Expert marker of Chinese character recognition: Left-side bias versus holistic processing?

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Abstract

Holistic processing and left-side bias are both behavioral markers of expert face recognition. In contrast, expertise in Chinese character recognition involves left-side bias but reduced holistic processing (Hsiao & Cottrell, 2009). Here we examine whether the reduction in holistic processing associated with expert Chinese character recognition can be better explained by writing rather than reading experience. Compared with non-Chinese readers (novices), Chinese readers who had limited writing experience (Limited-writers) showed increased holistic processing, whereas Chinese readers who could also write characters fluently (Writers) showed reduced holistic processing. These results suggest that writing/sensorimotor experience can modulate holistic processing effects, and that the reduced holistic processing observed in expert Chinese readers may depend on writing rather than reading experience. By contrast, both Writers and Limited-writers showed a similar level of left-side bias in processing symmetric Chinese characters, left-side bias may therefore be a consistent expertise marker for object recognition uninfluenced by motor experience.

Keywords: Chinese character recognition, holistic processing, reading, writing, left-side bias

Introduction

Holistic processing (HP) is the tendency to process separate features of an object as a single whole unit (Richler, Wong, & Gauthier, 2011), and it is shown to be a behavioral marker of face recognition expertise. Some have speculated that HP applies to other types of expert-level object recognition because it facilitates within-category discrimination by incorporating featural and configural information beyond individual parts (e.g., Bukach *et al.*, 2006; but for a contrasting view, see McKone *et al.*, 2007). For example, training participants to recognize novel artificial objects, Gauthier and colleagues (1998) found a positive correlation between HP and expertise in within-category object recognition. Wong and colleagues (2009) also showed that participants had an increase in HP when trained to individualize an artificial object type.

Left-side bias (LSB) is also consistently reported in face perception; it refers to the effect that a chimeric face made from two left half-faces is usually judged more similar to the original face compared with one made from two right half-faces from the viewer's perspective (Brady, Campbell, & Flaherty, 2005; Fig. 1), perhaps due to right hemisphere (RH) involvement in face recognition (Burt & Perrett, 1997).

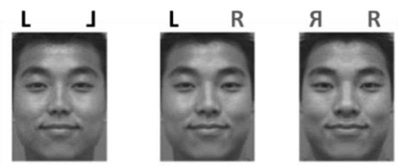

Fig. 1. Examples of chimeric face stimuli. Two left halves of an original face (middle) were combined to form the left chimeric face (left), and the two right halves formed the right chimeric face (right).

Chinese characters, sharing many visual properties with faces, may induce similar processing effects for expert readers in face recognition (McCleery *et al.*, 2008). More specifically, the Chinese writing system is logographic; Chinese characters have a homogenous, square configuration, and each character is a grapheme that maps onto a morpheme (Shu, 2003). Strokes are the basic units of Chinese characters which combine to form more than 200 basic stroke patterns in the Chinese writing system (Hsiao & Shillock, 2006); these stroke patterns in turn form the characters. A typical literate recognizes 3,000 to 4,000 characters. In addition, Chinese characters are generally recognized regardless of variations in font and handwriting style, similar to face recognition regardless of differences in facial expressions (Hsiao & Cottrell, 2009), and experts recognize Chinese characters individually like faces (Wong & Gauthier, 2006).

Indeed, similar to face recognition, Hsiao and Cottrell (2009) showed that expert Chinese readers demonstrated left side bias when viewing mirror-symmetric Chinese characters, whereas novices did not. Their finding suggests that LSB is an expertise marker for both face and Chinese character recognition and was consistent with research suggesting a RH involvement in Chinese orthographic processing (e.g. Yang & Cheng, 1999). However, unlike face perception, the expertise marker for Chinese character recognition turned out to be reduced HP (Hsiao & Cottrell, 2009). Experienced Chinese readers engage in less HP than novices in perceiving Chinese characters; perhaps they are more sensitive to the constituent components of Chinese characters and can more readily ignore some configural information unimportant for character recognition, such as exact distances between features (Ge *et al.*, 2006). Such constituent components may not look easily separable to novices, probably because novices are less able to distinguish individual features and components in Chinese characters (Ho, Ng, & Ng, 2003). Hsiao and Cottrell (2009) have therefore suggested that HP is not a general expertise marker for object processing; it depends on the features of the stimuli and the tasks typically performed on the stimuli (see also Wong *et al*., 2009).

Note however that learning to read Chinese characters is different from learning to recognize faces—for instance, while a typical Chinese reader can read and write characters proficiently, one is not expected to draw out all the faces seen every day. Thus, the reduced HP effect in expert Chinese character processing, in contrast to expert face processing, may be related to expert readers' writing rather than reading experience. Unlike writing alphabetic words, which only requires recalling a few dozens of letters in an alphabet together with the specific combinations corresponding to their sounds, writing Chinese characters requires retrieving more than a thousand pieces of script information from long term memory. One may have to attend analytically to detailed stroke patterns of individual Chinese characters in order to memorize and write them. Perhaps expert Chinese readers in Hsiao and Cottrell's (2009) study had reduced HP because of their writing experience. Indeed, Zhou and colleagues (2012) found that artists with face drawing experiences had reduced holistic face processing compared with ordinary observers.

In Hong Kong, although the internal structures of Chinese characters are not explicitly emphasized in formal lessons, Chinese children acquire better orthographic awareness as they progress to higher grades (Ho *et al*., 2003). One explanation has to do with motor programming through extensive copying and reading at school (Tan *et al.*, 2005). Copying performance (McBride-Chang *et al.*, 2011; Tan, *et al*., 2005), and dictation performance (McBride-Chang *et al.*, 2011) is correlated with reading performance. Writing performance may predict reading performance because children may consolidate knowledge of orthographic structures of characters with graphomotor memory of strokes as they copy the stroke sequences (Tan *et al*., 2005). Learning to write indeed seems to strengthen Chinese character recognition (Guan *et al*., 2011); writing experience also seems to shape the neural representation specialized for reading (e.g. James & Atwood, 2009; Longcamp *et al.*, 2003). Together, these results suggest a close relationship between increasing sensory-motor integration through writing practice and reading skills development.

However, Tso, Au and Hsiao (2011) identified some Chinese readers who have high reading proficiency but far poorer writing ability – whom we will call "Limited-writers (LW)". They are usually students or graduates of international schools who have learned to "write" in Chinese using computer software that converts input in a phonic alphabet (e.g., the Pinyin system) into Chinese characters, expatriates living in Chinese speaking countries, or overseas Chinese immigrants who learned to read in Chinese from environmental prints including Chinese mass media. Because writing in Chinese is more complex and resource-intensive than writing in an alphabetic language (Chan *et al*., 2006; Chung & Ho, 2010), marked discrepancy between reading and writing performance in Chinese is possible. With limited writing practice but plenty of reading experience, LW may recognize the holistic structures of characters similarly to face recognition, with limited analysis of the constituent structures. Thus, the cognitive processes involved in Chinese reading for LW may be different from readers who have received intensive character writing training (Writers). Without extensive writing experiences, these LW may still process Chinese characters holistically.

Here we aim to investigate whether perceptual expertise effects such as holistic processing (HP) and left-side bias (LSB) effects can be modulated by motor experience through examining how novices, Chinese Writers and limited-writers (LW) process Chinese characters. We first examine whether Writers perceive characters less holistically than LW, and whether the reduced HP effect is related to their reading and writing performance. Since writing practice may enhance orthographic awareness of characters and de-emphasize configural information in character recognition, Writers may perceive characters less holistically than LW, and this effect may be related to their difference in writing rather than reading performance – contrary to what the research literature suggests. The ability to perceive characters analytically (less holistically) may also be the underlying mechanism for how writing experience enhances Chinese character recognition. We also predict that compared to novices, increase in HP marks expert Chinese character recognition in LW whereas Writers show reduced HP.

We then examine whether LW and Writers have a similar LSB effect in Chinese character perception. Brady *et al*. (2005) showed that the LSB effect in face perception was stronger when viewing familiar faces compared with unfamiliar faces; this phenomenon suggests that the LSB effect may be related to familiarity with the stimuli. Since both Writers and LW are proficient readers and thus are familiar with Chinese characters, we predict that Writers and LW will have a similar degree of LSB in perceiving Chinese characters, while no LSB is shown in novices.

Methods

Participants

60 participants in Hong Kong participated in our study. 20 participants reported having no prior experiences in reading Chinese characters (i.e. novices); the remaining 40 were Cantonese native-speaking Chinese readers: 20 of them had always attended traditional local schools and reported to have fluent reading and writing proficiency (i.e., Writers), while 20 had either studied overseas or at international schools and had not received formal Chinese lessons that prepared students for the local public Chinese examinations (i.e., Limited-writers, LW). All LW reported being capable of reading Chinese but with limited writing ability. Writers' and LW's reading and writing abilities were tested by a word-naming and a dictation task respectively (see Procedures); their performance was used to corroborate their self-reports. That is, LW were expected to have similar

performance in the word-naming task as Writers, but have poorer performance in the dictation task (see Results). They were all right-handers, had normal or corrected-to-normal vision and similar college-level education background.

Procedures

Test for holistic processing

We adopted procedures from Hsiao and Cottrell (2009). 80 pairs of medium to high frequency Chinese characters in Ming font were chosen (character frequency information was obtained from Ho and Kwan, 2001). In each trial, participants were presented with two characters and instructed to attend to only half (either top or bottom) of each character and judge whether they were the same or different. Twenty pairs were presented in each of the four conditions (Fig. 2a): *same in congruent trials, different in congruent trials, same in incongruent trials, and different in incongruent trials*. The complete composite paradigm (Gauthier & Bukach, 2007) was adopted so that in congruent trials, the attended and irrelevant halves corresponded to the same response (i.e., both were the same or different) while in incongruent trials, the attended and irrelevant halves corresponded to different responses. Holistic processing was operationalized as the performance difference between the congruent and incongruent trials; it reflected the amount of interference from the irrelevant parts in the matching of the attended parts. This paradigm was adopted to avoid response biases that may occur in the partial composite design in which the irrelevant halves are always different (see Richler, Cheung, & Gauthier, 2011).

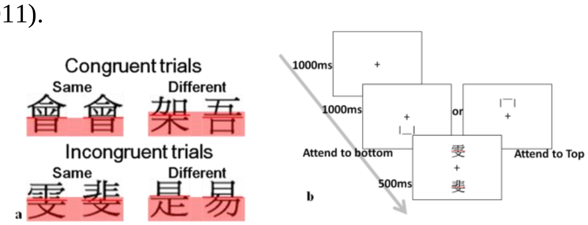

Fig. 2. (a) Illustration of stimulus pairs in the complete composite paradigm; the attended components are shaded in red. (b) Trial sequences.

After 1,000 ms of central fixation in each trial, participants were cued with a symbol that directed their attention to the particular halves of the stimuli. The pair of characters was then presented, with one above and one below the initial fixation point, followed by a mask. During the 500ms presentation time, participants looked at each character once and responded as quickly and accurately as possible by pressing corresponding buttons to judge if the character parts were the same or different (Fig 2b). We measured participants' discrimination sensitivity A' as:

$$A' = 0.5 + \left[sign(H - F) \frac{(H - F)^2 + |H - F|}{4\,max(H, F) - 4HF} \right]$$

H and F are the hit rate and false alarm rate, respectively. A' is a bias-free nonparametric measure of sensitivity; we did not use d' because response biases may affect its measurement when assumptions of normality and homogeneity of variance are not met(Stanislaw & Todorov, 1999). The A' difference between incongruent and congruent trials (i.e., Holistic A') measures HP—a more positive value marks a stronger HP effect.

Test for left-side bias

We adopted the procedure from Hsiao and Cottrell (2009). 80 Chinese mirror-symmetric characters of high frequency were selected (Ho & Kwan, 2001). There were a total of 160 trials with each character presented twice: once in Ming font (a common font in print) and once in Feng font (an unfamiliar font that simulates handwriting; Fig. 3). For characters presented in each font, mirror images were used in half of the trials; if a character was presented in Ming font, then the mirror image of the character was presented in Feng font, and vice versa; this was to counterbalance any differences between the two sides of each character. For each character, we counterbalanced the fonts used for the original and mirror-image characters across participants.

Fig. 3.An example of a Ming font (a) and a Feng font (b) character.

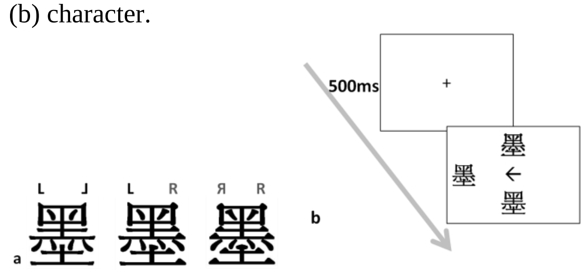

Fig. 4. (a) Examples of the stimuli, and (b) the test sequence in the LSB experiment(note that the chimeric characters are still legal Chinese characters).

For each character image, the left chimeric character was created from two left halves and the right chimeric character was created from two right halves of the character (Fig. 4a), similar to chimeric faces. Each character spanned about 6.7 degree of visual angle with a viewing distance of 55 cm. In each trial, after 1,000 ms of a central fixation, the original character was presented randomly either on the left or right side of the screen, at about 7.2 degree of visual angle away from the center. The left and right chimeric characters were presented along with the original image, with one above and one below an arrow at the center; the arrow directed the location of the original character at which participants were told to look first. Each character was about 3 degree of visual angle away from the center. The stimuli stayed on the screen until participants' response. Participants judged which of the two chimeric characters looked more similar to the original one by pressing the corresponding buttons (Fig. 4b). We measured the LSB effect as the percentage of trials in which the left chimeric character was selected.

Tests for reading and writing performance:

Naming and dictation tasks were administered to assess, respectively, reading and word recalling/writing abilities.

Naming task: Participants read aloud 40 two-character words arranged from high to low frequency (According to Taiwan Ministry of Education, 1997) as quickly and accurately as possible. Each trial started with a central fixation cross for 500ms, followed by the character presentation. After the response, the screen turned blank and the experimenter pressed a button to record the accuracy and to start the next trial. The response time was measured as the time difference between the stimulus onset and the onset of the pronunciation, detected by a microphone.

Dictation task: Participants wrote down 40 two-character words (same words as in the naming task) as quickly and as accurately as possible when they heard each word said in a female voice presented by a computer. Two-character words were used instead of characters to reduce ambiguity due to the many homophonic characters in the Chinese lexicon. Each trial started with the words "Get ready" on the screen for 500 ms. After hearing the word, participants pressed buttons to indicate whether they could recall the word or not, before they started writing. After they finished writing, the experimenter pressed a button to indicate accuracy and to reveal the next word. Accuracy was recorded.

These experiments were all conducted using E-prime v2.0 (Psychology Software Tools, Pittsburgh, PA).

Results

<u>Chinese reading and writing proficiency (Writers vs. LW)</u>

ANOVA revealed that Writers and LW did not differ in word naming accuracy, $F(1,38) = .471$, n.s., suggesting that both groups had high reading proficiency for words. Nevertheless, Writers had significantly shorter response times (RT) in word naming than LW, $F(1,38) = 12.365$, $p < .01$. In the dictation task, Writers were significantly more accurate than LW, $F(1, 38) = 140.53$, $p < .001$. Fig. 5a contrasts the discrepancy between dictation (word writing) and word naming accuracy in Writers and LW (i.e., they had similar word reading accuracy but differed in dictation/writing accuracy).

<u>Holistic Processing</u>

Repeated-measures ANOVA was used to investigate HP effects (congruency: congruent vs. incongruent x group: novices vs. LW vs. Writers). On *A′*, we found a main effect of congruency, $F(1,57) = 21.83$, $p < .001$, and an interaction between congruency and group, $F(2,57) = 5.421$, $p < .01$, but no main effect of group, $F(2,57) = .433$, n.s. Both novices and LW had a significantly smaller *A′* in incongruent trials than in congruent trials ($t(19) = 3.592$, $p < .01$, and $t(19) = 5.001$, $p < .001$, respectively), while this difference was not significant for Writers, $t(19) = 0.390$, n.s. In a post-hoc analysis, novices had a larger Holistic *A′* than Writers, $t(38) = 2.160$, $p < .05$, but a marginally small Holistic A' than LW, $t(38) = 1.58$, $p = 0.089$. LW had a larger Holistic *A′* than Writers $t(38) = 2.832$, $p < .01$ (Fig. 5b). For RT, we found a main effect of congruency, $F(1, 57) = 13.05$, $p < .01$, and an interaction between congruency and group, $F(2, 57) = 4.18$, $p < .05$, but no main effect of group, $F(1, 57) = 2.26$, n.s. LW responded significantly more slowly in incongruent trials ($M = 592$ms) than in congruent trials ($M = 499$ms), $t(19) = 5.489$, $p < .001$, while both Writers and novices recorded similar response times in congruent ($M = 476$ms and $M = 569$ms respectively) and incongruent trials ($M = 488$ms and $M = 611$ms respectively), $ts(19) = 0.894$, n.s.

These results reveal an inverted U-shape pattern in which Writers perceived Chinese characters less holistically than LW, while novices perceived Chinese characters more holistically than Writers[1] but less holistically than LW.

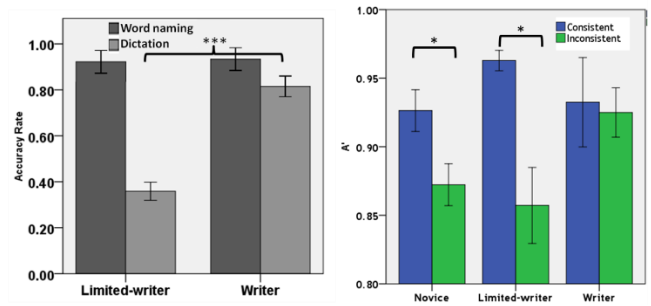

Fig.5. (a) Accuracy rate of Limited-writers and Writers for the dictation and word naming task (***$p < .001$). (b) *A'* of Limited-writers and Writers in congruent and incongruent trials of the holistic processing task (**$p < .01$).

<u>Left-side bias</u>

We found that both Writers and LW had a stronger LSB effect in Ming font than in Feng font ($t(19) = 2.111$, $p < .05$: and $t(19) = 2.778$, $p < .05$, respectively), while this font effect in novices was not significant ($t(19) = .693$, n.s.). There was a significant LSB effect in Ming font in both Writers, $t(19) = 2.378$, $p < .05$, and LW, $t(19) = 2.271$, $p < .05$, whereas no significant LSB was found in Feng font in either Writers or LW. Novices neither showed LSB in Ming font nor Feng font (Fig 7).When we compared Writers with LW, there was no group or font effect, nor interaction between group and font; this showed that both Writers and LW had a similar degree of LSB in perceiving Chinese characters in either font. On the other hand, when we compared novices with either Writers or LW, novices had a smaller LSB in Ming font than Writers, $t(38) = 2.394$, $p = .022$ and LW, $t(38) = 2.396$, $p = .022$. These results suggested that expert readers exhibited LSB for Chinese characters only in a familiar font (Ming) but not in

[1]To examine whether their difference in holistic processing was due to their difference in writing or reading abilities, we analyzed Holistic *A′* with their reading and writing performance measures put as covariates (ANCOVA). The difference in holistic processing between Writers and Limited Writers was still significant even when word naming accuracy, $F(1, 38) = 9.744$, $p< .01$, or word naming response time, $F(1, 38) = 7.916$, $p< .01$, was used as a covariate. However, when dictation accuracy was used as a covariate, the effect became insignificant, $F(1, 38) = 2.235$., *n.s.* These results suggest that the difference in holistic processing between Writers and Limited-writers was largely due to their writing performance, as reflected in the dictation task (i.e., the ability to recall and write down words). We also put all the reading variables simultaneously as covariates and the group difference of HP was still significant, $F(1, 38) = 5.365$, $p< .05$. Similar effects were obtained using RT.

an unfamiliar font (Feng), and LSB is a consistent expertise marker for Chinese character recognition unaffected by writing experience.

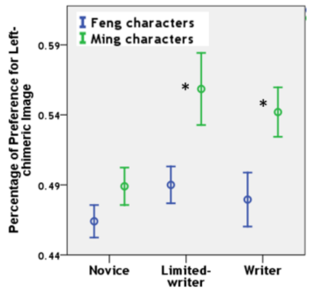

Fig. 6. Preference for left chimeric characters in Novices, Writers and Limited-writers in Ming and Feng fonts (*p < .05).

Discussion

Here we investigated how different learning experience modulates perceptual expertise effects, including HP and left side bias, through examining whether the following groups differ in how they process Chinese characters: Chinese Writers, who read and write Chinese proficiently; LW, who had similar Chinese reading proficiency as Writers (as measured by word naming accuracy) but much poorer writing performance than Writers (as measured by word dictation accuracy); and novices of Chinese characters. Compared with novices, LW processed Chinese characters more holistically, whereas Writers processed Chinese character less holistically. This U-shape pattern suggests that the reduced HP observed in expert Chinese readers (i.e., Hsiao & Cottrell, 2009) may be related to writing rather than reading performance, or more specifically, the ability to recall and write Chinese characters. These results are consistent with Zhou *et al.*'s (2012) findings that artists with face drawing experiences had reduced holistic face processing compared with ordinary observers. These effects suggest a close relationship between writing/motor experience and reduced HP in the recognition of Chinese characters/faces/visual stimuli. LW perceived Chinese characters more holistically than novices, consistent with the expertise hypothesis. It seems that HP is still an expertise marker for Chinese character recognition for experts with little or no writing experiences with Chinese characters. Consistent with previous evidence for sensorimotor learning influencing perception (James & Atwood, 2009; Longcamp, *et al.*, 2003), here we showed how writing experiences could be associated with reduced HP in Chinese character recognition. Note however that LW had slower naming time for Chinese words compared with Writers; thus, they were not as expert at reading Chinese as Writers, given that naming RT has been frequently used as a measure of perceptual expertise (e.g., Tanaka, Curran, & Sheinberg, 2005). A larger HP observed in LW may indicate an intermediate perceptual change from novices to high-performing experts in Chinese character recognition. Future work will further examine the relationship between HP and writing/motor experience by training novices to recognize Chinese characters/visual stimuli under different instruction conditions and observe their changes in HP.

Our study also showed that both Writers and LW had a significant left side bias effect in perceiving characters in Ming font (a familiar font) but not those in Feng font (an unfamiliar font); while novices showed no LSB effects. The LSB in Chinese character perception seems to depend on font familiarity. Since both Writers and LW exhibited a similar degree of LSB, writing/motor experience does not seem to modulate the LSB effect. The font familiarity effect is consistent with Brady *et al.*'s (2005) finding that people showed stronger perceptual asymmetries for familiar faces than for unfamiliar faces; however, their participants showed LSB even in the perception of unfamiliar faces, whereas in our study, the participants did not have significant LSB in an unfamiliar font. This may be due to processing differences between face and Chinese character recognition. In particular, configural information, i.e., distances between parts have been shown to be important in face recognition (Farah *et al.*, 1998) but not in Chinese character recognition, since changes in distance among character components do not change the character identity (e.g., Ge *et al.*, 2006). Recent literature has also suggested a link between configural processing and RH lateralization (see Hsiao & Cheung, 2011). Thus, face recognition may involve more RH processing than Chinese character recognition, and this involvement of RH configural processing may be transferable to the processing of unfamiliar faces/novel exemplars of a category. In contrast, the LSB/RH lateralization of Chinese character processing may be specific to familiar stimuli; this effect is consistent with the literature showing that the left visual field/RH advantage in tachistoscopic Chinese character identification was only found in real characters, but not in non-existing characters such as pseudo- or non-characters (Cheng & Yang, 1989). This difference between face and Chinese character recognition also suggests that the RH lateralization in face and Chinese character processing may involve different cognitive processes (Hsiao & Cheung, 2011).

In conclusion, our study is the first to report on the community of proficient Chinese readers with limited writing ability and to suggest a close relationship between writing experience – rather than reading experience as suggested by prior research – and reduced HP in Chinese character recognition. We uncovered an inverted U-shape pattern: compared with novices, increased HP marked the expertise in LW, while reduced HP marked a higher level of expertise in Writers. In contrast, the LSB effect of Chinese characters depended on font familiarity and is uninfluenced by writing experiences. Our results offer a window on HP and LSB in relation to expertise of complex object recognition by showing that HP can be modulated by both visual and motor experiences, whereas the LSB seems to be a reliable expertise marker not affected by motor experience.

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