Neuroscience Letters 478 (2010) 107–111

Contents lists available at ScienceDirect

Neuroscience Letters

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

Inversion effect in the visual processing of Chinese character: An fMRI study

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ARTICLE INFO

Article history:
Received 2 February 2010
Received in revised form 20 March 2010
Accepted 30 April 2010

Keywords:
Face inversion effect
Visual expertise
Region of interest
Fusiform face area
Visual word form area

ABSTRACT

Chinese people engage long-term processing of characters. It has been demonstrated that the presented orientation affects the perception of several types of stimuli when people have possessed expertise with them, e.g. face, body, and scene. However, the influence of inversion on the neural mechanism of Chinese character processing has not been sufficiently discussed. In the present study, a functional magnetic resonance imaging (fMRI) experiment is performed to examine the effect of inversion on Chinese character processing, which employs Chinese character, face and house as stimuli. The region of interest analysis demonstrates inversion leads to neural response increases for Chinese character in left fusiform character-preferential area, bilateral fusiform object-preferential area and bilateral occipital object-preferential area, and such inversion-caused changes in the response pattern of characters processing are highly similar to those of faces processing but quiet different from those of houses processing. Whole brain analysis reveals the upright characters recruit several language regions for phonology and semantic processing, however, the inverted characters activated extensive regions related to the visual information processing. Our findings reveal a shift from the character-preferential processing route to the generic object processing steam within visual cortex when the characters are inverted, and suggest that different mechanisms may underlie the upright and the inverted Chinese character, respectively.

Character processing plays important roles in the Chinese social communication, and the corresponding cognitive mechanisms have been studied intensively [23,14,17,24,25]. Recently, a series of studies have reported the visual expertise in Chinese character processing. In behavioral studies, shorter reaction time and higher accuracy were reported for Chinese subjects to process Chinese character than to process an unfamiliar artificial logographic language [25]. Using electrophysiology methodologies, Wong et al. [24] observed comparable expertise-related N170 components for Chinese-English bilinguals during Roman letter and Chinese character reading but a greater N170 for English readers during the Roman letter reading than during Chinese character reading. Using functional magnetic resonance imaging (fMRI) methodologies, Chinese character-preferential regions in ventral occipitotemporal cortex were identified for Chinese character [12], whose location was in consistent with that of visual word form area (VWFA) identified using alphabetic scripts processing [4]. Several studies have proposed that the preferential response to words of VWFA may depend on visual expertise of words [2,5,16,19].

Face is another type of visual stimuli exposed to Chinese extensively, which shares some similarities with Chinese character on many dimensions. First, Chinese people have visual expertise with both canonical upright Chinese characters and faces. Second, they are both processed at individual level. Third, both of them include configural and feature information. Additionally, similar neural structures have been found for their visual processing in the ventral occipitotemporal cortex [17].

For face processing, previous studies found that inverted presentation could lead to an increase of response time or a drop of perception accuracy for face recognition but not for other object recognitions, suggesting the processing of face was more affected by inversion than that of other objects ([26,7], see [18] for a review). Several neuroimaging studies revealed that within occipitotemporal visual cortex, face inversion could result in a response decrease of fusiform face-preferential area ([27], but see [1,6]) but a response increase of object-preferential cortical area [6,11,27].

Recently, similar inversion effect was reported for several no-face stimuli with which people had developed expertise. Reed et al. [21] reported a comparable behavioral inversion effects for body and face. Using electrophysiology methodologies, Busey and Vanderkolk [3] observed identical delays of the N170 component for

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doi:10.1016/j.neulet.2010.04.075

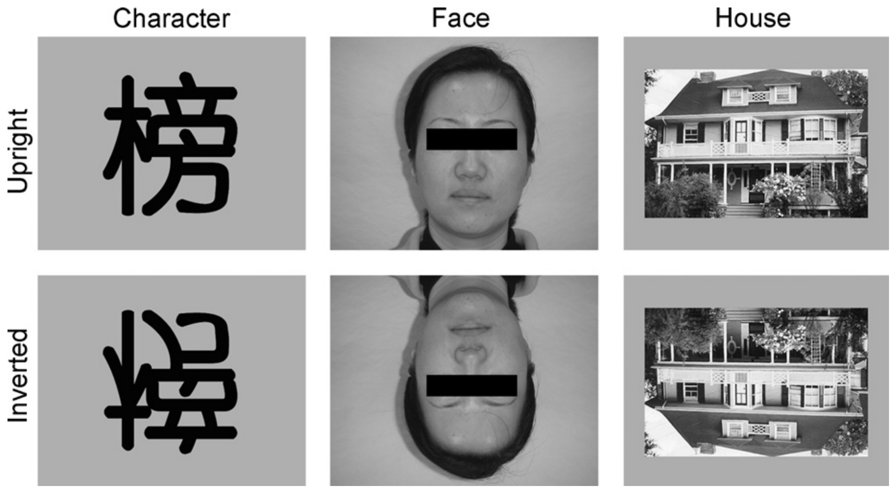

Fig. 1. Examples of stimuli used in the experiment.

fingerprint experts to the inverted fingerprint and face. Epstein et al. [6] also reported similar response patterns for the scene processing and the face processing to inversion in behavioral and neuroimaging results.

Given the similarities of characters and faces, especially on the visual expertise people have, it is curious to know whether the characters processing can be influenced by presented orientation. The aim of the present study is to investigate the influence of the inverted presentation on the neural mechanism of character processing using fMRI methodologies.

Fourteen right-handed Chinese undergraduates (mean age: 22, SD: 1.9, 8 females) with normal vision participated in this study. All subjects gave their written informed consent. The study was approved by The Human Research Protection Program of Tiantan Hospital.

Three types of stimuli categories were employed in the present study, namely Chinese characters (Youyuan font), faces and houses (Fig. 1). For each type of the stimuli categories, 42 gray-scale pictures and their inverted versions were used.

An image discrimination task was performed to ask subjects to decide whether or not the two pictures sequentially presented in a trial were the same. The task included three scanning sessions, each of which contained only one type of stimuli category. Each session included eight 28-s' blocks interleaved with seven 16-s' epochs in which cross-fixation was presented. Four upright blocks and four inverted blocks were alternately presented. At the beginning of each session, a 6-s scanning of fixation was showed allowing for stabilization of magnetization, and another 10-s scanning of fixation was included at the end for the delay of hemodynamic response. Each block included seven trials. Each trial began with 500-ms fixation and a following 500-ms null, then the first stimuli was presented 500 ms. After a 1000-ms fixation, the second 500-ms stimulus appeared. Last, another 1000-ms fixation was left to let subject judge whether the two stimuli in this trial were identical. Each session included equal number of the same and the different trails.

MRI scans were performed on a 3 T (Siemens Trio a Tim, German) scanner. A T2-weighted gradient-echo planar imaging sequence was used for fMRI scans (slice thickness = 4 mm, resolution = 3.75 mm × 3.75 mm, and TR/TE = 2000 ms/30 ms). For each participant, high-resolution (voxel size: 1 mm × 1 mm × 1 mm, matrix size: 256 × 256 × 256) anatomical images were acquired using a T1-weighted three-dimensional gradient-echo sequence.

Before processing, the first three scans of each session were discarded. Data were analyzed using SPM5 (http://www.fil.ion.ucl.ac.uk/spm). Preprocess included slice timing, realignment, normalization, and smoothness with a Gaussian Kernel of 6-mm FWHM. Data were high-pass filtered to eliminate low-frequency components (cut-off value of 128 s). For each participant, a general linear model including six condition regressors was constructed, namely characters, faces, houses and their inverted versions. Each regressor was created by convolving a canonical hemodynamic response function with a delta function corresponding to the onset time series of each condition.

Category-preferential regions of interest (ROI) within visual cortex were defined by the contrast of the corresponding stimuli category vs. the other two stimuli categories (including both the upright and the inverted stimuli) with the statistical threshold $p < 0.0001$. In the present study, our main aim was to investigate the response difference between the upright and the inverted presentation. Given the orthogonal experiment design and the equal number of time points for each condition, such ROI definition with both the upright and the inverted stimuli avoided biasing the results towards the orientation-caused response difference within each ROI [8,11,12]. The orthogonality of ROI definition with the contrasts of further analysis was also checked by taking the experiment design matrix into account [12]. To avoid the overlapping of different ROIs, regions with cluster larger than 500 voxels were replaced by a 4 mm-radius sphere with the centre at the peak response voxel. The radius was set less than the half of the minimum distance (9.38 mm) between two ROIs in the same subject.

Within each ROI, the percent signal change (PSC) of each condition was calculated by Marsbar toolbox (http://marsbar.sourceforge.net/). A three-way ANOVA of hemisphere (right, left) by stimuli categories (Chinese characters, faces and houses) by presented orientation (upright, inverted) found no significant difference in PSC between the right and the left hemispheres ($ps > 0.05$). Therefore, the PSC was collapsed across the right and the left hemispheres for each ROI. A two-way ANOVA of stimuli categories (Chinese characters, faces and houses) by orientation (upright, inverted) was performed on such collapsed PSC.

To further investigate inversion-caused changes in the response pattern of characters processing, a whole brain analysis was performed. For each subject, orientation-caused activation maps were obtained for each type of stimuli with contrast of upright presentation vs. the inverted presentation and the reverse. The group results for each contrast were obtained using random-effect analysis across all subjects. A conjunction analysis of contrasts [inverted characters–upright characters] and [inverted faces–upright faces] was performed. The regions exceeding the threshold of $p = 0.001$ (uncorrected) and with a cluster >25 voxels were analyzed.