The modulation of stimulus structure on visual field asymmetry effects: the case of Chinese character recognition

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This is a draft version of a paper accepted for publication in *Quarterly Journal of Experimental Psychology*

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Abstract

Recent research suggests that visual field (VF) asymmetry effects in visual recognition may be influenced by information distribution within the stimuli for the recognition task in addition to hemispheric processing differences: stimuli with more information on the left have a right VF (RVF) advantage because the left part is closer to the center, where the highest visual acuity is obtained. It remains unclear whether visual complexity distribution of the stimuli also has similar modulation effects. Here we used Chinese characters with contrasting structures: left-heavy, symmetric, and right-heavy, in terms of either visual complexity of components or information distribution defined by location of the phonetic component, and examined participants' naming performance. We found that left-heavy characters had the largest RVF advantage, followed by symmetric and right-heavy characters; this effect was only observed in characters that contrasted in information distribution, in which information for pronunciation was skewed to the phonetic component, but not in those that contrasted only in visual complexity distribution and had no phonetic component. This result provides strong evidence for the influence of information distribution within the stimuli on VF asymmetry effects; in contrast, visual complexity distribution within the stimuli does not have similar modulation effects.

Keywords: divided visual field paradigm; optimal viewing position; visual field asymmetry; Chinese character recognition.

Acknowledgments

We are grateful to the Research Grant Council of Hong Kong (project # HKU 744509H to J.H. Hsiao). We thank Yan Yan Ting for her help on the preliminary study of this project. We thank the editor and two anonymous reviewers for helpful comments.

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Introduction

The divided visual field (VF) paradigm has been a standard method to assess hemispheric lateralization effects in the recognition of visual stimuli (Bourne, 2006). In the paradigm, a stimulus is presented briefly in either the left visual field (LVF) or the right visual field (RVF). According to the human visual pathway, information in the LVF is initially projected to the right hemisphere (RH), whereas that in the RVF is initially projected to the left hemisphere (LH). Thus, behavioral differences between these two VF conditions may reflect hemispheric processing differences. Consistent with this assumption, VF asymmetries observed in this paradigm have been consistent with hemispheric lateralization effects in brain imaging studies. For example, in visual word recognition, the RVF advantage in English word naming (Bradshaw & Gates, 1978; Brysbaert & d'Ydewalle, 1990) and lexical decision (Barry, 1981; Measso & Zaidel, 1990) is consistent with fMRI studies showing a region within the left fusiform area (Visual Word Form Area, VWFA) selectively responding to words (e.g., Cohen et al., 2000; 2002; McCandliss, Cohen, & Dehaene, 2003) and a left-lateralized frontal network involved in word production that may modulate the lateralization of the VWFA (e.g., Van der Haegen, Cai, & Brysbaert, 2012). Also, in face recognition, a region within the fusiform area (Fusiform Face Area) is shown to selectively respond to faces with greater activation in the RH than the LH (Kanwisher, McDermott, & Chun, 1997), consistent with the LVF advantage observed in divided VF studies of face recognition (Ellis & Shepherd, 1975; Young, 1984).

In the divided VF paradigm, it has been suggested that stimuli should be presented outside foveal vision (usually 2-3° of visual angle at the center; Ellis & Brysbaert, 2010) since the human foveal representation is bilaterally projected to both hemispheres (Huber, 1962; Stone, Leicester, & Sherman, 1973). Nevertheless, recent research has suggested that the human foveal representation may also be split and contralaterally projected (Brysbaert, 2004; Lavidor & Walsh, 2004; Ellis & Brysbaert, 2010); accordingly, hemispheric lateralization effects can still be obtained when stimuli are presented within foveal vision. Jordan and Paterson (2009) recently questioned the viability of this split fovea claim by pointing out potential problems in maintaining accurate fixations in experiments that required participants to fixate a particular location within a word, and in the accuracy of reporting results from previous studies that were argued to support the split fovea claim (see also Jordan, Paterson, Kurtev, & Xu, 2009; and the responses in Ellis and Brysbaert, 2010). Thus, the split fovea claim remains controversial.

In recent years, an optimal viewing position (OVP) effect in visual word recognition has been reported. The OVP refers to the location to which the initial fixation is directed when the best recognition performance is obtained (O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984). In English word recognition, the OVP is to the left of the word center (with most of the word in the RVF). Different factors have been proposed to account for this asymmetric OVP effect, including (1) hemispheric lateralization: language processing is lateralized to the LH; (2) information distribution within the stimuli: English word beginnings are more informative for recognition than word endings; (3) perceptual learning: readers fixate word beginnings the most often during reading (Brysbaert & Nazir, 2005). Brysbaert, Vitu, and Schroyens (1996) suggested that these factors may also account for the RVF advantage in English word recognition, as both effects could be observed in an extended OVP curve that had a Gaussian distribution with the mode shifted to the left of the word center across both central and peripheral vision. More specifically, there is greater variability in English word beginnings than endings; thus word beginnings are usually more informative for recognition than endings (Shillcock, Ellison, & Monaghan, 2000). Consequently, word recognition may be facilitated when a word is presented in the RVF, since the word beginning is closer to the fixation location, where the highest visual acuity is obtained, than the word ending (Lindell & Nicholls, 2003). Also, since English is read from left to right and readers fixate word beginnings the most often during reading (the preferred viewing location, PVL, Rayner, 1979), words are recognized in the RVF more often than the LVF (Nazir & O'Regan, 1990); this may account for the RVF advantage in English word processing.

Since the three factors all predict a RVF advantage in English word recognition, the relative contribution from each factor remains unclear. To demonstrate the influence of hemispheric lateralization, Brysbaert (1994) showed that individuals with RH language lateralization had a rightward shifted OVP in visual word recognition compared with individuals with LH language lateralization. Also, Hsiao and Liu (2012) examined the OVP effect in face recognition and showed that perceptual learning had greater influence on the OVP effect than hemispheric lateralization did in central vision, whereas hemispheric lateralization effects started to emerge in peripheral vision. In contrast, the modulation of information distribution within the stimuli was not consistently observed in studies with words in alphabetic languages. Farid and Grainger (1996) compared the OVP of prefixed words (which have a more informative word ending) and suffixed words (which have a more informative word beginning) and found that the modulation of information distribution within the stimuli was observed in Arabic but not in French words (see also Holmes & O'Regan, 1987; 1992; Brysbaert et al., 1996). This insensitivity to information distribution of the words in French may be because the differences in information distribution among the words were too small to allow the effect to emerge. In addition, visual complexity distribution of the stimuli may also have similar modulation effects on VF asymmetry effects in recognition, since identification of stimulus parts in different locations of the VF can be influenced by both eccentricity and visual complexity of the stimulus parts due to visual acuity decrease and crowding effects in peripheral vision (see, e.g., Bernard & Chung, 2011; Sun, Chung, & Tjan, 2010). Nevertheless, this issue has never been examined in the literature to our knowledge, possibly because visual complexity distribution of either words in alphabetic languages or faces does not have obvious asymmetries for the examination of this effect.

Thus, to examine how stimulus structure modulates VF asymmetry effects in recognition, here we conduct a Chinese character recognition study because of some unique characteristics of Chinese orthography that enable us to tease apart and test on factors that are difficult to examine with other types of stimuli. First, in contrast to English text reading, in Chinese text reading readers do not have a tendency to fixate a particular location in a character more often than other locations, possibly because the length of a character is too short to allow the PVL phenomenon to emerge (Tsai & McConkie, 2003; see also Yan et al., 2010, Li, Liu, & Rayner, 2011). Thus, the influence from perceptual learning is minimized. In addition, in Chinese orthography there exist characters with contrasting structures in terms of visual complexity of components: right-heavy, left-heavy, and mirror-symmetric structures. As shown in Figure 1, both left-heavy and right-heavy characters consist of two components (radicals) arranged in a left-right structure. In right-heavy characters, the right radical has more strokes and is visually more complicated than the left radical, and thus the overall visual information is skewed to the right; vice versa for left-heavy characters. These characters provide a unique opportunity to examine the effect of visual complexity distribution within the stimuli on VF asymmetry effects in recognition. We hypothesize that, in right-heavy characters, hemispheric lateralization effects measured using the divided VF paradigm will be influenced by a LVF advantage created by the position of the visually more complicated, right component being presented closer to the center (vice versa for left-heavy characters).

(Figure 1 about here)

In addition to visual complexity distribution, Chinese characters may differ in information distribution for pronunciation. A majority of characters (about three-quarters; Hsiao & Shillcock, 2006) are phonetic compounds, which consist of a phonetic radical and a semantic radical. The phonetic radical usually provides information about the character pronunciation, whereas the semantic radical typically has information about the character meaning. Thus, when pronouncing a phonetic compound, the information is skewed to the phonetic radical position. About two-thirds of phonetic compounds have a left-right structure; about 90% of them have their phonetic radical on the right (sP characters); the rest 10% have an opposite arrangement (Ps characters). These characters enable us to examine the modulation of information distribution within the stimuli on VF asymmetry effects. Since phonetic radicals usually have more strokes and are visually more complicated than semantic radicals, most sP characters have a right-heavy configuration in terms of visual complexity, and most Ps characters have a left-heavy structure. In addition to phonetic compounds, ideographs are another type of compound characters, and the meaning of an ideograph is a composition of the meanings of it components. Similar to phonetic compounds, ideographs can also have either a left-heavy, symmetric, or right-heavy configuration in terms of visual complexity. In contrast to phonetic compounds, ideographs do not have a phonetic radical, and thus the information distribution for pronunciation is not as skewed to a particular component as in phonetic compounds. This contrast between phonetic compounds and ideographs provides a unique opportunity to examine whether VF asymmetry effects in recognition can be modulated by information distribution within the stimuli or simply by visual complexity distribution within the stimuli.

Previous divided VF studies of Chinese character recognition have generally shown a LVF/RH advantage in orthographic processing and a RVF/LH advantage in phonological processing. For example, in a character matching task, Yang and Cheng (1999) showed that when the orthographic similarity of two alternative items for choice was manipulated, there was a LVF/RH advantage (see also Tzeng, Hung, Cotton, & Wang, 1979; Cheng & Yang, 1989); in contrast, when the phonological similarity of two alternative items for choice was manipulated, there was a RVF/LH advantage. Leong, Wong, Wong, and Hiscock (1985) showed a LVF/RH advantage in a lexical decision task that depended on character configuration, and a RVF/LH advantage when participants were required to match characters according to pronunciations. Consistent with these behavioural findings, fMRI studies of Chinese character recognition usually showed RH lateralized/bilateral activation in the visual system, and a LH lateralized frontal network for phonological processing (Tan et al., 2000; Tan et al., 2001; Fu, Chen, Smith, Iversen, & Matthews, 2002; Chen, Fu, Iversen, Smith, & Matthews, 2002; Kuo et al., 2001; Tan, Laird, Li, & Fox, 2005; note however that Xue et al., 2005, showed left-lateralized activation in the fusiform area and no asymmetry in the primary visual area in primary school children performing semantic and phonological tasks with Chinese characters). Nevertheless, it remains unclear how different character structures can modulate VF asymmetry effects in character recognition.

Here we contrast the processing of phonetic compounds and ideographs in three different configurations in terms of visual complexity: right-heavy, symmetric, and left-heavy (Figure 1). We present these characters at five different horizontal locations across the VF (far-LVF, near-LVF, center, near-RVF, and far-RVF) to obtain an extended OVP curve (Brysbaert et al., 1996). We predict that in naming symmetric characters, participants will show the typical RVF advantage that reflects LH lateralization in phonological processing; in addition to the influence from hemispheric lateralization, the naming performance of left- and right-heavy characters across the VF will be modulated by the asymmetry in character structure in terms of either information or visual complexity distribution within the stimuli. If the modulation mainly depends on visual complexity distribution within the stimuli, both phonetic compounds and ideographs will have similar modulation effects; in contrast, if the modulation mainly depends on information distribution within the stimuli, the modulation effect will only be observed in phonetic compounds but not in ideographs.

Methods

Materials

The materials consisted of 360 Chinese characters in three visual complexity configurations: 120 of them had a mirror-symmetric configuration, another 120 had a right-heavy configuration, and the other 120 had a left-heavy configuration. In each character configuration, half of the characters had a phonetic radical (i.e., phonetic compounds), and the other half did not have a phonetic radical (i.e., ideographs). Here we refer to symmetric characters as Syp (phonetic compounds) and Sys (ideographs) characters, right-heavy characters as sP (phonetic compounds) and sS (ideographs) characters, and left-heavy characters as Ps (phonetic compounds) and Ss (ideographs) characters (Figure 1). In the materials, sP-sS character pairs and Ps-Ss character pairs were matched in character frequency (Ho, 1998), structural complexity, i.e., number of strokes in the left and right components (paired-t-tests, n.s.), and combinability/orthographic neighbourhood size of their left and right components, i.e., number of components that can be combined with the left/right component to form an existing character with a similar (left-right) structure (according to Zhongwen.com, Harbaugh, 1998; paired-t-tests, n.s.; see also Hsiao, Shillcock, & Lavidor, 2006; 2007; cf. Andrews, 1997.)[1]. Also, there were no significant differences in character frequency and number of strokes between any two of the six character types (t-tests, n.s.). The characters in the materials were around the medium to high frequency range (Ho, 1998; the median character frequency in the database was 16, and that in the materials was 85).

In Chinese orthography, phonetic radicals can usually be stand-alone characters, and a phonetic compound and its phonetic radical may have the same pronunciation and tone (regular characters), the same pronunciation but a different tone (semi-regular characters), or different pronunciations (irregular characters; Hue, 1992); the phonetic radical of an irregular character may have the same pronunciation onset (alliterating) or rhyme (rhyming) as the character, or a completely different pronunciation (radically irregular; Hsiao & Shillcock, 2006). Among the sP characters in our materials, 45 were regular/semi-regular, and 15 were alliterating/rhyming. In the Ps characters, 42 were regular/semi-regular, and 18 were alliterating/rhyming. In the Syp characters, 42 were regular/semi-regular, and 18 were alliterating/rhyming (according to Cantonese phonology). Radically irregular characters were not used here since we aimed to investigate the effect of phonetic radical position when the phonetic radical conveyed useful information towards the character pronunciation.

The relationship between phonetic compounds and their phonetic radicals can also be described in terms of consistency: a phonetic compound is consistent if all characters containing the same phonetic radical have the same pronunciation (Fang, Horng, & Tzeng, 1986; Han, Bi, Shu, & Weekes, 2005; Lee et al., 2005). The consistency index of a character can be calculated as the percentage of characters that have the same pronunciation as the character among all characters that have the same phonetic radical as the character (Fang et al., 1986). In our materials, the average consistency index of the phonetic compounds was 64.6% (according to Zhongwen.com, Harbaugh, 1998); there was no significant difference in consistency index between any two of the three types of phonetic compounds (t-tests, n.s.).

Participants

We recruited 48 native traditional Chinese readers from Hong Kong (Cantonese speaking) with 24 males and 24 females. They were all students at the University of Hong Kong with a mean age of 20 years and 6 months; all right handed according to the Edinburgh handedness inventory (Oldfield, 1971); all with normal or corrected to normal vision. Participants received some honorarium for their participation.

Design

The design had three within-subject variables: VF location (far-LVF vs. near-LVF vs. center vs. near-RVF vs. far-RVF), character structures in terms of visual complexity (left-heavy vs. symmetric vs. right-heavy), and phonetic radical (phonetic compounds vs. ideographs). The dependent variable was the response time (RT) to begin a correct character pronunciation[2]. The characters were displayed in Ming front, each measured $1.5 \times 1.5\ cm^2$ on the screen with a viewing distance of 57 cm; under this viewing distance, each character spanned about 1.5° of visual angle, similar to those used in previous studies of Chinese character recognition (Hsiao & Cottrell, 2009; Hsiao & Liu, 2010); its width was equivalent to that of a five-letter word used in previous OVP studies of words in alphabetic languages (Brysbaert, 1994; O'Regan et al., 1984).

We defined central vision as the vision within the central 3° of visual angle in the VF. Each character was presented at five different locations (Figure 2), either immediately outside and to the left of central vision (far-LVF), immediately to the left of the fixation point within central vision (near-LVF), at the fixation point (center), immediately to the right of the fixation point within central vision (near-RVF), or immediately outside and to the right of central vision (far-RVF). This design allowed us to examine the extended OVP curve across central and peripheral vision (Hunter, Brysbaert, & Knecht, 2007; Brysbaert et al., 1996).

(Figure 2 about here)

To reduce any possible priming effects, each participant did not see each character appear at all five VF locations; instead, they saw each character appear at two different VF locations that were not next to each other in two different blocks; in total there were six different possible combinations of the two VF locations. Thus, each participant performed

720 trials of character naming with the set of 360 stimuli repeated once. The presented VF locations for each stimulus were counterbalanced across participants through a Latin square design; as the results, six Latin square groups were created. To account for this difference in Latin square group among the participants, we included a Latin-square variable as a between-subject variable in the design (Pollatsek & Well, 1995; Brysbaert, 2007; Hsiao & Liu, 2010). For a participant and for each character type, the characters appeared at the five VF locations were matched in character frequency and number of strokes (for any two locations among the five, t-tests, n.s.). The 720 stimuli were put into 12 blocks with 60 stimuli each; among the 60 stimuli there were 10 characters from each of the six character types; among these 10 characters, there were 2 characters presented in each of the five VF locations. The block order was counterbalanced through a Latin square design across participants, and the stimulus presentation order in each block was randomized. Participants took a short break between blocks.

The experiment was conducted using E-Prime v2.0 Professional Extensions for Tobii (Psychology Software Tools, Inc.). To ensure participants accurately fixated at the fixation cross before the stimulus presentation, their eye movements were monitored by a Tobii T120 eye tracker (Tobii technology, Stockholm, Sweden), an infrared video-based eye tracking system with a high-resolution camera integrated into a 17” TFT monitor (1280×1024 pixels); it has 0.5° tracking accuracy[3]. Binocular tracking was used, and the tracking mode was bright and dark pupil tracking with automatic optimization at the data rate 120Hz. A chinrest was used to reduce head movements. Calibration was performed before the start of each block.

Procedure

Each trial began with a fixation cross at the center (Its horizontal length was 1.5 mm, which was 10% of the character size; its vertical length was 3mm); the participant was asked to accurately look at the cross whenever it appeared (Figure 3). When the eye tracker detected that the participant was foveating the fixation cross, a red box appeared around the cross. The experimenter then pressed a key to present the target character for 150 ms; this brief presentation time minimized the possibility of the character being foveated due to participants' eye movements towards the character when the character was presented off-center (Brysbaert, 1994; Hsiao & Shillcock, 2005; Bourne, 2006). The participant was asked to pronounce the character as fast as possible (in Cantonese). The RT was measured as the time difference between the character presentation onset and the participant's pronunciation onset, detected by a microphone. The character was replaced by a symbol '*' after the presentation, and the symbol disappeared after the participant's pronunciation onset. The screen then turned blank, and the experimenter pressed a key to record the correctness of the pronunciation and start a new trial.

(Figure 3 about here)

Results

Trials with naming or pronunciation detection errors were excluded from data analysis. The repeated measures ANalysis Of VAriance (ANOVA) was used[4]. As shown in Figure 4, the results showed a main effect of VF location, $F(4, 144) = 57.970$, $p < .001$, $MSE = 780.513$: characters presented in the RVF locations were named faster than corresponding locations in the LVF; and a main effect of character structure, $F(1.660, 59.745) = 74.928$, $p < .001$, $MSE = 900.116$ (Note that the Greenhouse-Geisser correction was applied whenever there was a violation of sphericity): symmetric characters were named faster than right-heavy characters, followed by left-heavy characters (This character structure effect was also found when we examined the central position alone, $F(2, 72) = 27.265$, $p < .001$, $MSE = 518.347$). There was an interaction between VF location and character structure, $F(5.943, 293.953) = 2.506$, $p < .05$, $MSE = 792.139$. Importantly, a three-way interaction among VF location, character structure, and phonetic radical was also observed, $F(8, 288) = 2.362$, $p < .05$, $MSE = 463.424$, suggesting that both character structure and phonetic radical could modulate the VF location effect.

(Figure 4 about here)

To better understand what these interactions suggest regarding VF asymmetry effects, we examined lateralized VF locations (far-LVF, near-LVF, near-RVF, and far-RVF) in a separate analysis. We defined the variable visual field as the VF that the character was presented in (LVF or RVF), and the variable eccentricity as whether the character was presented in central or peripheral vision (i.e., near or far). Repeated measures ANOVA was used, with VF (LVF vs. RVF), eccentricity (central vs. peripheral vision), character structure (left-heavy vs. right-heavy vs. symmetric), and phonetic radical (phonetic compounds vs. ideographs) as within-subject variables. The results showed a main effect of VF, $F(1, 42) = 61.450$, $p < .001$, $MSE = 945.127$: characters were named faster in the RVF than the LVF; and a main effect of eccentricity, $F(1, 42) = 119.433$, $p < .001$, $MSE = 761.019$: characters were named faster in central than peripheral vision. There was an interaction between VF and eccentricity, $F(1, 42) = 7.412$, $p < .01$, $MSE = 762.797$: the VF effect was weaker in central than peripheral vision (Figure 5). When we examined the data in central and peripheral vision separately, the VF effect was significant in both central vision, $F(1, 42) = 17.939$, $p < .001$, $MSE = 766.233$, and peripheral vision, $F(1, 42) = 53.080$, $p < .001$, $MSE = 941.692$. These effects were also observed when we examined symmetric characters alone, in which the influence from character structure on VF asymmetry effects was minimized: there was an interaction between VF and eccentricity, $F(1, 42) = 4.263$, $p < .05$, $MSE = 660.584$; the RVF advantage was significant in both central vision, $F(1, 42) = 6.061$, $p < .05$, $MSE = 376.071$, and peripheral vision, $F(1, 42) = 18.095$, $p < .001$, $MSE = 833.253$ (Figure 5). The effect that

VF difference could be observed in central vision (within 3°) was consistent with the split fovea theory (Ellis & Brysbaert, 2010), although it was stronger in peripheral vision.

(Figure 5 about here)

In addition, there was a main effect of character structure, $F(1.700, 71.421) = 61.598$, $p < .001$, $MSE = 814.987$, and more importantly, there was a three-way interaction among VF, character structure, and phonetic radical, $F(2, 84) = 4.764$, $p < .05$, $MSE = 449.908$. This effect suggests that phonetic compounds and ideographs had different interaction effects between VF and character structure. To better understand this three-way interaction, we examined the data of phonetic compounds and ideographs separately. The results showed that the interaction between VF and character structure was significant in phonetic compounds, $F(2, 84) = 5.735$, $p < .01$, $MSE = 326.381$, but not in ideographs, $F(2, 84) = 1.167$, n.s. As shown in Figure 6, among phonetic compounds, Ps characters had the largest VF effect, $F(1, 42) = 62.590$, $p < .001$, $MSE = 406.127$, followed by Syp characters, $F(1, 42) = 19.246$, $p < .001$, $MSE = 437.952$, and sP characters, $F(1, 42) = 14.257$, $p < .001$, $MSE = 436.365$. The data in naming Syp (symmetric) characters demonstrated that when the influence from character structure on VF effects due to visual acuity drop-off was minimized, there was a RVF advantage in character naming, which may reflect LH lateralized phonological processing. In naming Ps characters, this RVF advantage may have been increased by the position of the more informative, left phonetic radical being closer to the center when the character was presented in the RVF than the LVF. As for sP characters, this RVF advantage may have been offset by the position of the right phonetic radical being farther away from the center when the character was presented in the RVF than the LVF (Figure 7). In contrast to phonetic compounds, this interaction between VF and character structure was not observed in ideographs (Figure 6). This phenomenon suggested that the modulation of stimulus structure on VF asymmetry effects was not due to the asymmetry in visual complexity distribution;

instead, it depended on information distribution within the stimuli for the task. More specifically, the phonetic radical is the most informative component for naming phonetic compounds; in contrast, for ideographs, all character components may contribute similarly to the pronunciation regardless of their visual complexity, and thus the modulation effect of character structure was not observed.

(Figures 6 and 7 about here)

Discussion

Here we investigated whether VF asymmetry effects in the recognition of visual stimuli can be influenced by information distribution or visual complexity distribution within the stimuli: stimuli with more information for recognition or higher visual complexity on the left may have a RVF advantage due to the more informative/visually complicated left part being presented closer to the center, where the highest visual acuity is obtained. The modulation effect of information distribution within the stimuli has been proposed in previous studies of visual word recognition; nevertheless, the effect was not consistently found in words in alphabetic languages, possibly because the differences in information distribution among words were too small to allow the effect to emerge. In addition, it remains unclear whether visual complexity distribution within the stimuli also has a similar modulation effect. Here we used Chinese character stimuli because Chinese orthography provides a unique opportunity to examine the modulation of stimulus structure in terms of either visual complexity distribution or information distribution for recognition. We contrasted characters with and without a phonetic radical (i.e., phonetic compounds and ideographs) in left-heavy (Ps and Ss characters), symmetric (Syp and Sys characters), and right-heavy configurations (sP and sS characters) in terms of visual complexity, and examined participants' naming performance when the characters were presented at different horizontal VF locations. The results showed an interaction between VF and character structure in phonetic compounds, but not in ideographs. Among phonetic compounds, Ps characters showed the largest RVF advantage, followed by Syp characters and then sP characters. In contrast, in ideographs, Ss, Sys, and sS characters showed a similar RVF advantage effect to one another (Figure 6). This result suggests that the modulation of stimulus structure on VF asymmetry effects in recognition depends on information distribution within the stimuli (i.e., the location of the most informative component for the task, the phonetic radical), instead of visual complexity distribution. It also suggests that the modulation effect of stimulus structure may depend on top-down attentional modulation rather than low-level visual features.

Previous research proposed three factors that may account for VF asymmetry effects in recognition: (1) hemispheric lateralization, (2) information distribution within the stimuli, and (3) perceptual learning due to eye fixation behavior (Brysbaert & Nazir, 2005). Since Chinese readers do not have a tendency to fixate a particular location in a character more often than other locations during reading (Tsai & McConkie, 2003), the influence from perceptual learning is minimized. By using characters with different structures, our results provide strong evidence for the influence from information distribution within the stimuli, instead of low-level visual complexity distribution of the stimuli. This effect also demonstrates that not all VF asymmetry effects in recognition suggest hemispheric processing differences; they may be due to information distribution within the stimuli for the recognition task (see also Hsiao, 2011), or perceptual learning effects due to eye fixation behavior (Hsiao & Liu, 2012).

Hsiao and Liu (2012) showed that in face recognition, perceptual learning had greater influence on VF asymmetry effects than hemispheric lateralization did when faces were presented within central 8° of visual angle, whereas the RH (LVF) advantage in face recognition started to emerge when faces were presented outside central 8° of visual angle.

This effect suggests greater influence from perceptual learning on VF asymmetry effects in central vision than in peripheral vision. Here we observed modulation effects of information distribution of the stimuli on VF asymmetry effects in Chinese phonetic compound recognition; although this effect did not significantly interact with presentation eccentricity, $F(1.742, 73.178) = 1.169$, n.s., post hoc analysis showed that this effect was significant when phonetic compounds were presented in central vision, $F(2, 84) = 5.684$, $p < .01$, $MSE = 420.926$, but not when they were presented in peripheral vision, $F(1.578, 66.264) = .315$, n.s. This suggests that the modulation of information distribution of the stimuli may also be stronger in central than peripheral vision because of the steeper visual acuity drop-off in central than peripheral vision. In addition, when we examined the processing of sP characters alone, in which a RVF/LH advantage has been consistently reported (Hsiao & Liu, 2010, Weekes & Zhang, 1999), similar to Hsiao and Liu's (2012) results, there was a significant interaction between VF and eccentricity, $F(1, 42) = 5.394$, $p < .05$, $MSE = 549.387$ (this interaction was not significant in Ps or Syp characters): the RVF advantage was significant only in peripheral vision but not in central vision. This effect again demonstrated greater influence from information distribution within the stimuli in central than peripheral vision. Thus, complementing Hsiao and Liu's (2012) results, our results suggest that the influence from information distribution within the stimuli may also be stronger in central than peripheral vision.

Here we observed VF asymmetry effects when symmetric characters were presented within the central 3° of visual angle. This effect may have reflected LH lateralization in phonological processing, since with symmetric stimuli the influence from information distribution within the stimuli was minimized. This phenomenon suggests that hemispheric asymmetry effects can be obtained within central (3°) vision. Note however that our study was not a strict test for the split fovea claim, as our stimuli spanned about 1.5° of visual angle and were presented within central 3° of visual angle, in contrast to those used in previous studies examining the split fovea claim, which were usually presented within central 1-2° of visual angle (Hsiao & Shillcock, 2005; Hsiao, Shillcock, & Lee, 2007; Lavidor & Walsh, 2003). Thus, our results could not rule out the possibility that a small region within central vision is bilaterally projected, resulting in the weaker VF asymmetry effect in central than peripheral vision. Further investigation is required to examine this possibility.

Here we also found that in Chinese character recognition, with character frequency and visual complexity controlled, in general symmetric characters were named the fastest, followed by right-heavy characters, whereas left-heavy characters were named with the longest RT. Note that the advantage in naming symmetric characters could not be accounted for by character type frequency in Chinese orthography, since the right-heavy structure is the most frequent structure; it could not be accounted for by difference in component combinability either, since in our stimuli the right-heavy characters had the largest component combinability (36.7 on average across left and right components), and the left-heavy characters had the smallest component combinability (11.5 on average). One possibility is the facilitation of symmetry in visual processing. It has been shown that people are remarkably sensitive to mirror-symmetric patterns, especially to those with a vertical axis of symmetry and being centrally fixated (Corballis & Roldan, 1975; Barlow & Reeves, 1979; Wenderoth, 1994); mirror symmetry is argued to be detected preattentively (Locher & Wagemans, 1993). This processing efficiency may be related to the mirror symmetry of the human visual system and the economical description of a mirror-symmetric pattern due to the redundancy in its form (Barlow & Reeves, 1979; Wagemans, 1997; Brady, 2011). Thus, the advantage in naming symmetric over right-heavy or left-heavy characters may be due to the facilitation of the mirror-symmetric structure. In contrast, the advantage of naming right-heavy characters over left-heavy characters may be related to the dominance of the right-heavy structure in Chinese orthography (Hsiao & Shillcock, 2006).

In summary, through examining the extended OVP curve in Chinese character recognition, here we show that VF asymmetry effects in recognition measured in divided VF studies can be influenced by information distribution of the stimuli for the recognition task due to the visual acuity drop-off from center to periphery: stimuli with a left-heavy information distribution have an advantage for recognition in the RVF, since the more informative left half is closer to the center, where the highest visual acuity is obtained (and vice versa for those with a right-heavy information distribution). In contrast, low-level visual complexity distribution within the stimuli alone does not have similar modulation effects, suggesting that this effect may depend on top-down attentional modulation rather than low-level visual features. In addition, this influence from information distribution within the stimuli may have greater effects in central than peripheral vision, suggesting that presentation eccentricity is another factor that may influence VF effects measured in divided VF studies. The contrasting character structures in Chinese orthography provide a unique opportunity to demonstrate these effects. Thus, while the divided VF paradigm is a commonly used behavioral method for examining hemispheric asymmetry effects, caution is required in experimental design and data interpretation, as VF differences observed in the paradigm can be influenced by several factors other than hemispheric processing asymmetry.

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Footnotes

[1] Note that since semantic radicals usually have a larger combinability than phonetic radicals, in our right-heavy characters, the left component (the semantic radical) had a larger combinability than the right component; vice versa for the left-heavy characters. Note also that Cantonese and Mandarin share the same orthography and only differ in character pronunciation, and thus the orthographic properties of Chinese characters such as the functions of phonetic and semantic radicals and radical combinability apply to both Cantonese and Mandarin.

[2] Since the participants were all Chinese native speakers/readers and the characters in the materials were of medium-to-high frequency of usage, the participants all had high naming accuracy (97% on average) and thus the accuracy data were not analyzed here (Hsiao & Liu, 2010; Hsiao & Shillcock, 2005).

[3] The tracking accuracy of T120 Tobii eye tracker is similar to other eye tracking systems currently available, such as the Eyelink II system (SR Research Ltd., Canada). Despite of using the eye tracker to ensure participants' fixations, there may still be noise introduced in exact positioning of fixations due to the limitation of the eye tracker. Using an eye tracker with better accuracy, resolution, and sampling rates can reduce the noise.

[4] Here we reported the results of the analysis based on the average per condition per participant (i.e., subject analysis). Note however that all the effects reported here were also significant in the analysis based on the average per condition per stimulus (i.e., item analysis); effects that were significant in only one type of analysis were not reported.

Figures

Figure 1. Examples of different character structures.

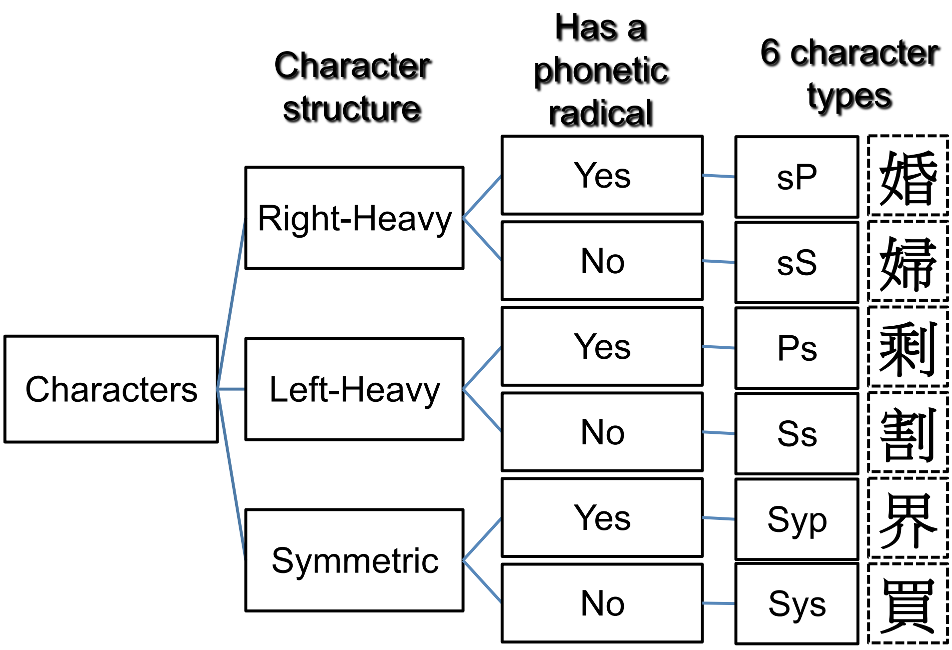

Figure 2. Five different VF locations in the experiment. The fixation point is indicated by the cross at the center.

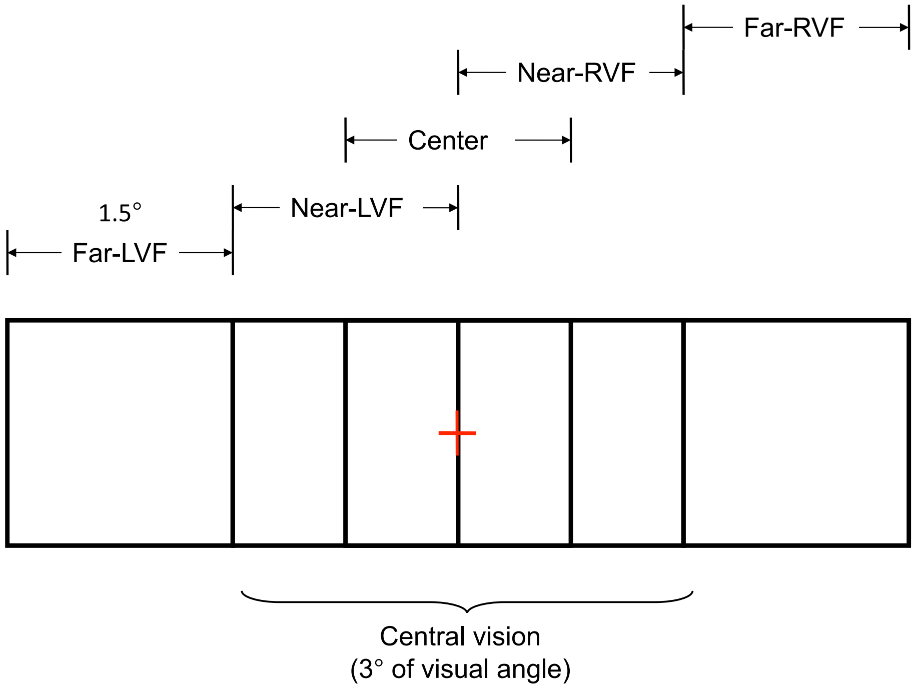

Figure 3. Procedure of the experiment. Participants were required to fixate the fixation cross at the beginning of a trial. A red box appeared around the fixation cross (here shown in grey) when the participant was accurately fixating the fixation cross.

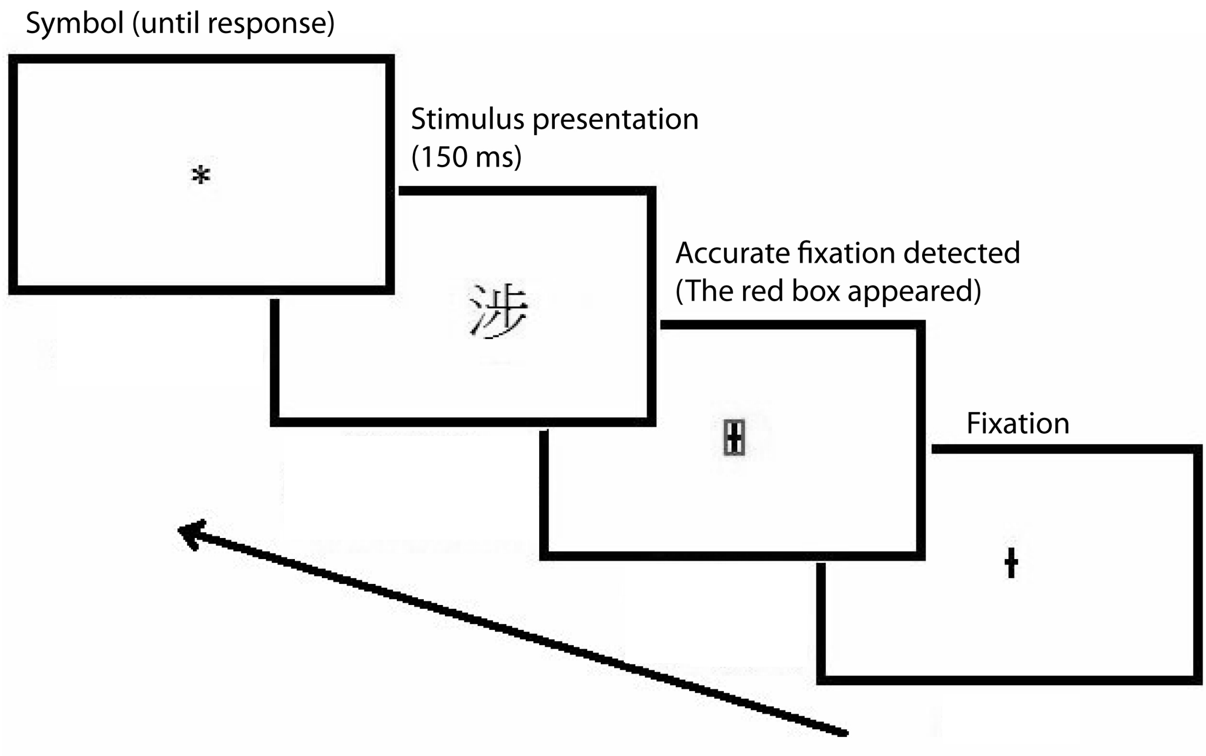

Figure 4. The extended OVP curves of the six character types.

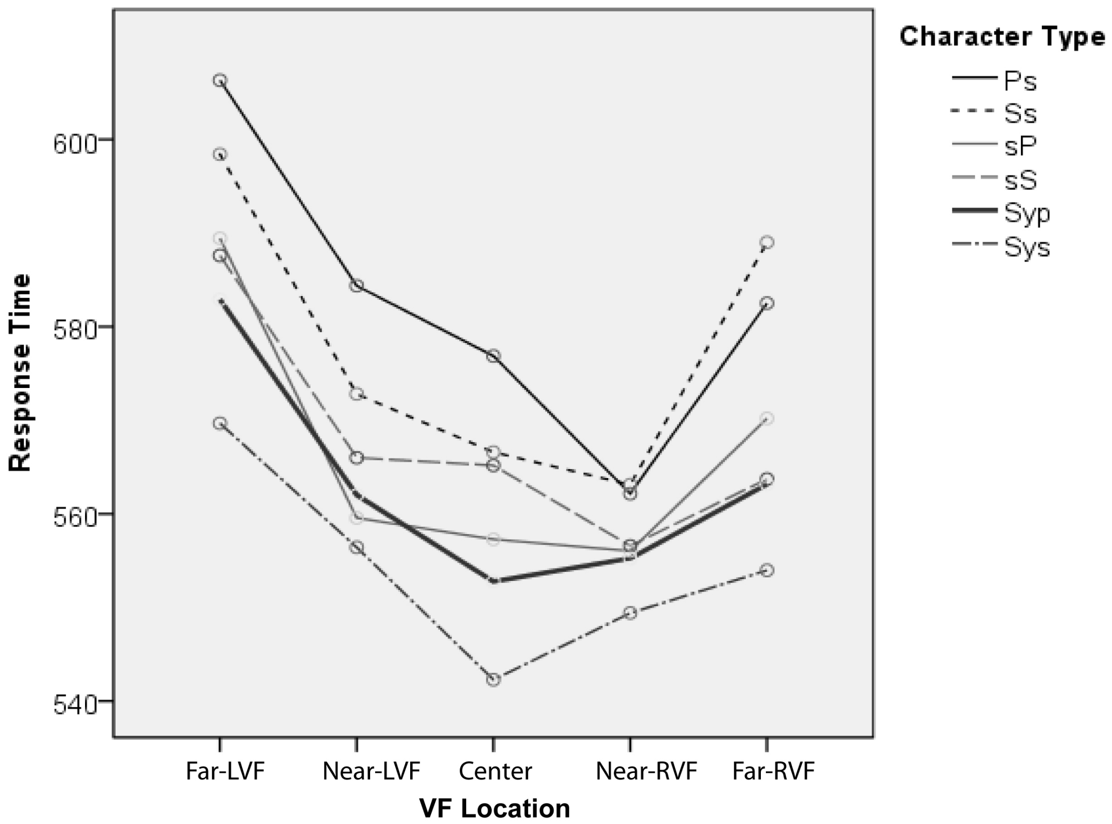

Figure 5. Naming RTs across different VF locations. Error bars show one standard error (** p < 0.01; *** p < 0.001).

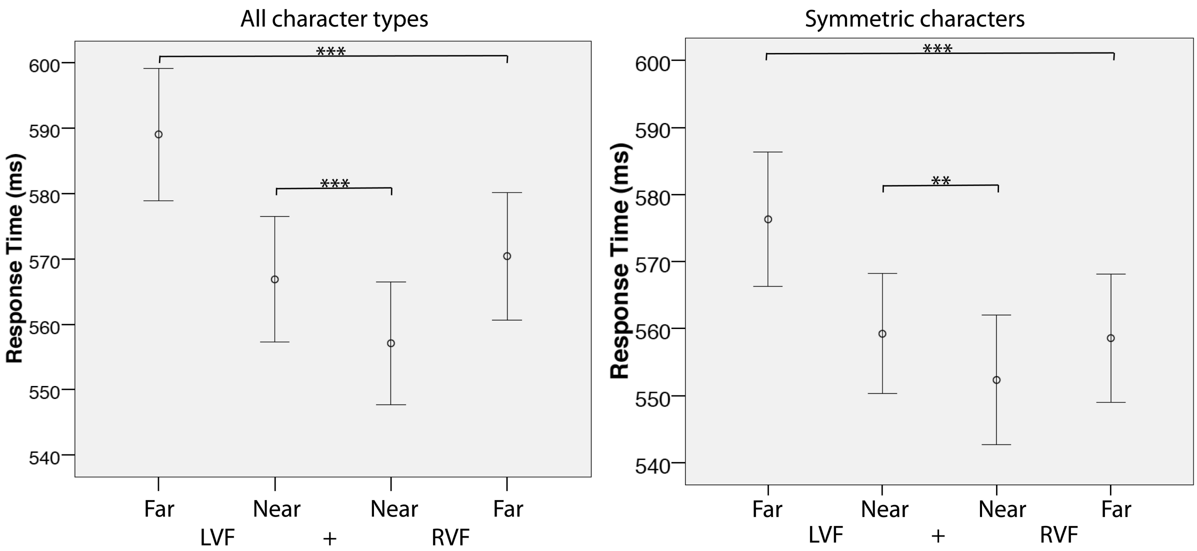

Figure 6. Naming RTs of six character types in the LVF and RVF with data collapsed across near and far eccentricity conditions. The interaction between VF and character structure was significant in phonetic compounds: Ps characters had the largest VF effect, followed by Syp and sP characters; in contrast, this interaction was not observed in ideographs. Error bars show one standard error (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

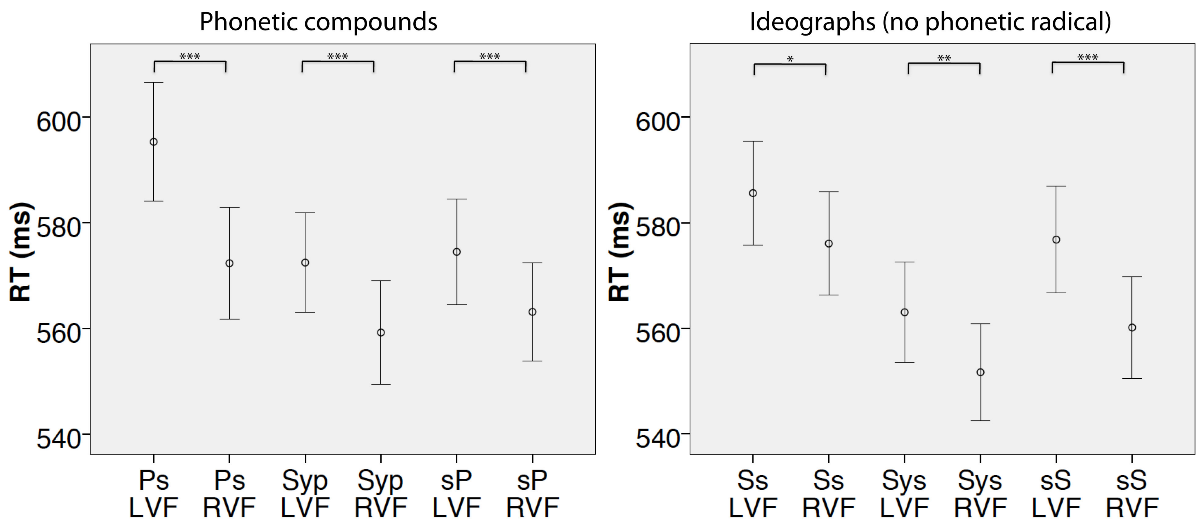

Figure 7. Relationship between visual acuity fall-off and information distribution of characters. The more informative, right phonetic radical of an sP character is closer to the center when being presented in the LVF than in the RVF. In contrast, the more informative, left phonetic radical of a Ps character is closer to the center when being presented in the RVF than the LVF.