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Expertise modulates hemispheric asymmetry in holistic processing: Evidence from Chinese character processing

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Abstract

Holistic processing (HP) has been proposed to be a characteristic of right hemisphere (RH) processing. Here we test this claim using the divided visual field paradigm with Chinese character stimuli. HP is assessed through the composite paradigm, which is commonly used in perceptual expertise research. We found that in novice Chinese readers, a standard HP pattern emerged only in the left visual field/RH but not in the right visual field/left hemisphere, consistent with the analytic/holistic hemispheric dichotomy in the literature. However, in expert Chinese readers, neither visual field showed the HP pattern, consistent with the finding that reduced HP is an expertise maker for Chinese character recognition. Thus, the RH does not always employ holistic processing; it depends on the perceivers' experience with the stimuli. This is the first study demonstrating that expertise with a visual object type can modulate hemispheric difference in HP.

Keywords: holistic processing; Chinese character processing; hemispheric asymmetry

Introduction

In the past few decades, it has been proposed that our left and right hemisphere process information in qualitatively different styles, which is also known as the "analytic/holistic processing dichotomy" (Cohen, 1973; Hillger & Koenig, 1991; Levy-Agresti & Sperry, 1968; Rossion et al., 2000). It hypothesizes that our left hemisphere (LH) tends to process information analytically whereas our right hemisphere (RH) tends to process information in a more holistic manner. Researchers have spent years in examining the analytic/holistic processing dichotomy. One simple and efficient way to compare between hemispheres is the use of the divided visual field methodology, in which a stimulus is presented to only one visual field so that it is initially received and processed by the contralateral hemisphere (see e.g., Bourne, 2006).

To test the analytic/holistic dichotomy, one can measure holistic processing (HP) and compare its magnitude across the two hemispheres. Various paradigms have been developed to measure HP. The part-whole task and the composite task, in particular, are the two most common methods for assessing HP particularly in the face perception literature (Piepers & Robbins, 2012). The part-whole task is a two-alternative forced choice recognition task (Tanaka & Farah, 1993). This task requires participants to first study a face (e.g., "This is Peter"), and then to either identify the studied face from two faces that differ only by one feature (e.g., Peter vs. Peter with John's mouth), or identify the isolated facial feature that belongs to that studied face (e.g., Peter's mouth vs. John's mouth). It was shown that participants performed better when identifying features in the whole face condition than in the isolated feature condition, suggesting faces are represented as an undifferentiated whole rather than composition of parts. While the part-whole task is a memory task, the composite task involves less memory retrieval and relies more on perceptual judgments. In the composite task, participants are presented with two composite faces and are asked to judge whether the top halves of the two faces are the same or different. In general, participants report two identical top halves to look different when they are combined with two different bottom halves. Nonetheless, the illusion fades when the top and bottom halves are spatially separated (Figure 1; see Rossion, 2013, for a review). This task thus measures HP as failure of selective attention to parts. It suggests that participants tend to process faces as a whole, and thus getting interference from the unattended halves. Here we will measure HP using the complete composite paradigm that has been commonly used in many recent studies (e.g., Hsiao & Cottrell, 2009; Richler, Bukach, & Gauthier, 2009; Richler, Cheung, & Gauthier, 2011; Wong, Palmeri, & Gauthier, 2009).

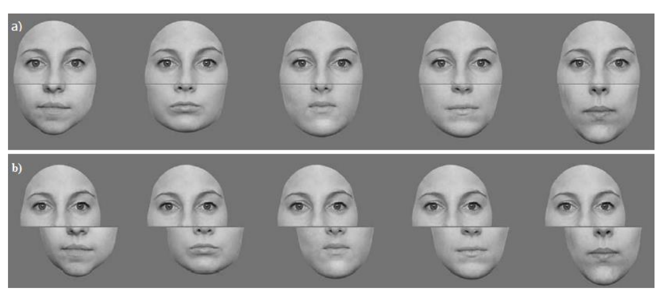

Figure 1: The composite face illusion. a) Participants perceive 5 identical top halves as being different when they are aligned with 5 distinct bottom halves; b) Participants perceive the top halves as being the same when the distinct bottom halves are spatially misaligned with the top halves (taken from Rossion, 2013).

To examine the relationship between RH lateralization and HP as assessed in the composite paradigm, Ramon and Rossion (2011) presented faces either in the left visual field

(LVF/RH) or in the right visual field (RVF/LH) in the composite paradigm. They found a higher level of HP in the LVF compared with the RVF, suggesting a RH dominance in HP for faces. This result is consistent with the analytic/holistic dichotomy between the two hemispheres.

In addition to behavioral data, neuroimaging studies also provided converging evidence supporting the RH's role in HP. For example, in Rossion et al.'s (2000) study, participants were asked to perform a delayed-matching task on either faces or houses during PET scanning. They found that the right FFA was more activated when matching whole faces than isolated face features while the reversed pattern was found in the left FFA. Nevertheless, this effect seemed to be specific to faces but not in houses.

While it is widely believed that HP is lateralized to the RH, this hypothesis has been challenged by some recent studies. For instance, Hsiao and Cottrell (2009) found that Chinese expert readers showed reduced HP and increased RH lateralization for Chinese characters (as indicated by a stronger left side bias in perceiving Chinese characters) as compared with novice readers. This result suggested that RH lateralization and HP may not always go together. In a computational modeling study of face recognition, Galmar and Hsiao (2013) showed that when the face recognition task relied purely on configural information, there was a strong positive correlation between HP and RH lateralization; however, a negative correlation between the two processes was found when the task relied purely on featural information. Thus, HP may not necessarily be a property of RH processing. Rather, their relationship may be influenced by task requirements.

The above claim was also supported by a study investigating callosotomy patients who had disconnected hemisphere after surgery (split brain patients; Trope, Rozin, Nelson, & Gur, 1992). These patients were asked to perform similarity judgments with triads of stimuli in which one pair matched on a criterial attribute (analytic) and another pair showed a family resemblance structure (holistic). It was found that the RH had a stronger bias to judge based on the criterial attribute (analytic). However, when they were engaged in a concept formation task, both analytic and holistic processing strategies were seen in the RH. Their results revealed that the RH could use either analytical or holistic processing, depending on the nature of the task. Consistent with this finding, a recent fMRI study showed that neural populations in the right FFA seemed to be capable of both analytic and holistic processing (Harris & Aguirre, 2010).

While some previous studies have suggested that the relationship between RH and HP processing may depend on task requirements, it remains unclear whether it also depends on the perceivers' experience with the stimuli. Thus, here we aim to test the hypothesis that RH lateralization and HP do not always go together; it depends on the perceivers' experience with the stimuli. We chose Chinese characters as the stimuli because Chinese characters allow us to examine the modulation effect of expertise by comparing between Chinese expert readers and novices (non-Chinese readers), which could be relatively difficult to investigate with face stimuli. Also, despite the fact that Chinese characters share many properties with faces, configural information was shown to be important for face processing but not for character processing (Ge, Wang, McCleery, & Lee, 2006), whereas featural information is important for both. Thus, according to Galmar and Hsiao (2013), the relationship between RH lateralization and HP in character processing may be different from face processing.

We hypothesize that according to the analytic/holistic dichotomy between the two hemispheres proposed in the literature, a HP pattern may be observed in the RH but not in the LH in non-Chinese readers. In contrast, based on Hsiao and Cottrell's finding (2009) showing reduced HP among Chinese expert readers, and Galmar and Hsiao's (2013) modeling study suggesting that HP and RH may be separate processes that do not always go together, depending on the task demands, we predict that the expertise in Chinese character recognition may modulate the relationship between HP and RH lateralization such that Chinese expert readers may not show HP in either the RH or the LH.

Method

Here we implemented the composite task for assessing HP effects. In the composite task, two stimuli were presented briefly and sequentially. Participants were asked to pay attention to either the top or the bottom halves of the two stimuli and judge whether they were the same or different. In congruent trials, the attended and the unattended halves elicited identical responses (i.e., both are the same or both are different). In incongruent trials, the attended and the unattended halves elicited conflicting responses. If participants processed the stimuli holistically, then they would get interference from the unattended halves in incongruent trials but not in congruent trials, resulting in performance difference between congruent and incongruent trials. This effect should be diminished when the two halves were spatially misaligned since perceptual grouping became difficult. Therefore, HP was typically indicated by the interaction between congruency and alignment. Indeed, recent research has suggested that this interaction between congruency and misalignment is particularly sensitive to expertise driven and perceptually focused HP (Richler et al., 2009; Richler et al., 2011; Rossion, 2013; Wong et al., 2009). Here in order to examine lateralization effects, in each composite task trial, we presented the first character either in the LVF, RVF, or center randomly. To ensure characters presented in all locations were perceived with similar visual acuity, characters in the center condition were presented in either the upper or the lower visual field, and at each of the four locations, the edge of the attended halves was 2.2° of visual angle away from screen center (at a 60 cm viewing distance; Figure 2).

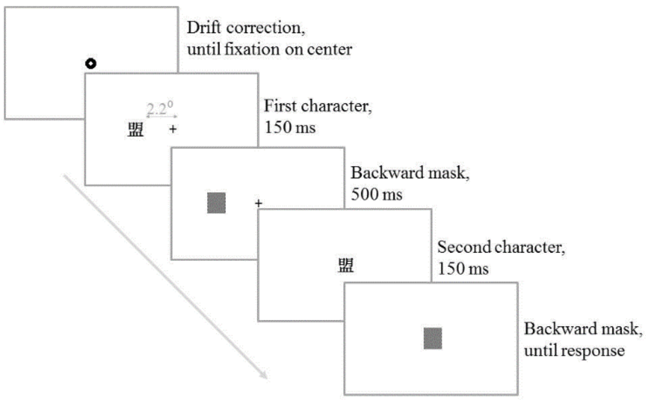

Figure 2: Illustration of a trial sequence

Participants

Twenty-four Chinese expert readers (18 females, 6 males) and 24 non-Chinese readers (novices; 19 females, 5 males) were recruited at the University of Hong Kong. All Chinese expert readers were native Chinese speakers/readers; they had passed public examinations in Chinese Language and obtained grade E or above; whereas all novices received no training and had no experience in learning Chinese language. The two groups were similar in age (experts: M = 19.33, SE = .437; novices: M = 20.63, SE = .567). All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision.

Materials

The stimuli consisted of 192 pairs of Chinese characters. All characters had a top-bottom configuration that could be horizontally separated into two halves. The pairs were equally distributed into each of the four conditions illustrated in Figure 3a. Characters were carefully selected such that each pair of attended halves appeared in one congruent and one incongruent trial. A 3 pixel wide red line was added in the middle of each character to avoid ambiguity in defining the top and bottom halves. All characters were existing characters within a medium to high frequency range (Research Centre for Humanities Computing, n.d.). The frequency and the number of strokes of the characters did not differ significantly between congruent trials and incongruent trials (frequency: $t(382) = -.29$, *n.s.*; number of strokes: $t(382) = -.559$, *n.s.*). All characters were displayed in Ming font. The width of the characters was about 1.5˚ of visual angle (viewing distance: 60 cm). To avoid possible ceiling effects, the contrast level of the characters was adjusted using Adobe Photoshop CS6 (adjusted to lightness of 90). For the misaligned condition, the unattended half of each character was moved either to the right or left so that one side was aligned with the center of the attended half (Figure 3b).

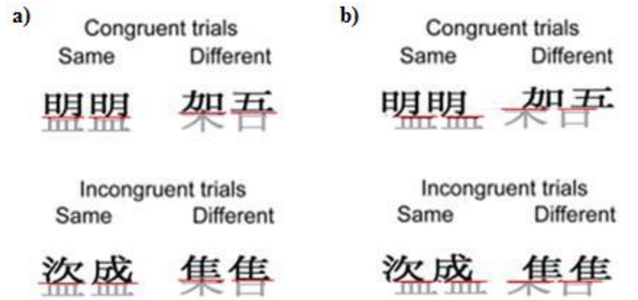

Figure 3: Illustration of the stimulus pairs. a) The halves to be attended are in grey; this example illustrates attending to bottom trials. b) Examples of misaligned trials.

Design

The study contained a between-subjects variable: expertise (expert vs. novice); and three within-subjects variables: visual field (left vs. center vs. right), alignment (aligned vs. misaligned), and congruency (congruent vs. incongruent). The dependent variable was discrimination sensitivity measured by A'[1], which is a bias-free nonparametric measure of sensitivity.

Procedure

The experiment consisted of 384 trials. They were blocked by alignment (aligned or misaligned) and attended part (attend to top halves or attend to bottom halves), resulting in 4 blocks with 96 trials in each block. The block order was counterbalanced across participants. Participants' eye movement was monitored by an Eyelink 1000 eye tracker. Each trial proceeded only if participants were accurately fixating at the screen center. Such monitoring could ensure that the stimuli were presented in the desired visual field locations. After the center fixation was ensured, two characters were then presented sequentially: the first character was presented in one of the four different locations for 150 ms (LVF, RVF, center upper visual field, or center lower visual field), whereas the second character was always presented at the center of the screen for 150 ms. Each character was followed by a backward mask. Participants were asked to judge whether the top halves (or bottom halves, depending on the given block) of the two characters were the same or different with a Cedrus response box (see Figure 2 for an illustration of a trial sequence). Six practice trials were given to participants prior to each block in order to get them familiar with the task.

[1] A' is calculated as follows:

$$A' = .5 + \left[sign(H-F)\,\frac{(H-F)^2 + |H-F|}{4\max(H,F) - 4HF} \right],$$

where H and F represent hit rate and false alarm rate respectively.

Results

The analysis consisted of two parts. The first part focused on examining the overall picture of participants' performance by comparing across all three visual field conditions. The second part, in contrast, was central to the research question: it examined whether there was any hemispheric difference in HP, by comparing just between the LVF and RVF conditions. Figure 4 illustrated participants' performance in *A'* for all conditions.

Analysis with all visual field conditions

A mixed analysis of variance (ANOVA) showed a main effect of visual field, $F(2, 92) = 34.428$, $p < .001$, $\eta_p^2 = .428$; and a main effect of congruency, $F(1, 46) = 59.168$, $p < .001$, $\eta_p^2 = .563$. In general, participants performed worse in the center condition than in the LVF or the RVF condition (both adjusted by Bonferroni, $p < .001$). Also, their performance was worse in incongruent trials than in congruent trials (adjusted by Bonferroni, $p < .001$). In addition, there was a marginal three-way interaction between expertise, alignment, and congruency, $F(1, 46) = 3.528$, $p = .067$, $\eta_p^2 = .071$. There was also a marginal interaction between expertise, visual field, alignment, and congruency was found, $F(2, 92) = 2.606$, $p = .079$, $\eta_p^2 = .054$. This marginal four-way interaction indicated that the HP effect in the three visual fields might differ between the groups. When the data was split by visual field, an interaction between expertise, alignment, and congruency was significant only in the LVF condition ($F(1, 46) = 10.21$, $p = .003$, $\eta_p^2 = .182$), but not in the center ($F(1, 46) = .194$, *n.s.*) or the RVF condition ($F(1, 46) = .146$, *n.s.*). In order words, expertise modulates HP effect in the LVF. Further analyses in the following section will examine how HP effects emerged in the LVF and RVF differently between the two groups.

Comparison between LVF vs. RVF

Here we focused on comparing the LVF and RVF conditions so as to tap into hemispheric lateralization effects. When we directly compared the LVF and RVF condition, the four-way interaction between expertise, visual field, alignment, and congruency was significant, $F(1, 46) = 6.589$, $p = .014$, $\eta_p^2 = .125$.[2] To understand this four-way interaction, further analyses were done separately on expert and novice group. For the novice group, there was a significant interaction between visual field, alignment, and congruency, $F(1, 23) = 5.629$, $p = .026$, $\eta_p^2 = .197$: an alignment by congruency interaction was found in the LVF, $F(1, 23) = 10.213$, $p = .004$, $\eta_p^2 = .308$, but not in the RVF, $F(1, 23) = .238$, $p = .631$, $\eta_p^2 = .01$. As revealed by paired samples t-tests, novices' performance in the LVF was better in congruent trials than in incongruent trials when the stimuli were aligned, $t(23) = -4.977$, $p < .001$, and this congruency effect disappeared when the stimuli were misaligned, $t(23) = -1.622$, $p = .118$. Hence, misalignment reduced the congruency effect only in the LVF but not in the RVF, suggesting that a reliable HP effect was observed only in the LVF but not in the RVF. The expert group, in contrast, did not show any significant interaction (the interaction among visual field, alignment, and congruency was insignificant, $F(1, 23) = .972$, *n.s.*): specifically, the alignment by congruency interaction was insignificant in either the LVF ($F(1, 23) = 1.145$, *n.s.*) or the RVF ($F(1, 23) = .047$, *n.s.*). Thus, RH lateralization in HP was observed only in novices but not in experts.

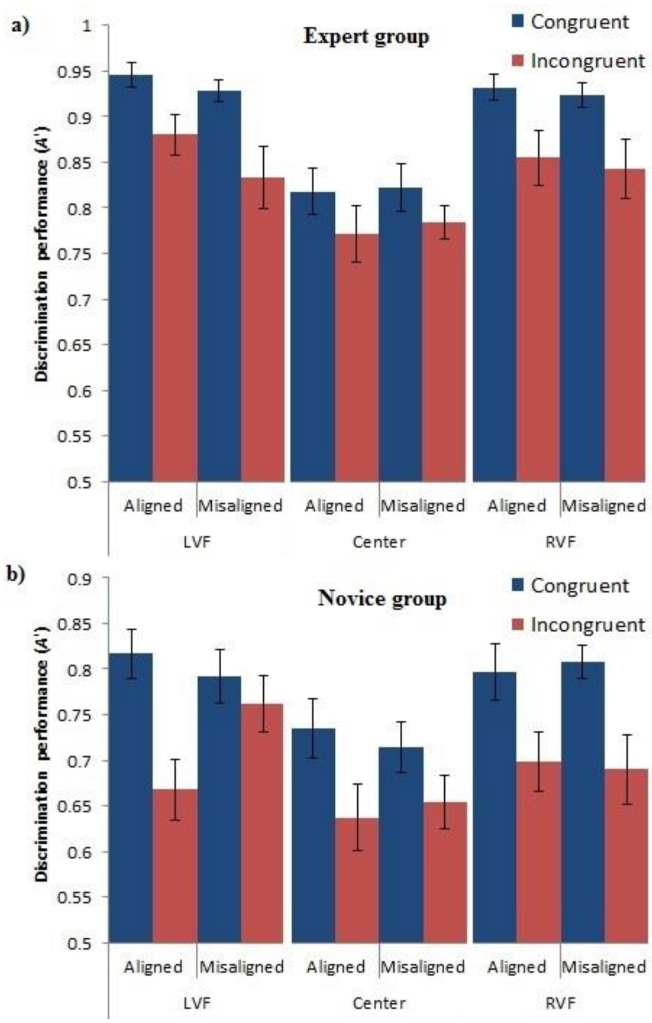

Figure 4: Discrimination performance for the composite task. a) Expert group. b) Novice group. Error bars represent 1 *SE*.

Discussion

Here we assessed HP through the composite task and examined hemispheric lateralization of HP using the divided visual field paradigm with Chinese character stimuli. Through comparing Chinese expert readers and non-Chinese readers (novices), using Chinese character stimuli allowed us to examine modulation effects of expertise on the relationship between RH lateralization and HP.

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[2] Note however that, in the response time data, this four-way interaction was insignificant, $F(1, 46) = 1.229$, *n.s.*.

Our results showed that RH lateralization for HP was observed only in novices but not in experts. In novices, their LVF/RH showed a typical HP pattern (as indicated by the significant interaction between congruency and alignment), whereas such pattern was absent in the RVF/LH. This is consistent with the analytic/holistic hemispheric dichotomy proposed in the literature (e.g., Cohen, 1973; Hillger & Koenig, 1991; Levy-Agresti & Sperry, 1968). Based on our results, it suggests that the RH's role in HP is unlikely to be specific to face processing, but also to other types of visual stimuli, such as Chinese characters. Note however that in contrast to face processing, here our novices' HP on Chinese characters was not driven by experience or expertise. Thus, it suggests the RH's natural role/default mode is to process information in a holistic manner.

In contrast, while the RH seems to be the more holistic hemisphere in novices, no hemispheric difference was observed in expert Chinese readers. More specifically, Chinese readers showed no HP in either the LVF/RH or RVF/LH. Thus, our results revealed a modulation effect of expertise on the lateralization of HP. Nonetheless, this modulation effect of expertise seems to depend on the type of the stimuli. In a training study, Gauthier and Tarr (2002) trained participants to recognize a novel artificial object type (greebles) with both behavioral and neurological measures recorded. They found that increase in HP after training was positively correlated with increased activation in the right FFA, while no such correlation was found in the left FFA. Thus, HP in greeble expertise seemed to be associated with RH lateralization. Similarly, in face recognition, holistic face processing seems to be associated with RH processing (Ramon & Rossion, 2011). In contrast, in our results with Chinese character stimuli, expertise seems to reduce HP in the RH. This difference may be due to the nature of the recognition task. According to Gauthier and Tarr (1997), configural information is crucial for expert-level object (and face) recognition. In contrast, configural information is less important in Chinese character processing (Ge et al., 2006). Galmar and Hsiao's (2013) modeling work suggests that the relationship between HP and RH lateralization may depend on whether the recognition task demands more featural or configural processing. Thus, this difference between object/face and Chinese character recognition in their reliance on configural information may explain the differential effect of expertise on the relationship between RH lateralization and HP.

The different modulation effects of expertise between greebles/faces and Chinese characters may also be related the nature of the expertise. Unlike face or object recognition (i.e., greebles), expert Chinese readers are also experts in writing Chinese characters. Recent research has shown that the reduced HP observed in Chinese character expertise is related to readers' writing rather than reading ability; writing experience hones analytic processing, which enhances the ability to separate and identify individual character components (Tso, Au, & Hsiao, 2014). More specifically, Tso et al. (2014) observed an inverted-U shape curve in HP in learning to read Chinese characters: as compared with novices who showed a weak HP effect, intermediate readers without much writing experience were more holistic, whereas expert readers who excelled in both reading and writing became less holistic. This result suggests that both holistic and analytic processing abilities may be important for mastering visual object recognition. A similar reduced HP effect was also observed among individuals who had extensive face drawing experience (Zhou, Cheng, Zhang, & Wong, 2012). Our results here further suggest that expert Chinese readers' experience in both reading and writing Chinese characters may have modulated the relationship between HP and RH lateralization, consistent with previous findings (Hsiao & Cottrell, 2009; Tso et al., 2014). Future work will investigate whether face drawing artists who have expertise in both recognizing and drawing faces will show similar modulation effects as reported here.

Our results here, together with several previous behavioral and modeling studies (e.g., Galmar & Hsiao, 2013; Hsiao & Cottrell, 2009; Tso et al., 2014), suggest that HP is not always a property of RH processing. Rather, their relationship may be more flexible than they were previously thought. This speculation is consistent with some recent brain imaging studies. For example, by examining adaptation responses in the perception of whole faces and face parts in an fMRI study, Harris and Aguirre (2010) found that neural populations in the right FFA seemed capable of representing both individual features and their integration into a face gestalt; in contrast, the left FFA consistently showed a part-based pattern of neural tuning across all experiments. Similarly, in our results, HP was absent in the RVF/LH in both novices and experts, whereas the RH lateralization for HP was modulated by expertise. These results are also consistent with Trope et al.'s (1992) study with split brain patients. All together, these results suggest that the RH and HP do not always go together, depending on the nature of the task and the perceivers' experience with the stimuli.

In line with the past literature on Chinese character perception (e.g., Hsiao & Cottrell, 2009; Tso et al., 2014), here we showed that a typical HP pattern was observed only in novices but not in experts. Note that experts were still getting interference from the unattended parts, as indicated by the significant congruency effects across all conditions. However, the congruency effect was not reduced by misalignment, suggesting that the congruency effect was not due to perceptual integration of parts (as observed in faces and other objects of expertise). Rather, the congruency effect observed in experts could arise merely due to response interference from the irrelevant halves not related to perceptual grouping. Similar effects were also observed in a previous study with Chinese characters using a similar design (Wong et al., 2012), and a recent study examining HP effects in speech perception of Cantonese syllables (Liu & Hsiao, 2014). The congruency effect observed in experts might also be due to their lexical knowledge of the characters, which lead to automatic integration of lexical representations of the components even when the two halves of the characters were perceptually separated. Further work will examine this possibility using non-existing characters such as pseudo-characters or non-characters.

In conclusion, here we provide the first behavioral evidence showing that the analytic/holistic hemispheric dichotomy between the two hemispheres can be modulated by experience in visual recognition. More specifically, in Chinese character processing, while RH lateralization for HP was observed in novices, results from experts showed no HP effect in either hemisphere, suggesting that the RH may be capable of both holistic and analytic processing, depending on the perceivers' experience with the stimuli. Thus, a clear-cut analytic/holistic distinction may not be sufficient to describe information processing differences between the two hemispheres.

Acknowledgments

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