When is a Visual Perceptual Deficit More Holistic but Less Right-lateralized? The Case of High-school Students with Dyslexia in Chinese

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Abstract

Expert face recognition has been marked by holistic processing and left-side bias/right hemisphere involvement. Hence recognition for Chinese characters, sharing many visual perceptual properties with face perception, was thought to induce stronger holistic processing and left-side bias effect. However, Hsiao & Cottrell (2009) showed that expertise in Chinese character recognition involved reduced holistic processing, while Tso, Au & Hsiao (2014) suggested this effect may be modulated by writing experiences; in contrast, left-side bias was found to be a consistent expertise marker regardless of writing experiences. Here we examine holistic processing and left-side bias effect of Chinese character recognition between adolescents with and without dyslexia. Students with dyslexia were found to recognize Chinese characters with a stronger holistic processing effect than the typical controls. However, compared with the controls, dyslexics showed a more reduced left-side bias in processing mirror-symmetric Chinese characters. The theoretical and educational implications of these results were discussed.

Keywords: Reading, Dyslexia, Left-side bias, Holistic Processing, Perceptual Expertise

Introduction

Holistic Processing

Holistic processing is the tendency to process separable features of an object as a single whole unit. This concept was originally derived from Gestalt psychology, which postulates that the perception of an object as a whole that is a qualitative difference from the sum of its individual parts (Köhler, 1929; see also Wagemans, Elder, et al., 2012; Wagemans, Feldman, et al.,2012). Holistic processing has been a perceptual phenomenon commonly observed in face perception in which all facial parts are integrated and viewed as a whole (Piepers & Robbins, 2012). Holistic processing in face recognition can be demonstrated with the composite paradigm in which it induces the composite face illusion: the two identical top halves of a pair of faces are judged as different when the bottom halves of the two faces are from different faces (see Rossion, 2013). This illusion suggests a failure of selectively attending to facial parts as a result of people obligatorily attending to all facial features as a whole (i.e. holistic processing, see Figure 1; Richler, Wong, & Gauthier, 2011). The holistic processing assessed in the above paradigm demonstrates the second type of configural processing as suggested by Maurer, Le Grand, and Mondloch (2002), which is the inclination to perceive a stimulus as a Gestalt (Pomerantz & Portillo, 2011). Beyond face perception, some studies have posited that expertise-level recognition for subordinate-level objects requires holistic processing (Bukach et al., 2006; though some has suggested limited to face recognition, c.f. Mckone, Kanwisher, & Duchaine, 2007).

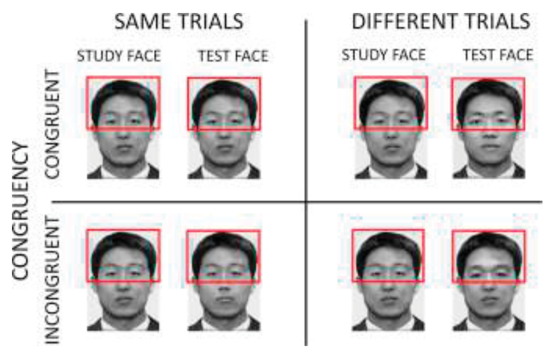


Figure 1. Complete composite paradigm to measure holistic processing for face stimuli. In each trial, participants are cued to attend to top or bottom half of each stimulus pair and judged whether the attended halves are the same or different (attended halves encircled in the figure). Holistic processing is demonstrated by the interference of the irrelevant halves (adapted from Hsiao & Galmar, 2016)

Holistic processing in Chinese character recognition

At first glance, Chinese characters may seem to be a separate class of visual stimuli to that of faces. For example, while the single features (such as eyes and mouth) of each individual face differ but appear in the same positions, the same radicals and strokes can appear in different positions in a character. While faces are always in a symmetrical top-bottom configuration, Chinese characters can appear in more than 10 types of configurations including top-bottom and left-right (Shu, 2003). However, Chinese characters also share many visual properties with faces: They have a homogenous, square configuration—with each character a grapheme mapping onto a morpheme (Shu, 2003). Moreover, strokes are the basic units which combine to form more than 200 basic Chinese character patterns (Hsiao & Shillcock, 2006), which in turn form the Chinese characters. Faces also have homogenous configurations, with facial features combining to form endless different individual faces. A person can differentiate and recognize different faces regardless of their facial expression, similar to a literate typically needing to recognize over 3000 characters regardless of fonts (Hsiao & Cottrell 2009; Wong & Gauthier, 2007). The process of individualizing different faces seems to be comparable with that of naming individual Chinese characters. Hence, theoretically Chinese characters should induce a similar perceptual expertise effect as faces (McCleery *et al.*, 2008).

However, using the complete composite paradigm, Hsiao and Cottrell (2009) found that expert Chinese readers had a reduced holistic processing effect (i.e. more analytic) compared with novices. Tso, Au, and Hsiao (2014) showed that the reduced holistic effect of the expert readers in Hsiao and Cottrell's (2009) study may be explained by writing experiences. They showed that compared with novices, expert readers with limited writing performances (Limited-writers) showed increased holistic processing, while expert readers with typical writing abilities (Writers) showed a reduced holistic effect (Tso, Au, & Hsiao, 2014). These findings hint a modulating role of writing abilities on holistic processing: the typical Chinese-reading experts flexibly employ holistic or analytic processing to read and write Chinese characters. It seems that the use of holistic or part-based processing may depend on how readers allocate attention for task relevant information (Chung, Leung, Wong, & Hsiao, 2018).

Holistic processing in the population with special needs

There has been accounts of perceptual differences in processing visual stimuli in populations with a cognitive disability compared with typical controls. For example, reduced holistic processing in has been associated with face-recognition difficulties in patients with prosopagnosia (Avidan, Tanzer, & Behrmann, 2001). Reduced holistic processing also marks a cognitive deficit in people with autism, who were often tested to have poorer abilities in face and facial expression recognition than the general population (Tanaka, Wolf, & Schultz, 2010).

People with dyslexia in the Chinese language is also shown to be characterized by a visuospatial deficit (e.g. visual-orthography processing and visual-spatial attention skills; see Liu et al, 2017), while English dyslexia is generally associated with core deficits in phonological skills. Indeed, developmental dyslexia in an alphabetic script and in the Chinese writing system is characterized by different brain abnormalities (e.g. Siok et al., 2004; Siok et al., 2009): while dyslexia in alphabetic languages is characterized by neurological deficits related to phonological skills (e.g. left temporoparietal regions), dyslexia in Chinese is more associated with abnormalities in regions that are responsible for orthography or visuospatial processing (e.g. middle frontal regions). Chinese-word reading has indeed a strong basis in visual-orthographic processing demonstrated by writing and copying abilities (Tan et al., 2005). Children with reading difficulties are often observed to have a marked discrepancy between reading and writing abilities due to writing in Chinese being a more resource-intensive process than writing in alphabetic languages (Chung & Ho, 2010). As expert reading and writing in Chinese depends on one's ability to analyze local components within a Chinese character (Chung et al, 2018; Hsiao & Cottrell, 2009), people with dyslexia – who generally have backward reading and writing attainments – may fail to employ analytic processing as the components and radicals in a Chinese character may look inseparable to them (Ho, Ng, & Ng, 2003).

Left-side bias

Left-side bias is another visual-perceptual phenomenon commonly reported in face recognition (Burt & Perrett). This effect has also been demonstrated in Chinese character recognition and is suggested to be associated with right-hemisphere involvement (Hsiao & Cottrell, 2009). Left-side bias effect is usually demonstrated using chimeric faces, that is, people often judge faces that composed of two left halves to be more similar to the original face than faces composed of two right halves (Brady, Campbell, & Flaherty, 2005).

Though left-side bias or right-hemisphere lateralization have been thought to correlate with increase in holistic processing in visual object recognition (Gauthier & Tarr, 2002), left-side bias was found to be a consistent behavioral marker of Chinese character recognition regardless of writing experiences, whereas holistic processing could be affected by writing experiences (Tso, Au, & Hsiao, 2014). This effect is consistent with studies that showed right-hemisphere involvement in processing the Chinese orthography (Hsiao, Shillcock, & Lee, 2007; Yang & Cheng, 1999). However, compared with typically developing students, stronger left fusiform and weaker right hemisphere activities have been found in dyslexic children during Chinese character recognition (Siok et al, 2004; Xue et al., 2005). Hence students with dyslexia in this study may display reduced left-side bias compared with the controls.

The present study

This paper hence investigates the role of holistic processing in Chinese recognition by examining how Chinese readers in secondary school with and without a diagnosis of dyslexia process Chinese characters. Reduced holistic processing marks expert Chinese character recognition in Chinese readers with both typical reading and writing abilities. As developmental dyslexia in Chinese in characterized by difficulties in literacy, predominantly in writing performances, students with dyslexia are predicted to processing Chinese characters more holistically than their typical counterpart. Left-side bias of mirror-symmetric Chinese characters was also examined, and this effect was compared between students with and without dyslexia, in relations to holistic processing.

Materials and procedures

Chinese literacy

Dictation performance and Chinese word reading in both timed and untimed context were measured as a reference for their literacy performance. The stimuli were adopted from HKT-P(III). As the purpose of the study was not to yield diagnostic results, we used stimuli from HPT-P(III) for research purposes only to compare the literacy performance between students with and without dyslexia.

i) The untimed Chinese word reading task assessed students' Chinese word reading accuracy. Students read aloud from a set of 150 two-character Chinese words listed in ascending order of difficulty. A participant scored one point for pronouncing both characters of a word correctly.

ii) The Chinese one-minute word reading task assessed students' Chinese word reading fluency. Ninety simple two-character Chinese words were displayed in 9 rows containing 10 words each. Students read aloud as many words as they could in one minute, earning one point every time they read both characters of a word correctly, and the total number of points gave the score.

iii) The Chinese dictation task assessed children's Chinese word writing ability. Students wrote out 45 two-character Chinese words, read out by the examiner in ascending order of difficulty. A student scored one point for writing each character correctly.

Non-verbal Intelligence

To control for the effect of IQ on reading, nonverbal intelligence was assessed using the 9-item subset of Raven's standard progressing matrices (Raven, Court, & Raven, 1996; see Bilker et al., 2012, for its psychometric properties).

Holistic processing

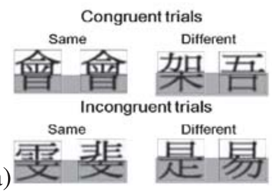
One hundred and sixty pairs of medium to high frequency Chinese characters in Ming font were used as the character stimuli—half of the pairs in top-bottom configuration while the other half in left-right configuration (See Figure 2). 40 pairs were presented in each of the four conditions – same-congruent trials, different-congruent trials, same-incongruent trials and different-incongruent trials. In the congruent trials, the attended halves and the irrelevant halves always 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 (Figure 3a).

Figure 2. Examples of Chinese characters with a left-right configuration (left) and a top-bottom configuration (right).

The participants' performance in each condition (congruent vs incongruent) is measured by discrimination sensitivity A' as:

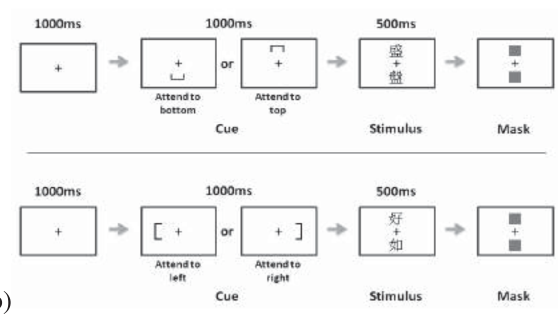
$$A' = 0.5 + \left[sign(H-F)\frac{(H-F)^2 + |H-F|}{4\max(H,F) - 4HF} \right]$$

(H and F are the hit and false alarm rate respective) A' is used to measure sensitivity due to its bias-free nonparametric property (Stanislaw & Todorov, 1999). Hence the degree of HP is measured as the A' difference between the congruent trials and the incongruent trials—the larger the discrepancy, the larger the holistic effect. The discrepancy in response time between congruent and incongruent trials was also measured to demonstrate holistic processing. In addition, a misaligned condition was included to tease out the possibility of composite effects due to inhibition abilities, such that if the holistic-processing effect in students with dyslexia is indeed due to interference from the irrelevant halves, misalignment should reduce this effect. See Figure 3.



3(a)

3(c)



3(b)

Figure 3. (a) Illustration of stimulus pairs in the complete composite paradigm (b) Trial sequences. (c) character in aligned (left) and misaligned conditions (right).

Left-side bias.

To test for left-side-bias effect, procedures from Tso, Au, & Hsiao (2014) were adopted. Eighty high-frequency mirror-symmetric Chinese characters were selected. Each character was presented once in Ming font. For each character, half of the trials displayed the originals were used on half of the trials, whereas in the other half of the trials displayed chimeric characters constructed from half of the original character and its mirror image, and this was counter-balanced across participants.

For each character stimuli, two left halves constructed the left chimeric character while two right halves formed the right chimeric character (Figure 4a). Each character spanned a visual angle of about 6.7° from a 55 cm viewing distance. After 500 ms of a central fixation cross in each trial, the original character was displayed either on the left or right side of the screen randomly, at about 7.2° of visual angle away from the center. Each trial displayed the left and right chimeric characters such that one was above and one below an arrow at the screen center which pointed to the original character image. Each chimeric character image subdued about 3°of visual angle away from the center. All image stimuli were displayed on the screen until participants responded to judge which of the two chimeric characters looked more similar to the original one by pressing one of two buttons on the response box. Left-side bias was measured as the percentage of trials in which participants selected chimeric characters composed of two left halves (Figure 4b).

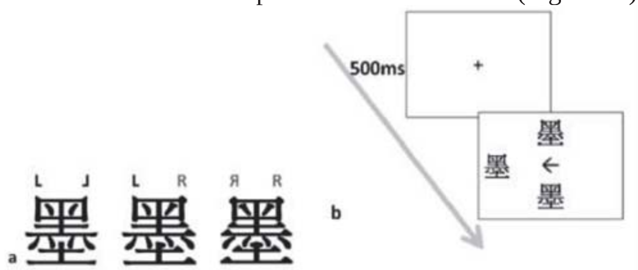


Figure 4. (a) Examples of the stimuli, and (b) the test sequence in the LSB experiment (note that the chimeric characters are still legal Chinese characters).

Results

Literacy abilities and non-verbal intelligence

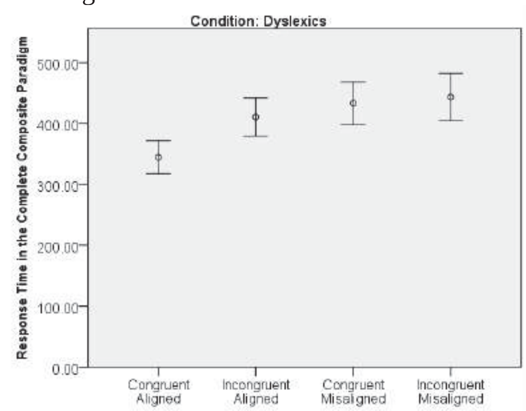
Separate one-way analyses of variance (ANOVAs) were carried out to examine the effect of group (Dyslexics vs Control) on each literacy test. We found that participants in the control condition had a marginally better performance than participants with dyslexia in Chinese word-reading $F(1, 39) = 3.076$, $p = .087$, but their performance in the one-minute word-reading task did not differ, $F(1, 39) = 1.551$, $p = .219$, suggesting that both groups having similar performance in word recognition and fluency in naming over-learned Chinese characters. However, participants in the control condition had significantly better performance in the Chinese word dictation task, $F(1, 39) = 7.229$, $p = .01$, suggesting the students with dyslexia had persistent difficulties in writing Chinese characters even when in high-school grades. The scores are summarized in Table 1.

Table 1. Summary of the scores of Chinese word-reading, Chinese one-minute word reading, Chinese dictation and non-verbal IQ (9-item Raven's) in high-school students with and without dyslexia.

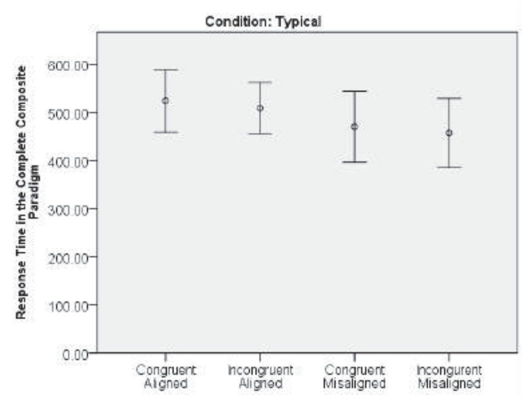
	Control *Mean (SE)*	Dyslexics *Mean (SE)*
Chinese Word-reading	102 (1.82)	99.96 (3.41)
One-minute word reading	93.43 (4.62)	85.91 (3.95)
Chinese dictation	59.73 (13.14)	47.52 (17.35)
Non-verbal IQ	3.91 (1.74)	3.96 (1.34)

Holistic processing

We next examined the ability to holistically process Chinese characters in participants with and without dyslexia. We first conducted a 2 (congruency: congruent vs. incongruent) × 2 (group: dyslexics vs. control) repeated measures ANOVA on A', which showed a main effect of congruency, $F(1, 38) = 27.35$, $p = .000006$, $\eta p2 = .419$, but no interaction between congruency and group, $F(1, 38) = 1.354$, $p = .252$, or main effect of group, $F(1, 38) = 1.342$, $p = .254$, was found. We then conducted a 2 (congruency: congruent vs. incongruent) × 2 (group: dyslexics vs. control) repeated measures ANOVA on response time. We found a significant interaction between congruency and group, $F(1, 38) = 5.854$, $p = .02$, $\eta p2 = .133$, and a main effect of group, $F(1, 38) = 5.306$, $p = .027$, $\eta p2 = .123$, but no main effect of congruency, $F(1, 38) = 2.254$, $p = .150$. Post-hoc ANOVA showed that students with dyslexia responded more slowly in incongruent than in congruent trials, $F(19) = 34.3$, $p < .000012$, $\eta p2 = .644$, whereas response times in congruent and incongruent trials were similar in typically developing students, $F(19) = 0.254$, $p = .620$. See Figure 5.



5a)



5b)

Figure 5. The composite effect in character perception was significant among dyslexics (a), but not the typically developing readers (b). Misalignments significantly reduced the effect in the dyslexics.

The results also showed that misalignment significantly reduced the congruency effect demonstrated by response time among students with dyslexia: a significant interaction between congruency and misalignment (aligned vs. misaligned), $F(1, 19) = 5.662$, $p = .029$, $\eta p2 = .239$; there was no misalignment effect among typically developing students.

Together, these results suggest that participants with dyslexia perceived Chinese characters more holistically than controls.

Left-side Bias

Finally, the results on left-side bias suggests that typical readers have a stronger left-side bias than students with dyslexia, $F(1,38) = 6.439$, $p = .015$, $\eta p2 = .145$. It seems that although the participants with dyslexia were more holistic than typical readers in Chinese character recognition, they revealed weaker left-side bias (Figure 6).

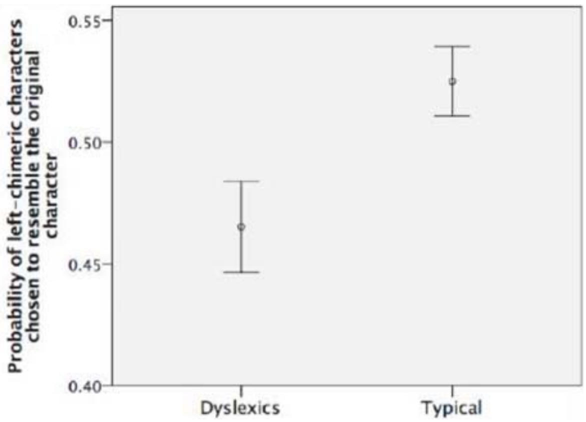


Figure 6. Preference for left chimeric characters in participants with and without dyslexia.

Discussions

This study investigated how high-school students with and without dyslexia differed in how they processed Chinese characters by examining two perceptual expertise phenomena: holistic processing and left-side bias. Our results show that high-school participants with dyslexia demonstrated a stronger holistic processing effect in Chinese character recognition compared with the typically developing controls. This study is consistent with Hsiao and Cottrell's (2009) study in which they showed that reduced HP is associated with expert Chinese character recognition compared with novices, though our study compared between typically developing expert readers and dyslexics in which the dyslexic participants were not completely novices but had relatively weaker Chinese literacy abilities. Our result is also comparable with Tso et al. (2014)'s study that suggested a modulating role of writing abilities on holistic processing: While the students with dyslexia in this study had marginally comparable reading performance to that of typical controls, they recalled and wrote fewer words. Unlike everyday face recognition in which one is not required to recall and draw faces, a typical Chinese reader is fluent in both Chinese character recognition and writing. Indeed, Zhou, et al. (2012) demonstrated reduced HP in artists with face-drawing experience compared with ordinary face-observers. Stronger holistic processing in students with dyslexia than in the typical controls, then, may indicate a perceptual difference between poor and proficient writers.

According to Maurer et al. (2002), holistic processing is a second-order configural processing in which both featural and spatial-distal information within an object are integrated and processed. Hence, the stronger holistic processing effect of the dyslexic students in the present study may also suggest that they recognized characters with an over-dependence on their visuo-spatial information of components, which may hinder developing literacy expertise, particularly in writing. It seems that students with dyslexia demonstrated persistent perceptual abnormalities even when they are in secondary school, which hinders them to selectively attend to individual character components. This in turn hindered Chinese character recognition as it is an ability facilitated by sensitivity to the specific positions of components radicals and structures within a character (Ho, Ng, & Ng, 2003). This speculation warrants future follow-up studies.

This study also echoed with Hsiao and Cottrell's (2009) and Tso, Au and Hsiao's (2014) findings demonstrating that left-side bias was a consistent expertise marker of Chinese character recognition: The dyslexic readers showed reduced left-side bias of Chinese characters than typically developing readers. Our result is also consistent with previous studies that suggested a stronger left-hemisphere but weaker right-hemisphere involvement for Chinese character recognition in readers with dyslexia (Siok et al, 2004; Xue et al., 2005). These effects suggest that dyslexics employ a strategy to process Chinese characters which may be both perceptually and neurologically different from typical readers. Similar to face perceptual processes which involves RH/LSB, our results are consistent with that in prosopagnosic patients who had a reduced left-side bias in facial perception—suggesting a reduced RH involvement in face recognition (Malaspina, Albonic, & Daini, 2016).

However, while HP was previously thought to associate with RH activation as demonstrated in face and subordinate visual-object recognition, the results of this study echoed Hsiao and Cottrell's (2009) study, demonstrating that increased LSB but reduced HP as expertise markers of Chinese character recognition. Holistic processing effect brought about by the composite-face illusion is due to obligatory attention directed to all facial parts, resulting in failure to selectively attending to parts (Hole, 1994; Richler, Tanaka, Brown, & Gauthier, 2008; Richler, Wong, & Gauthier, 2011). Therefore, one reason why Chinese character recognition is different from that of face perception may be because the spacing information between typical Chinese character components may be unimportant to typical Chinese readers (Hsiao & Cottrell, 2009), while spatial information is important in typical face recognition processes (i.e. small changes in spacing between features typically change the face identity; see Farah, et al., 1998). Hence, the relationship between holistic processing and right hemisphere lateralization may be modulated by whether spatial information is used during recognition of visual stimuli. To test above speculations, Hsiao and Galmar (2016) demonstrated through a computational simulation a positive relationship between holistic processing and RH lateralization when a face recognition task relied purely on spatial information (i.e., all faces stimuli differ only spacing among the same features). On the other hand, when the task recognized faces based purely on features (i.e., all faces differed in features but the same spacing between them), holistic processing correlated negatively with RH lateralization (see also Chung et al., 2018). Therefore, whether the RH engages holistic processing in a recognition task may depend on the type of information used for its processing. Indeed, Chinese character recognition is facilitated by sensitivity to components radicals at specific positions within a character (Ho, Ng, & Ng, 2003), not the spatial distances between components. Hence left-side bias in Chinese character recognition is perhaps related to sensitivity to first-order relations in configural processing, i.e. the relative spatial locations of individual components within a character (Maurer et al., 2002).

To conclude, this study is the first to report the perceptual difference between typically developing and dyslexic students in high school by investigating holistic processing and left-side bias of Chinese character recognition. It has demonstrated preliminary evidence for the link between inability to reduce holistic processing and difficulties in Chinese literacy: dyslexic Chinese are less readily to engage in analytic processing to attend to character components. Finally, the reduced left-side bias of Chinese characters in the dyslexics may be related to deficits in forming first order relationship between components. This study suggested that high-school students with dyslexia in Chinese may still encounter difficulties in reading and writing due to persistent deficits in their literacy-related cognitive abilities, and they may require further supports in their learning to enhance attention to Chinese character components or radicals.

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