$). Follow-up comparison revealed that the hemispheric difference in the N170 (larger in the right relative to the left hemisphere) for faces was significantly greater than simple characters [$t(15) = 2.48$, $p < .05$] but not compound characters [$t(15) = 2.08$, $p = .06$]. In connection with the three-way interaction, the interaction between orientation and hemisphere [$F(1,15) = 17.70$, $p = .001$, $\eta_p^2 = .54$] was significant, so was the interaction between stimulus type and hemisphere [$F(1.11,16.60) = 5.03$, $p = .036$, $\eta_p^2 = .25$]. There was a significant main effect of stimulus type [$F(1.38,20.66) = 3.77$, $p = .050$, $\eta_p^2 = .20$]. The N170 was larger for simple Chinese characters than faces (see Fig. 2 and Table 3).*

3.2.3.1.2. Latency. As in Experiment 1, we observed a significant effect of orientation [$F(1,15) = 67.42$, $p < .001$, $\eta_p^2 = .82$], showing a delayed N170 for inverted compared to upright stimuli. No other effects were significant.

3.2.3.2. Character frequency.

3.2.3.2.1. Amplitude. We did not observe any character frequency effects. The effect of orientation [$F(1,15) = 37.56$, $p < .001$, $\eta_p^2 = .72$] and orientation by hemisphere interaction [$F(1,15) = 7.00$, $p = .018$, $\eta_p^2 = .32$] were significant.

3.2.3.2.2. Latency. Character frequency interacted with orientation and hemisphere [$F(1,15) = 6.09$, $p = .026$, $\eta_p^2 = .29$] in such a way that the effect of orientation was significant in the right hemisphere regardless of character frequency (showing a delayed N170 for inverted characters) while, in the left hemisphere, it was significant only for high-frequency characters. The main effects of character type and orientation were also both significant [orientation: $F(1,15) = 39.54$, $p < .001$, $\eta_p^2 = .73$; character type: $F(1,15) = 6.26$, $p = .024$, $\eta_p^2 = .29$].

3.2.3.3. Scalp distribution.

Again, as we found in Experiment 1, there was no significant main effect of stimulus type ($p = .08$, $\eta_p^2 = .17$) and the interaction between stimulus type and electrodes ($p > .1$, $\eta_p^2 = .08$) in the topographical distribution of the N170 inversion effect using normalized differences in voltage between inverted and upright stimuli ($ps > .1$).

3.2.3.4. ERPs correlation.

The only significant correlation was that between faces and simple Chinese characters on right-hemisphere N170 amplitude effect of inversion ($r = .55$, $p = .027$). In Experiment 1, however, the correlation was found between faces and compound Chinese characters. As a whole, correlations were observed only for right-hemisphere amplitude but they were not consistent with respect to the type of Chinese characters that correlated with faces. These limited correlations did not lend support to the associations between faces and Chinese characters in the size of N170 inversion effects.

3.2.3.5. Time course of N170 interaction effect.

The time course analysis showed that significant interaction effects started around 150 ms, 180 ms, and 160 ms after stimulus onset for faces, simple characters, and compound characters, respectively (see Fig. 5). The right-lateralized inversion effect lasted longer (until 230 ms) for faces, compound characters (until 210 ms) than simple characters (until 190 ms). The onset and duration of the right-lateralized inversion effect appeared to be sensitive to task demands. In faces, the right-lateralized effect onset earlier and extended longer in Experiment 2 compared to Experiment 1. In contrast, the right-lateralized effect onset later and extended a shorter duration for Chinese characters in Experiment 2, compared to Experiment 1. This difference between faces and Chinese characters may reflect the recruitment of the left hemispheres for linguistic stimuli that reduced right-hemisphere involvement for Chinese characters in Experiment 2, compared to Experiment 1. It may also suggest the recruitment of face-selective processes that were more active in Experiment 2 than in Experiment 1.

3.3. Discussion

Despite possible task differences, Experiment 2 replicated the behavioral and N170 inversion effects for faces and Chinese characters. The N170 inversion effects were observed in latency for all three types of stimuli and in right-lateralized amplitudes for faces and compound Chinese characters. The behavioral and N170 inversion effects of compound Chinese characters mimicked those of faces. However, behavioral measures and N170 amplitudes in the right hemisphere still exhibited the face inversion effect, that is, greater difference between upright and inverted stimuli was observed in faces than in Chinese characters on average.

In both experiments, the N170 inversion effects appeared to dissociate between the latency and the amplitude measure. The latency effect was consistently found across stimulus types and hemispheres while the amplitude effect was right-lateralized for faces and compound Chinese characters. This disparate pattern was also consistent with the results of correlation pattern in which significant correlations between faces and Chinese characters were found only for right-hemisphere N170 amplitudes. These results suggest that the N170 amplitude effects of inversion in faces and Chinese characters are more likely to be based on similar processes than latency effects.

It is noted that character frequency did not modulate the effect of inversion in Experiment 1 but it interacted with orientation and hemisphere in this experiment. The reason for this difference is not clear although it appears to reflect the greater individuated processing in the identity matching task than in the orientation judgment task used in Experiment 1. Although the effect of inversion on the right hemisphere reflected the nature of visual processing for faces and Chinese characters alike, this effect on the left hemisphere may have be constrained by the linguistic network when dealing with Chinese characters. As identification of Chinese characters is demanded by the identity matching task in this experiment, the linguistic network in the left hemisphere might be recruited earlier or more extensively that served as the basis for an effect of character frequency.

While P1 did not correlate with behavioral performance as in the case of N170 (Jacques & Rossion, 2007), it is noted that inversion has been shown to affect the P1 components in some previous studies (Itier & Taylor, 2002, 2004; Marzi & Viggiano, 2007). In both Experiments 1 and 2, however, the N170 was the earliest component that was affected by inversion. The P1 was also larger and relatively delayed in faces compared to Chinese characters in both experiments. This pattern of P1 differences across the three types of stimuli was consistent with Rossion et al. (2003) who also found larger and delayed P1 for faces compared to English words. Although this difference could have been due to uncontrolled low-level visual differences (e.g., spatial frequency spectra), the consistent findings suggest that more extensive low-level visual processing could have been invoked for faces than linguistic stimuli. The finding of a right lateralized P1 for Chinese characters in Experiment 2 was also consistent with Hsiao, Shillcock, and Lee (2007). Hsiao et al. found right lateralized P1 for Chinese characters although the P1 for the alphabetic scripts was in general left-lateralized (Cohen et al., 2000; Grossi et al., 2001).

In both experiments, the size of faces was larger than the size of Chinese characters. This difference, however, did not appear to affect our results in a major manner. On the one hand, the relatively smaller sizes did not reduce the perceptibility of Chinese characters relative to faces. The accuracy performance for Chinese characters was over 95% in both experiments regardless of the orientation and the type of the character. On the other hand, presenting faces and Chinese characters in sizes that corresponded with their "real" relative sizes may actually help reduce unwanted variances due to sizes. Recent evidence supports our finding. For instance, Mercure et al. (2008) showed that size differences did not affect the lateralization of the N170 while the N170 amplitude varied with size in a category specific manner. For (English) words, the N170 amplitude was equivalent across size manipulations ($5^\circ \times 6.5^\circ$ vs. $10^\circ \times 13^\circ$). For high-resolution face images, the N170 was smaller when faces were presented in smaller sizes. They interpreted these findings in terms of the "natural" sizes of respective stimulus in the visual environment. As such, words could elicit relatively larger N170 than faces when both faces and words are small while faces elicit larger N170 than words when they both are large. Thus, presenting faces and words in their respective "real" relative sizes could actually reduce, rather than induce, undesirable variations in N170.

4. General discussion

Inversion delayed the N170 in a similar fashion for faces, simple and compound Chinese characters when the participants were engaged in an orientation judgment task (Experiment 1) and a one-back identity matching task (Experiment 2). N170 amplitudes were also consistently increased by inversion only on the right hemisphere for faces and compound Chinese characters, although the size of the amplitude difference between upright and inverted stimuli was larger for faces than Chinese characters.

Our findings regarding how inversion affected N170 latency and amplitude across different stimulus types is, in a large part, consistent with the N170 literature. Rossion et al. (2003) showed delayed N170 for upside-down faces, cars and English words with no hemispheric differences. Similarly, we found a N170 delayed effect for faces, simple and compound Chinese characters in the current study. Itier, Alain, Sedore, and McIntosh (2007) also found similar latency effects for faces, isolated eyes, faces without eyes and houses. The latency effect has also been demonstrated in inverted artificial stimuli of one's expertise such as Greebles and fingerprints (Busey & Vanderkolk, 2005; Rossion et al., 2002), either in the left or the right hemisphere. In contrast, the effect of inversion on N170 amplitude appears to be larger and especially right lateralized for faces (Rossion et al., 2003; Rousselet, Mace, & Fabre-Thorpe, 2004). It is less common to observe any inversion effects on N170 amplitude in non-face stimuli and when the N170 amplitude was affected by inversion in such cases, the effect was left lateralized (English words) or bilateral (objects) (Rossion et al., 2003). In other words, no previous studies have shown a right-lateralized N170 amplitude effect of inversion in non-face stimuli as we have found for compound Chinese characters.

This disparate pattern of results for N170 latency and amplitude effects of inversion is generally consistent with proposals of multiple sources for the N170 and N170 inversion effect (Itier & Taylor, 2004; Rosburg et al., 2010; Rossion et al., 2003; Watanabe, Kakigi, & Puce, 2003). For instance, Rosburg et al. (2010) recently examined the source of N170 face inversion effect with simultaneous intracranial and scalp recording in epilepsy patients. The N170 amplitude and the latency effects were associated with neural processors from different brain regions: ventral temporal cortex was sensitive to the latency inversion effect and lateral occipital cortex was related to both the amplitude and latency effects. Based on this and other imaging evidence, the effect of inversion on N170 amplitude was attributed to the increased activation in both face sensitive regions and regions that respond more favorably to non-face stimuli (e.g., lateral occipital cortex) (Jacques & Rossion, 2010; Rossion & Gauthier, 2002), while the latency effect was suggested to reflect the speed in accruing evidence for the presence of a face (Jacques & Rossion, 2010). Although this latter proposal does not fit in well with the latency effects found for both simple and compound Chinese characters in this study, our findings were in general consistent with the differential treatment of N170 amplitude and latency effects of inversion.

4.1. Why is the N170 effect of inversion on the Chinese character "face-like"?

Chinese characters, especially compound characters, exhibited N170 inversion effects that resembled effects from faces in terms of the amplitude, latency and lateralization of the effect. These findings showed, for the first time, that stimulus inversion from a non-face category could lead to effects that closely mimic those from faces.

It has been proposed that the face-specific N170 is generated by a face holistic processor and a face component processor (Bentin et al., 1996; Sagiv & Bentin, 2001). The N170 inversion effect was, therefore, attributed to the additional engagement of a face-component processor, such as eye-sensitive neurons (Itier et al., 2006, 2007), when faces are inverted (Bentin et al., 1996; Sagiv & Bentin, 2001). Although it is unlikely that these face-component processors were recruited to generate the inversion effect for Chinese characters, Chinese character identification have been shown to recruit some face sensitive brain regions.

In a recent study, Liu et al. (2009) asked participants to make same/different judgments for pairs of faces or Chinese characters. They observed highly similar fMRI patterns of activity for faces and Chinese characters at the bilateral fusiform gyrus. Furthermore, the correlations between the response patterns in faces and Chinese characters were not only high (.62–.69) but also approached the correlations within each stimulus categories (.68–.77). They attributed this strong correlation between faces and Chinese characters to their similarity in early visual processing. Although the exact nature of the shared processing is not yet clear, recent evidence showed that face representation in fusiform gyrus is an integrated one that includes both configural and part information. The responses to face configuration (i.e., the T-shaped configuration) and face parts were correlated across voxels in the fusiform gyrus while other nearby face sensitive regions (occipital face area and superior temporal sulcus) responded to face part but not configuration information (Liu, Harris, & Kanwisher, 2010). Chinese characters share with faces the division of structural information into configuration (i.e., the horizontal or vertical character structure) and parts (i.e., the radical) as well as the need to integrate this different information. The shared *hierarchical stimulus structure* may prompt the recruitment of similar neural processes for faces and Chinese characters.

Two aspects of a hierarchical stimulus representation could be the specific determinants of similar neural response patterns in Chinese characters and faces. First, while virtually any visual stimulus could be represented in a hierarchical fashion (in terms of spatial frequency, for example), Chinese characters and faces are importantly similar in that component representation (subordinate to the whole pattern) is individually identifiable or meaningful. Face parts are identifiable as eyes, nose, mouth etc., while character components are usually themselves real characters as they stand alone. For example, 理 (*li3, theory*) is composed of 王 (*wang2, king*) and 里 (*li3, neighborhood*), components that stand as simple characters themselves. Another example is 雷 (*lei2, thunder*) which consists of a top radical which is 雨 (*yu3, rain*) and a bottom radical 田 (*tian2, field*). Even when the radical is a *boushou* (i.e., dictionary entry unit) that do not stand as independent characters, they are still namable and carry semantic denotation, e.g., the 扌 (*shou3, hand*) in 抽 (*chou1, extract*) (other examples can be seen in Fig. 1). The presence of individually identifiable components may automatically recruit neural processes involved in part identification. The activation of individuated part representations may increase the difficulties/demands in integrating them with the whole representation.

The right-lateralized N170 amplitude effects of inversion may reflect the disruptions of this part-whole integration process that is related to the functional specialization of the right hemisphere (Hillger & Koenig, 1991; Parkin & Williamson, 1987; Sergent, 1988). This effect was exhibited both in faces and compound Chinese characters since they both embodied identifiable components and required extensive part-whole integration. Little integration is required when the component representation is the same as the holistic representation in simple characters which consists of only one radical. The right-lateralized N170 amplitude effect was thus not observed for simple characters. The time courses of the right-lateralized inversion effect were also relatively shorter for simple characters than for faces and compound characters in Experiment 2. The attribution of the right-lateralized effect to part-whole integration is consistent with the general absence of the N170 amplitude effect of inversion in objects and artificial stimuli. Although objects are generally composed by parts (Biederman, 1987), these parts are, to a lesser extent, nameable or meaningful exclusively. For artificial stimuli such as fingerprints and Greebles, although experts may appear to gain access to part representation more efficiently than novices (Busey & Vanderkolk, 2005), their part representation of these artificial stimuli is unlikely to be as robust as part representation in naturally well learned stimuli. The integration mechanism was probably not required or recruited differently for objects and artificial stimuli, resulting in an absent or weakened N170 amplitude effect of inversion.

Second, faces and Chinese characters are also similar in their regularity of first-order relational information, that is, relative part or feature locations are highly regular in both faces and Chinese characters. This regularity helps process parts or features diagnostic of identity. For faces, locating eyes, nose and mouth at regular locations facilitates the efficiency of subsequent computing of second-order relational information such as the distance between eyes, nose and mouth. For compound Chinese characters, locating semantic and phonetic radicals in the horizontal or vertical alignment structure may result in subsequent differential treatment of these two types of radicals in orthographic representation of the characters. For simple Chinese characters, relative locations of different types of strokes (the stroke pattern) are also regular. The computing of second-order relational information is likely to be relieved for strokes arranged in expected relative locations.

Additional operation may have to be invoked to deal with the disruption of the spatial regularity scheme by the inversion, e.g., reverse the regularity pattern so as to look for eyes at the bottom of an inverted face and the phonetic radical on the left of an inverted character. As such, a small but reliable delay in N170 latencies is expected for upside-down stimuli. This latency delay may occur for any stimulus category as long as identification makes use of the spatial regularity structure for part or feature co-variations. For objects and artificial stimuli, part locations are not well constrained. However, the N170 latency effect of inversion could be expected when task conditions result in regularity of part locations. Examples may include the Greeble categorization task in which parts are arranged in a highly constrained configuration (Gauthier & Tarr, 1997) and categorization tasks using different exemplars of a basic-level category (Itier et al., 2006; Rossion et al., 2003). In the latter case, part locations are regular with respect to different exemplars in the experiment, e.g., “tires” in different exemplars of the “car” category are all at the bottom. In such cases, inversion may result in an N170 delay since it disrupts the regularity of part locations.

Although we drew on the similarity between faces and Chinese characters to explain their similar behavioral and electrophysiological responses representative of early visual processing, faces and Chinese characters are nevertheless very different. In terms of our findings, although the inversion effects for faces and Chinese characters were qualitatively similar, faces did still result in more prominent effects of inversion on behavioral measures and N170 amplitudes than Chinese characters, constituting the face inversion effect. In addition, the right-lateralized inversion effect for faces extended longer in its time course (see Fig. 5) in Experiment 2 than Experiment 1 while the reverse was true for Chinese characters, suggesting a close relationship between the right-lateralized N170 effects in amplitude and face-selective processes. As a whole, face-selective neural processes (Bentin et al., 1996; Itier et al., 2006, 2007; Sagiv & Bentin, 2001) were likely to be active for faces to result in these findings.

4.2. The right-lateralized N170 for Chinese characters

In addition to the effect of inversion, the current study also showed that the N170 was larger in the right than in the left hemisphere not only for faces but also for Chinese characters. This right-lateralized N170 for Chinese characters is in contrast with the left-lateralized N170 findings for alphabetic scripts (Bentin et al., 1999; Maurer et al., 2008; Rossion et al., 2003). It also appears inconsistent with the findings of Maurer et al. (2008) and Wong et al. (2005), who found left-lateralized N170 for logographic characters. Differences in stimuli from the current study, however, may contribute to this deviation. Maurer et al. (2008) adopted Japanese Kanji stimuli that corresponded with two-character Chinese words instead of single characters as used in the current study. Wong et al. (2005) adopted simple Chinese characters or unrelated character strings to produce N170 amplitudes that appeared to be larger in the right than the left hemisphere. It is not clear if this effect is significant since their stimulus type (Chinese characters vs. English letters vs. pseudo-fonts) by hemisphere interaction was not explained thereof.

Right-lateralized N170 has also been found in other ERP studies examining Chinese characters. Using source localization analysis, Hsiao et al. (2007) showed that the neural generator of the N1 (N170) to Chinese characters was found in the fusiform gyrus and the inferior temporal gyrus in the right hemisphere. Other ERP studies have found bilateral N170 responses (Hsu, Tsai, Lee, & Tzeng, 2009; Kim et al., 2004). Bilateral activation in ventral occipito-temporal regions was observed commonly in imaging studies examining the processing of Chinese characters while alphabetic words activate only the left ventral occipito-temporal system (Liu et al., 2009; Nelson, Liu, Fiez, & Perfetti, 2009; Tan, Laird, Li, & Fox, 2005). The greater involvement of the right hemisphere for Chinese characters is usually attributed to extensive visual processing required in order to identify Chinese characters. The current study highlighted the nature of this right hemisphere activity that has remained obscure in these previous literatures.

It is noted that the left-lateralized N170 elicited by English words was considered to reflect sub-lexical processing (Dien, 2009). As such, the N170 for words should be sensitive to word frequency and this expectation was supported by the finding of a larger and delayed N170 for low compared to high-frequency words, after controlling for bigram and trigram frequency (Hauk & Pulvermuller, 2004). It is, therefore, of interest to see whether character frequency resulted in a similar effect on the N170 for Chinese characters. This is especially the case because this effect is right lateralized and Chinese character recognition is supposedly associated more strongly with visual than with orthographic processing. In the current study, differences in character frequency resulted in N170 effects that were consistent with Hauk and Pulvermuller (2004) in Experiment 1, but not in Experiment 2. The nature of the word frequency effect in Experiment 1, nevertheless, could be different from that found with left lateralized N170, with effects from Experiment 1 reflecting familiarity, not lexical, differences due to differential exposures. The fact that there was not a significant character frequency effect in Experiment 2 is probably attributable to the immediate repetition in the one-back matching task. The repetition (in the matched trials, also see Fig. 1) necessary for this task design may have dampened the word-frequency effect that was based on pre-experimental repetition differences. It is even not clear whether consistent effects of character frequency should ever be expected for the N170 if one take character frequency as an underlying dimension for familiarity. The effect of familiarity on face N170 was not consistent in previous studies. While some studies showed unfamiliar faces elicited larger N170 than familiar faces (Marzi & Viggiano, 2007), others showed absence of such effects or effects in reversed directions (Bentin & Deouell, 2000; Caharel, Courtay, Bernard, Lalonde, & Rebaï, 2005).

To conclude, the current study presented novel findings that Chinese compound characters exhibited face-like N170 inversion effects in amplitudes, latency and lateralization using different tasks in two experiments. These findings supported the general conviction that Chinese character recognition relies on configural processing as in face recognition. They also prompted the comparisons between faces and Chinese characters for their structural similarity responsible for the parallel findings. We suggest that visual spatial processing of relational information in response to stimulus inversion is responsible for these effects.

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