Right hemisphere lateralization and holistic processing do not always go together: An ERP investigation of a training study

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Abstract

Holistic processing (HP) and right-hemispheric lateralization both mark expertise in visual object recognition such as face and sub-ordinate object perception. However, counter-examples have been found recently: Experiences of selective attention to parts such as writing experiences in Chinese characters reduced HP while increased right hemisphere lateralization. We investigated the association between HP and brain activities measured by event-related potentials (ERP) in participants trained to recognize artificially-created scripts using either whole-word or grapheme-to-phoneme approaches. Stronger N170 activities were found in both hemispheres in both training approaches. Though the type of training approaches induced opposite directions in correlations between HP and the ERP signals in the right hemisphere: In the whole-word condition, the HP effect increased with stronger right-hemispheric N170 activities; while the direction of this correlation was reversed in the grapheme-to-phoneme condition. This demonstrates that HP and right hemispheric lateralization are separate processes that are associated with different perceptual mechanisms.

Keywords: holistic processing, hemisphere lateralization, ERP, EEG, perceptual expertise

Introduction

Holistic processing and right hemisphere lateralization

Holistic processing (HP) has consistently been reported to be a perceptual marker of visual expertise in face and subordinate-level visual object recognition (Bukach *et al.*, 2006; c.f. Mckone, Kanwisher, & Duchaine, 2007). For example, Gauthier, Williams, Tarr, and Tanaka (1998) trained participants to recognize "Greebles"—novel artificial objects—and found a positive relationship between HP and performance in within-category object recognition. Similarly, when participants were trained to individualize "Ziggerins" (an artificial object type), they showed an increase in HP (Wong, Palmeri, & Gauthier, 2009).

HP in face perception can be demonstrated with the composite face illusion induced by the composite paradigm: Two identical top halves of two faces are more likely judged as different when the two bottom-half faces are from different faces, (see Rossion, 2013, for a review). The composite illusion suggests that all facial parts are obligatorily attended to, which results in the failure of selectively attention to parts (Richler, Wong, & Gauthier, 2011). This paradigm demonstrates one of the three types of configural processing according to Maurer et al. (2002).

Hemispheric asymmetry may be another expertise marker for object recognition. Neuroimaging studies generally showed stronger activation in the right occipitotemporal area for face recognition (Rossion, Hanseeuw, & Dricot, 2012). Complementing this finding, Gauthier and Tarr (2002) found that as participants were trained to recognize individual Greebles, increase in HP was correlated with activation changes in the right occipitotemporal regions. Because of the concurrence of robust HP in face and objection recognition with stronger right-hemisphere (RH) activations, HP is suggested to be a property of RH visual processing (Ramon & Rossion, 2012). It is also consistent with the holistic-analytic dichotomy proposed in the hemispheric asymmetry literature (Cooper & Wojan, 2000).

However, recent studies suggest that HP and RH lateralization do not necessarily go together. For example, in Chinese character perception, Hsiao and Cottrell (2009) found that while expert readers showed a reduced HP as compared with novice readers, the left-side bias effect, which is suggested to be an indication of RH lateralization, was shown only in experts[1]. Tso et al. (2014) reported an inverted U-shape development pattern in HP of Chinese characters: as compared with novices, Chinese readers with limited writing experiences showed increased HP, whereas Chinese readers skilled in writing Chinese characters showed reduced. This result suggests that HP is modulated by sensorimotor experiences while RH lateralization is not.

Theories and model of hemispheric processing

The RH has long been suggested to preferentially execute whole-based/configural/coarse/global processing while part-based/analytic/fine/local processing is more involved in the left hemisphere (LH) (e.g., Sergent, 1982). Ivry and Robertson (1998) proposed the Double Filtering by Frequency (DFF) theory, which suggests that visual information is processed in the brain by frequency-based

[1] Left-side bias in face perception refers to the phenomenon that people often judge chimeric faces formed by two left halves of the original face to be more similar to the original face than those formed with two right halves (Brady, Campbell, & Flaherty, 2005). This effect was also observed in Chinese literates viewing mirror-symmetric Chinese characters (Hsiao & Cottrell, 2009).

representations at two stages: at the first stage, attention processes select a task-relevant frequency range; at the second stage, high spatial frequency (HSF) information is amplified in the LH while low spatial frequency (LSF) information is amplified in the RH. The DFF theory is able to account for hemispheric asymmetry in processing local (HSF) and global (LSF) information. For example, using Navon's hierarchical patterns (1977; Fig. 1), Sergent (1982) found a left-visual field (LVF)/RH advantage in judgements made based on global information and a right-visual field (RVF)/LH advantage in judgements made based on local information. Similarly, a LVF/RH advantage was found in identifying LSF gratings while a RVF/LH advantage for HSF gratings (e.g., Christman, Kitterie, & Hellige, 1991). These results suggest that the LH is more tuned to processing local/HSF information while the RH more tuned to processing global/LSF information.

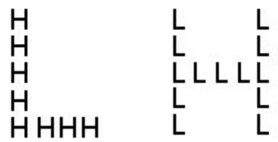

Fig. 1. Hierarchical letter patterns. The pattern on the left shows the global form 'L' consisting of local elements 'H'. The one on the right shows the global form 'H' and local elements 'L'.

In visual word recognition, a stronger LH lateralization is typically observed for alphabetic than logographic scripts. Hsiao and Lam (2014) showed that this effect could be accounted for by a computational implementation of the DFF theory: the decomposition of words into graphemes for grapheme-phoneme mapping requires more HSF/LH processing than logographic reading. Hsiao and Cheung (2011) and Hsiao and Galmar (2016) examined the relationship between HP and RH lateralization in visual recognition using the same model (with triangular symbols consisting of 3 English letters and faces respectively). They found a positive correlation between HP and RH lateralization when the recognition task relied purely on the distanced between features (i.e., the second order relationship, a type of configural processing; Maurer et al., 2002), while this correlation became negative when the recognition task relied purely on the identity/features of local components. These results suggest that HP and RH lateralization are separate processes modulated by different recognition requirements. Since the recognition of words in alphabetic languages relies more on the identity of local components for grapheme-phoneme conversion than that in logographic languages, it is possible that alphabetic and logographic reading will result in different relationships between HP and RH lateralization.

ERP component N170

In EEG studies, the ERP component N170, peaking between 150 and 200 ms after the onset of visual stimulus presentation, was found to be associated with perceptual expertise effects (e.g. ,Maurer, Zevin, & McClandiliss, 2008). Consistent with neuroimaging and behavioural research on hemispheric asymmetry in visual object recognition, EEG/ERP studies also showed reliable hemispheric asymmetries of visual expertise effects in N170, such as a larger N170 response in the RH for faces (e.g., Scott & Nelson, 2007), and a larger N170 response in the LH for words (e.g. Maurer, Brandeis, & McCandliss, 2005). Thus, the N170 responses towards visual stimuli, which are suggested to reflect occipito-temporal activities in visual object recognition, can be considered an electrophysiological indication of hemispheric asymmetry in visual object processing (e.g., Maurer et al., 2008).

The present study

Here we aim to examine how different visual object recognition requirements modulate the relationship between HP and RH lateralization. We specifically contrast the difference between visual word recognition in alphabetic and logographic languages, the two major types of scripts currently in use. To do this, we trained participants to recognize artificially-created characters and examined the perceptual and electrophysiological changes. Participants learned to recognize the same set of characters under which the decoding method was manipulated to be using either whole-word (logographic) or grapheme-to-phoneme (alphabetic) approaches. Any difference in the perceptual or hemispheric lateralization changes occurring after the training should mainly come from the difference in the decoding methods (logographic vs. alphabetic). According to the previous studies (e.g., Hsiao & Galmar, 2016), the requirement of grapheme-phoneme conversion in learning to read the characters alphabetically may induce a negative correlation between HP and RH lateralization, whereas a positive correlation may be observed when learning to read the same characters logographically. This is the first training study to investigate HP and its association with hemispheric lateralization of reading alphabetic and logographic scripts.

Methods

Participants

54 college students aged 18 to 26 with no prior knowledge to Korean Hanguls were recruited: 18 of which spoke English as a native language and 34 were Cantonese-English bilinguals who spoke Cantonese as a native language. 25 of them were females. They were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971) with normal or corrected to normal vision. Half of them were randomly assigned to the logographic condition while half of them were assigned to the alphabetic condition, with native language and gender matched between the conditions.

Materials

A total of 30 artificial components were created to make 80 Artificial Korean-like Characters (AKC). The AKCs were of a top-bottom configuration with two top components and one bottom component in each character—this arrangement simulated the top-heavy configuration of faces as well as a structure of Chinese characters. In the Alphabetic condition, each component in an AKC corresponded to a phoneme. Each AKC mapped onto a syllable with its combination of components following a consonant-vowel-consonant (CVC) phonological rule. In the Logographic condition, each AKC was randomly assigned a syllable pronunciation that appeared in the Alphabetic condition (Fig. 2).

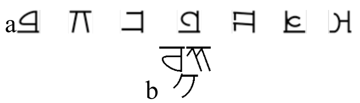

Fig. 2. Examples of (a) AKC components and (b) an AKC

Training Phrase

Each participant learned all 80 AKCs during 3 learning sessions in 3 consecutive days. Each learning session consisted of two blocks with 40 AKCs learned in each block. Two learning blocks in each learning session allowed participants to be exposed to all 80 AKCs per day. In the Logographic condition, each AKC was shown as a whole character for four times in each trial, accompanied by its pronunciation read by a female voice in each display. Each of the first three displays lasted for 500 ms, with the fourth display stayed on the screen for the participants to familiarize with for 5 seconds. In the Alphabetic condition, each AKC was also shown as a whole character for four times in each trial. A different component was highlighted in each of the first 3 displays, accompanied by the pronunciation of the component's phoneme read in a female voice in each display, for 500ms. The last display of the AKC was accompanied by the pronunciation of the whole AKC and stayed on the screen for 5 seconds.

To monitor and encourage learning progress, after each learning session, participants completed a forced-choice quiz. In each trial, two AKCs were displayed on the screen accompanied by a syllable sound. Participants chose the AKC that matched the sound by pressing the corresponding buttons on a response box. There were a total number of 160 trials with each AKC-sound pair appearing twice. A feedback on the correctness with the accumulated percentage of correct responses was given immediately at the end of each trial. At the end of the last training session, participants in both the Alphabetic and Logographic condition developed over 80% accuracy in the quiz.

Post-test and Pretest

Participants performed a complete composite task and a sequential matching task with EEG recording with AKC stimuli once before and once after the training

Complete Composite Task. We employed the complete composite paradigm to examine HP of AKCs, adopting the procedures from Hsiao and Cottrell (2009). Eighty pairs of AKCs taught in the training were selected. 20 pairs were presented in each of the four conditions: same-congruent, different-congruent, same-incongruent, and different-incongruent trials (Fig. 3a). In the congruent trials, the attended halves and the irrelevant halves led to the same response (i.e. both the attended part and the irrelevant part were the same or different). In the incongruent trials, the attended halves and the irrelevant halves led to different responses: In same incongruent trials, the attended halves were the same while the irrelevant halves were different; whereas in different incongruent trials, the attended halves were different while the irrelevant halves were the same[2].

Each trial started with a fixation cross for 1000 ms, followed by a cue indicating the part that participants should attend to (either top or bottom) for 1000 ms. A pair of AKCs–one above and the other one below the initial fixation respectively, about five degrees of visual angel away from each other–appeared for 500ms, followed by a mask. Participants were instructed to judge whether the attended halves of the two AKCs were the same or not as quickly and as accurately as possible by pressing the corresponding buttons on the response box (Fig. 3). Accuracy of each trial was recorded.

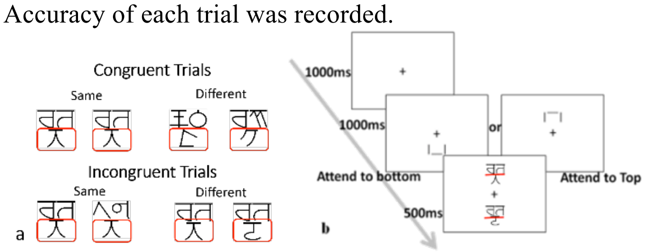

Fig. 3. (a) Illustration of stimulus pairs in the complete composite paradigm; the attended components are circled in red. (b) Trial sequences, the red line shows the splitting point between top and bottom halves.

Each AKC was approximately 1.5 cm x 1.5 cm in size on the screen, spanned about 1.6 degree of visual angle at a viewing distance of 55 cm. The participants' discrimination sensitivity A' was measured as:

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

where H and F are the hit and false alarm rate respectively. We used A' to measure sensitivity due to its bias-free nonparametric property, as d' may be affected by response biases when normality and equal standard deviations are not assumed (Stanislaw & Todorov, 1999). We measured *Holistic* A' as a normalized measure of HP that takes into consideration the individual baseline performance differences (Singer & Sheinberg, 2006): the greater the magnitude, the stronger the degree of holistic processing.

$$Holistic\ A' = \frac{A'in\ congruent\ condition - A'\ in\ incongruent\ condition}{A'in\ congruent\ condition + A'\ in\ incongruent\ condition}$$

[2] The part-whole paradigm (Tanaka & Farah, 1993) can also demonstrate HP (Maurer et al., 2002). However, it involves memory performance heavily (Piepers & Robbins, 2012). As the focus of this study is to examine perceptual effects, the complete composite paradigm was used to minimize memory demands and response biases (Richler, Cheung, & Gauthier, 2011).

EEG recording and analysis A sequential matching task was used to measure ERPs in response to the presentation of AKCs. The task consisted of 240 trials, separated into 6 blocks. Each trial started with a central fixation for 500 ms, followed by an AKC appearing at the screen center for 150 ms. The screen then turned blank for 1000 ms. A second character then appeared at the center and remained until participants made a response judging whether the two characters were the same or different. Each character subtended a visual angle of around 1.7 degree. Participants were instructed not to blink during a trial until they saw the letter 'B' on the screen. These trials were conducted using E-prime v2.0 (Psychology Software Tools, Pittsburgh, PA).

EEGs were recorded using a 64-channel ANT system (Electro-cap International). EEG activities were sampled at 512 Hz. The data analysis was performed using EEGLAB (Delarme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014). Only trials with correct responses were included in the EEG analysis. Bin-based epochs were extracted from -200 ms to 800 ms of the stimulus onset. The time window 140 to 200 ms (170±30 ms) was chosen based on the grand average data of the participants in the Alphabetic and Logographic training conditions for identifying N170 peak amplitudes. PO7 electrode in the LH and its symmetrical electrode PO8 in the RH were selected for analysis as these electrodes were where the peak amplitude was found within the selected time window (see Hsiao et al., 2007 Yoncheva et al., 2010).

Results

Holistic processing (HP)

Repeated-measures ANOVA was used to investigate HP effects (time: Pretest vs. Post-test x condition: alphabetic vs. logographic). For Holistic A', there was a marginal effect of time, $F(1, 47) = 2.868$, $p = .097$, $\eta_p{}^2 = .057$: HP decreased as the result of training. There was no main effect of condition or an interaction between time and condition.[3] (Fig. 4).

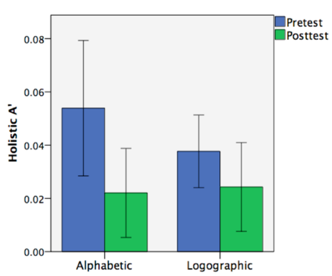

Fig. 4. Holistic A' in the pretest and post-test in the Alphabetic and Logographic conditions

EEG neural correlates

Mixed ANOVA was used for analyzing N170 peak amplitude data (Time: Pretest vs. Post-test x Hemisphere: Left vs Right x Condition: Alphabetic vs. Logographic). A significant main effect of time was observed, $F(1, 53)= 7.457$, p = .009, $\eta_p{}^2 = .123$, showing that N170 amplitude was increased after training. There was a marginal main effect of hemisphere, $F(1, 53) = 3.064$, p = .086, $\eta_p{}^2 = .055$, and a marginal effect of condition, $F(1, 53) = 3.678$, $p = .061$, $\eta_p{}^2 = .065$. No significant interaction effect was observed.

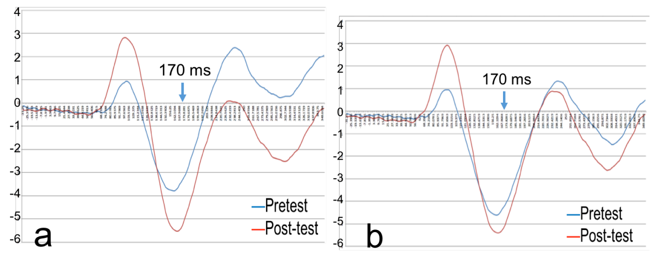

Fig. 5. N170 responses (μV) in (a) PO7 (left hemisphere) and (b) PO8 (right hemisphere) in the pretest and post-test, averaged across all participants.

Pearson's correlation and moderation analysis

Correlation analyses between Holistic A' and N170 amplitude at PO7 (LH) and PO8 (RH) were performed separately for the Alphabetic and Logographic conditions to examine the relationship between HP and RH lateralization. In the Alphabetic condition, Holistic A' in the post-test was correlated positively with the N170 amplitude at PO8 (RH) in the post-test, $r^2 = .435$, $p < 0.05$, as well as the N170 amplitude change between the pretest and the post-test at PO8, $r^2 = .506$, $p < 0.05$. In contrast, these correlations were negative in the logographic condition, $r^2 = -.483$, $p < 0.05$, and, $r^2 = -.409$, $p < 0.05$, respectively. See Fig. 6

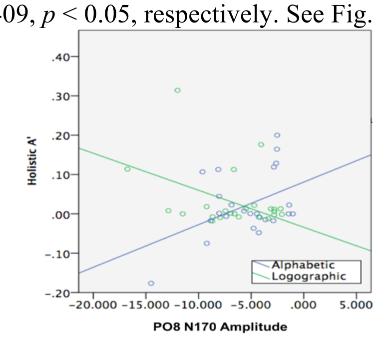

Fig. 6. The correlation between Holistic A' and PO8 N170 Amplitude (μV).

To further understand the differences in the direction of the correlations between Holistic A' and N170 amplitude at PO8 in the post-test, a moderation analysis was conducted. In the first step, training condition (Logographic vs. Alphabetic) and N170 amplitude at PO8 were entered in the regression analysis. In the second step, the interaction term between training condition (Logographic vs. Alphabetic) and N170 amplitude at PO8 was entered, and it explained a significant increase in variance in Holistic A', $\Delta R^2 = 0.203$, $F(1,48) = 11.593$, $p = .001$. Thus, training condition significantly moderated the correlations between Holistic A'

[3] Hsiao and Cottrell (2009) showed that when character halves were misaligned, the HP effect of Chinese characters disappeared, suggesting that the effect reflected the inability to selectively attend to aligned character halves rather than inhibition control.

and N170 amplitude at PO8 in the post-test: While a more negative/larger N170 amplitude at PO8 correlated with a weaker HP effect in the alphabetic condition, a more negative/larger N170 amplitude at PO8 correlated with a stronger HP effect in the logographic condition (Fig. 5). This suggests a stronger N170 activity correlated with a weaker HP effect in the alphabetic condition, while it is vice versa in the logographic condition in the RH. However, we did not find significant correlations between HP and N170 at PO7 in either condition.

Discussions

In the current study, we aimed to examine how learning to read words alphabetically or logographically modulates the relationship between holistic processing (HP) and right hemisphere (RH) lateralization in the perception of visual words. Previous computational modeling studies have suggested that in visual object recognition, when the recognition task relies purely on the distances among local components (second order relationships, a type of configural processing; Maurer et al., 2002), there was a positive correlation between HP and RH lateralization. In contrast, when the recognition task relies purely on the identity of local components, this correlation becomes negative (Hsiao & Cheung, 2011; Hsiao & Galmar, 2016). This result is consistent with the face recognition and perceptual expertise literature, which typically shows an increase in HP coincided with RH lateralization, especially when the task involved processing of configural information (e.g., Gauthier & Tarr, 2002; Ramon & Rossion, 2012). It is also consistent with the literature on expert Chinese character processing: decreased HP due to writing experience, which required selective attention to local components, was correlated with increased left side bias/RH processing (Tso et al., 2014). Here we tested this modeling prediction through a training study, in which we measured changes in HP and ERP N170 amplitude as the result of learning to read artificial Korean-like characters (AKCs) either alphabetically or logographically.

Our study revealed that training to read AKCs in either the Alphabetic or the Logographic conditions increased N170 amplitude in both hemispheres at electrodes PO8 and PO7. This result is consistent with the perceptual expertise literature, which typically showed an increased N170 amplitude as the result of the expertise (e.g. Maurer et al., 2008; Tanaka & Curren, 2001).

More importantly, in the post-test, we found that the HP effect of AKCs correlated with N170 amplitude in the RH differently between the 2 conditions: while the correlation analysis showed the stronger the HP effect, the more negative the N170 amplitude at PO8 in the Logographic condition, the direction of this correlation was reversed in the Alphabetic condition. It seems that different learning approaches to recognizing a written script moderates the direction of the correlation between HP and neural activities in the right occipital temporal regions. This effect is consistent with the modeling data based on the DFF theory (Hsiao & Galmar, 2016; Hsiao & Cheung, 2011). In the Logographic condition, participants may have used a whole-word recognition approach, which led to increased HP, as well as a higher sensitivity to the distances the components, a type of configural processing (Maurer et al., 2002). This type of configural processing has been shown to involve RH lateralization (Scott & Nelson, 2006). Thus, in this condition, RH lateralization and holistic processing are positively correlated with each other. In contrast, in the Alphabetic condition, the requirement of grapheme-phoneme conversion during learning may have encouraged local featural/high spatial frequency processing for identifying local component, which is typically left-lateralized (Ivry & Robertson, 1998). In addition to identifying local components, word recognition in the Alphabetic condition also required recognizing components in a particular sequence/configuration, or more specifically, the first order relationship among features (Maurer et al., 2002). This processing may require integration of information among components, leading to increase in HP. Thus, in the Alphabetic condition, HP was negatively correlated with RH lateralization, since the increase in HP due to the use of configural information for relative positions of components (i.e., the first order relationship among features) may coincide with decreased reliance on RH global processing. Future work will examine these possibilities.

Consistent with the modeling data, the current results suggest that HP (as measured in the composite paradigm) and RH lateralization do not always go together in visual object recognition. It depends on the requirements of the recognition task. Consistent with this finding, in an fMRI study, Harris and Aquirre (2010) showed that neurons in the right occipito-temporal region (fusiform face area, FFA) could flexibly represented two facial features either conjointly (suggesting HP) or separately, depending on the recognition task requirements. Note however that our current results regarding the relationship between HP and RH lateralization is limited to the HP as measured in the composite paradigm. In the literature, HP effects have been demonstrated using different paradigms, such as the part-whole task (Farah, Wilson, Drain, & Tanaka, 1998) in addition to the composite paradigm. HP effects demonstrated using different paradigms likely involve different underlying mechanisms (Richler et al., 2012). Future work will examine whether similar relationships between HP and RH lateralization can also be observed using other HP paradigms.

In conclusion, this is the first training study to report on the changes in both HP and hemispheric lateralization in learning to read an artificial script under different decoding methods (i.e., logographic vs. alphabetic). Different learning approaches induced opposite directions of correlations between HP and RH activities: Learning a script alphabetically induced a negative correlation between HP and RH lateralization, while that induced by learning a logographic script was positive. It seems that HP and RH lateralization do not always go together, depending on the decoding strategy in visual object recognition, or more specifically, the type of configural information used in the recognition processes.

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