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

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A B S T R A C T

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 fingerprint experts to the inverted fingerprint and face. Epstein et

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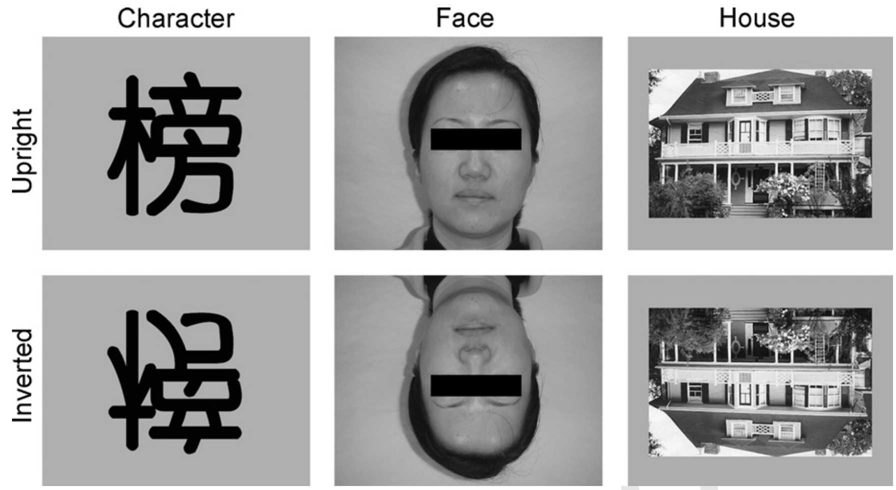

Fig. 1. Examples of stimuli used in the experiment.

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 were presented 500 ms. After a 1000-ms fixation, the second 500-ms stimuli 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.

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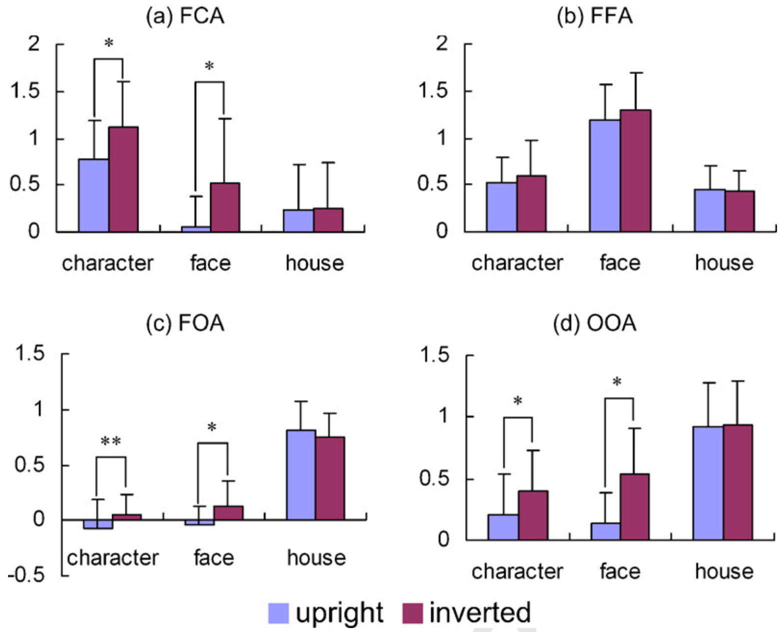

Fig. 2. MR responses within each of the category-preferential areas. Unit on *y*-axis is percent signal change (PSC). $^{*}p < 0.05$, $^{**}p = 0.080$. *Abbreviation*: FCA: fusiform character area; FFA: fusiform face area; FOA: fusiform object area; OOA: occipital object area.

A two-way ANOVA of stimuli categories (characters, faces and houses) by orientation (upright, inverted) revealed a significant interaction effect for the reaction times ($p = 0.002$), which was due to the fact that the reaction times for inverted faces were significantly longer than that for the upright faces ($p = 0.003$) but there was no inversion-caused difference in reaction time for the characters ($p = 0.798$) and houses ($p = 0.196$), respectively. In contrast, there was no significant interaction effect of stimuli categories by orientation in the accurate rate ($p = 0.097$) due to the high accurate rates for all the conditions (for more detail see Table s1 in Supple ment Materials online).

Character-preferential regions were identified within the left fusiform gyrus (−45 ± 4, −59 ± 5, −10 ± 4, 11/14, fusiform character area, FCA); face-preferential regions were identified within bilateral fusiform gyrus (42 ± 3, −51 ± 5, −22 ± 3, 13/14; −41 ± 5, −54 ± 5, −20 ± 4, 7/14, fusiform face area, FFA); the house-preferential regions were identified within bilateral medial fusiform gyrus (29 ± 3, −46 ± 3, −13 ± 3, 12/14; −28 ± 3, −54 ± 7, −13 ± 4, 12/14; fusiform object area, FOA) and bilateral occipital cortex (34 ± 3, −82 ± 3, 8 ± 3, 12/14; −33 ± 4, −86 ± 4, 11 ± 4, 11/14, occipital object area, OOA).

Within FCA, we observed significant interaction effect (F (2, 20) = 4.378, $p = 0.026$) due to the fact that inversion caused significant response increase for characters (t (10) = 3.643, $p = 0.005$) and faces (t (10) = 3.104, $p = 0.011$) but not for houses (t (10) = 0.140, $p = 0.891$) (Fig. 2a). A significant orientation effect was found (F (1, 10) = 16.446, $p = 0.002$). To further investigate the influences of inversion on characters processing and faces processing, the house condition was excluded. A two-way ANOVA of remaining stimuli (characters, faces) by orientation (upright, inverted) was performed. There was no significant interaction effect of remaining stimuli categories by orientations (F (1, 10) = 0.332, $p = 0.577$).

Within FFA, no significant interaction effect was found (F (2, 24) = 0.870, $p = 0.432$) (Fig. 2b). The orientation effect was marginally significant (F (1, 12) = 4.454, $p = 0.056$). There were no significant differences in responses between the upright and the inverted presentation for each type of stimuli categories ($ps > 0.155$).

Within FOA, we found significant interaction effect (F (2, 22) = 4.602, $p = 0.021$) because of the fact that inversion caused marginal response increase for characters (t (11) = 1.932, $p = 0.080$) and significant response increase for faces (t (11) = 3.642, $p = 0.004$) but not for houses (t (11) = −1.727, $p = 0.112$) (Fig. 2c). A significant orientation effect was found (F (1, 11) = 15.280, $p = 0.002$). Additionally, when the house condition was excluded, there was no significant interaction effect of remaining stimuli by orientations (F (1, 11) = 0.216, $p = 0.615$).

Within OOA, we detected significant interaction effect (F (2, 24) = 15.145, $p < 0.001$) due to the fact that inversion caused significant response increase for characters (t (12) = 5.700, $p < 0.001$) and faces (t (12) = 6.773, $p < 0.001$) but not for houses (t (12) = 0.578, $p = 0.574$) (Fig. 2d). A significant orientation effect was found (F (1, 12) = 67.703, $p < 0.001$). More interesting, when the house condition was excluded, there was a significant interaction effect of remaining stimuli by orientations (F (1, 12) = 10.859, $p = 0.006$) due to the larger response increase caused by face inversion than by character inversion.

The results of whole brain analysis were showed in Table 1. Compared to inverted characters, upright characters activated bilateral superior temporal gyrus, left superior frontal gyrus, right anterior cingulate, right cingulate gyrus and bilateral postcentral gyrus. Compared to upright characters, inverted characters significant activated bilateral middle occipital gyrus, bilateral fusiform gyrus, bilateral precuneus, bilateral middle frontal gyrus and declive. The comparison of upright faces relative to inverted faces did not yield any significant results. However, compared to upright faces, inverted faces activated bilateral fusiform gyrus, bilateral inferior occipital gyrus, bilateral precentral gyrus, bilateral superior parietal lobule, left inferior frontal gyrus and right precuneus. Upright houses, compared to inverted houses, activated right inferior occipital gyrus. Inverted houses aroused stronger activation in left inferior parietal lobule than upright houses.

The conjunction analysis revealed the inverted characters and faces, compared to their upright versions, commonly activated bilateral fusiform gyrus, bilateral middle occipital gyrus, bilateral precuneus and right inferior frontal gyrus (Table 2).

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Table 1
Q2 Brain mappings responding to the uptight and the inverted stimuli differently ($p = 0.001$ (uncorrected) and with a cluster >25 voxels).

Region	BA	Voxel	*Z*	Talairach		
				x	*y*	*z*
Upright Chinese characters vs. inverted Chinese characters						
R. superior temporal gyrus	38	47	4.33	42	16	−14
R. anterior cingulate	33	49	4.19	3	14	20
L. cingulate gyrus	24	134	4.18	−5	−15	42
R. postcentral gyrus	40	93	4.14	60	−26	21
L. postcentral gyrus	40	25	3.85	−55	−28	22
L. superior frontal gyrus	9	28	3.69	−22	40	35
L. superior temporal gyrus	22	25	3.19	−55	6	0
Inverted Chinese characters vs. upright Chinese characters						
R. middle occipital gyrus	18	893	4.61	32	−75	5
R. fusiform gyrus	19		4.07	43	−61	−10
L. precuneus	7	241	4.83	−26	−66	32
L. fusiform gyrus	19	552	4.65	−42	−66	−13
L. middle occipital gyrus	18		4.46	−31	−81	3
R. precuneus	7	242	4.35	19	−62	38
Declive	*	44	4.03	−20	−64	−15
L. middle frontal gyrus	46	28	3.57	−44	23	20
R. middle frontal gyrus	46	47	3.39	40	26	25
Upright faces vs. inverted faces						
	No activation region					
Inverted faces vs. upright faces						
R. precentral gyrus	6	254	4.23	38	3	32
R. fusiform gyrus	37	137	4.16	43	−62	−12
R. superior parietal lobule	7	258	4.15	24	−56	41
L. fusiform gyrus	37	280	3.88	−40	−55	−9
L. superior parietal lobule	7	102	3.56	−28	−58	43
R. middle occipital gyrus	18	53	3.65	32	−84	2
L. precentral gyrus	6	47	3.62	−38	0	27
L. inferior frontal gyrus	9	45	3.62	−55	7	31
L. fusiform gyrus	19	43	3.56	−29	−85	−11
R. precuneus	31	35	3.42	26	−72	27
L. middle occipital gyrus	19	47	3.38	−29	−86	3
R. middle occipital gyrus	19	28	3.3	32	−78	12
Upright houses vs. inverted houses						
R. inferior occipital gyrus	19	31	3.54	29	−85	−14
Inverted houses vs. upright houses						
L. inferior parietal lobule	40	32	3.71	−41	−43	41

The present study aims to examine the influence of presented orientation on Chinese character processing. The main finding of the present study is that the response pattern of characters processing can be modulated by characters' presented orientation. As indicated by ROI analysis, greater responses were elicited by the inverted characters and faces relative to their upright version within FCA, FOA and OOA. In contrast, there was not any difference in response between the upright and the inverted houses within each of those regions.

The locus of the FCA in the present study is highly consistent with that of VWFA [4], which is suggested to be involved in the orthographic-processing of words [19,4]. It is also suggested that such cortical region integrates shape elements into elaborated shape descriptions corresponding to whole objects [22], and its activation depends on the degree to which the shape processing is demanded [19]. The inversion increases the demands of orthographic-processing and shape-analysis for characters, and thereby increases the response of such region. It is not clear why the inverted faces also elicit more response than the upright faces within FCA. One possible explanation may be that it needs more efforts to integrate the face features into a whole for the inverted faces than the upright faces.

Within FOA and OOA, the inversion-caused increases of response are observed for both characters and faces with the later in high agreement with recent studies [10,13,6]. It has been suggested the FOA and OOA are involved in the spatial arrangement of multiple object parts [20] and shape-analysis of elementary object [9], respectively. So, when the characters or faces are inverted, they may

Table 2
Conjunction analysis of [inverted characters vs. upright characters] and [inverted faces vs. upright faces], $p = 0.001$, voxel size >25.

Region	BA	Voxel	*Z*	Talairach		
				x	*y*	*z*
R. precuneus	7	119	4.54	22	−54	43
L. fusiform gyrus	37	253	4.41	−44	−66	−7
R. fusiform gyrus	37	112	4.39	48	−63	−7
L. precuneus	7	122	4.11	−22	−58	40
R. middle occipital gyrus	19	132	4.07	34	−77	11
L. middle occipital gyrus	19	94	3.82	−30	−83	12
R. inferior frontal gyrus	44	34	3.68	44	7	25

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be partly processed as the generic object, suggesting a shift from the character-preferential processing route to the generic object processing steam within visual cortex.

With respect to the FFA, there is not any inversion-caused change of response for each of the three categories. Previous studies have reported inconsistent results about the inversion effect for faces. Several studies reported inversion led to significant response decrease within FFA [10,27]. However, some recent studies [1,6] failed to find the difference in response between the upright and the inverted faces within FFA. The reason for such disagreement of the faces inversion effect within FFA is yet not clear. Further studies are needed to address this issue.

Compared to inverted characters, upright characters activate bilateral superior temporal gyrus, left superior frontal gyrus, right anterior cingulate, right cingulate gyrus and bilateral postcentral gyrus. Recent studies have demonstrated such regions participate in phonological coding, semantic representations and working memory retrieval [23]. In contrast, the inverted character processing recruits bilateral fusiform gyrus, middle occipital gyrus, and middle frontal gyrus. Fusiform gyrus and middle occipital gyrus are suggested to respond for the fine-gained analysis of the characters' visual-spatial information. Recently studies suggest the right middle frontal gyrus participates in processing orthography of Chinese characters, while the left middle frontal gyrus mediates the access to phonology and semantics [15]. Such results suggest that the processing of upright characters may focus on linguistic aspects such as phonology and semantics, while the processing of the inverted characters may focus more on the visual-spatial properties of characters. Further, as revealed by conjunction analysis, bilateral fusiform gyrus and bilateral middle occipital gyrus are commonly activated by the inverted characters and faces relative to their upright versions. This result is in agreement with the result of ROI analysis, suggesting the shift from the character-preferential or face-preferential processing route to generic object processing steam within visual cortex when the inverted characters or faces are processed.

In the present study, we examine the influence of presented orientation on Chinese character processing. We find different neuron processing mechanisms are recruited for the processing of the upright and the inverted Chinese character. Inversion leads to a shift from the character-preferential processing route to the generic object processing steam within the visual cortex when the inverted characters or faces are processed.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neulet.2010.04.075.

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