Writing facilitates learning to read in Chinese through reduction of holistic processing: A developmental study

Ricky Van Yip Tso (richie13@hku.hk)
Terry Kit-fong Au (terryau@hku.hk)
Janet Hui-wen Hsiao (jhsiao@hku.hk)

Department of Psychology, University of Hong Kong
604 Knowles Building, Pokfulam Road, Hong Kong SAR

Abstract

Holistic processing has been identified as an expertise marker of face and object recognition. In contrast, the expertise marker of recognizing Chinese characters is reduced holistic processing (Hsiao & Cottrell, 2009), which is driven by Chinese writing experiences rather than reading ability (Tso, Au, & Hsiao, 2011). Here we investigate the developmental trend of holistic processing in Chinese character recognition and its relationship with reading and writing abilities by testing Chinese children who were learning Chinese at a public elementary school in Hong Kong on these abilities. We found that the holistic processing effect of Chinese characters in children was reduced as they reached higher grades; this reduction was driven by enhanced Chinese literacy rather than age. In addition, we found that writing performance predicts reading performance through reduced holistic processing as a mediator. We thus argue that writing hones analytic processing, which is essential for Chinese character recognition, and in turn facilitates learning to read in Chinese.

Keywords: Chinese character recognition, holistic processing, reading, writing, copying

Introduction

Holistic processing (HP)—the ability to process separate features as a single whole unit—is an expertise marker for face and object recognition (see e.g., Bukach, Gauthier, & Tarr, 2006; Gauthier & Bukach, 2007; Richler, Wong, & Gauthier, 2011; though some argue that it is specific to faces, e.g, McKone, Kanwisher, & Duchaine, 2007). Chinese characters share many visual properties with faces. In contrast to words in most alphabetic languages that are linear in structure and consist of letter series of varying length, the Chinese writing system is logographic—The configuration of Chinese characters is more homogenous and square, and each character is a grapheme that represents a morpheme (Shu, 2003; Wong & Gauthier, 2006). The basic units of a Chinese character are strokes that combine to create more than a thousand different stroke patterns in the Chinese writing system; these stroke patterns form the characters (Hsiao & Shillock, 2006). A typical literate recognizes more than 3,000 individual Chinese characters regardless of variations in font (Hsiao & Cottrell, 2009). This is similar to face recognition in which faces are recognized individually regardless of variations in facial expressions (Hsiao & Cottrell, 2009; Wong & Gauthier, 2006). Despite the similarity between Chinese characters and faces, the expertise marker for Chinese character recognition is reduced HP (Hsiao & Cottrell, 2009).

Experienced Chinese readers employ less HP than novices in perceiving Chinese characters; this may be because Chinese readers are more sensitive to the internal constituent components of Chinese characters. They can readily ignore some configural information, such as exact distances between features, which are unimportant for character recognition (Ge, Wang, McGleery, & Lee, 2006). In contrast, these internal constituent components may not look easily separable to novices as they are less able to distinguish individual features and components in Chinese characters (Chen, Allport, & Marshall, 1996; Ho, Ng, & Ng, 2003; Hsiao & Cottrell, 2009). In addition, reduced holistic processing (i.e., analytic processing) of Chinese characters is enhanced by Chinese writing experiences (Tso, Au, & Hsiao, 2011). In Tso and colleagues' (2011) study, two groups of Chinese readers were tested: Chinese literates who could read and write (i.e., Writers), and Chinese literates who had limited writing exposure and thus had reading performance far better than writing performance (i.e., Limited-writers). Limited-writers had reading performance comparable to Writers', yet Limited-writers had far poorer performance than Writers in a dictation task (i.e., recall and write down a Chinese word when instructed). Writers perceived Chinese characters less holistically than Limited-writers—this between-group difference in HP could mainly be explained by dictation (writing) performance when the reading and copying variables were statistically controlled.

In Hong Kong, elementary schools do not explicitly place emphasis in its curriculum on teaching the Chinese character radicals (i.e., character components that consist of one or more identifiable stroke patterns); yet, children become more aware of the internal orthographic components in Chinese characters as they progress to higher grades (Ho et al., 2003). This may be explained by motor programming through extensive copying and writing as a requirement in Chinese lessons at school (Guan, Liu, Chan, Ye, & Perfetti, 2011; Tan, Spinks, Eden, Perfetti, & Siok, 2005). Reading performance is significantly predicted by copying ability (Chan, Ho, Tsang, Lee, & Chung, 2006; McBride-Chang, Chung, & Tong, 2011; Tan et al., 2005), as well as dictation performance (McBride-Chang et al., 2011; Tse, Kwan, & Ho, 2010). Writing experience may enhance reading ability because children may consolidate knowledge of graphomotor memory of character strokes as they copy the stroke patterns (Tan et al., 2005; Tse et al., 2010). Learning to write was experimentally shown to strengthen Chinese

character recognition (Guan et al., 2011). Neuroimaging studies also suggested that writing experience plays an important role in shaping reading-specialized neural representations (James & Atwood, 2009; Longcamp, Anton, Roth, & Velay, 2003; Siok, Perfetti, Jin, & Tan, 2004). All these results suggest a close relationship between sensory-motor integration development through writing practice and the development of reading skills, particularly for recognizing Chinese characters.

Although previous studies have suggested a close relationship between Chinese writing and reading performance in children, the underlying mechanism remains unclear (e.g., Guan et al., 2011; McBride-Chang et al., 2011)[1]. As reduction in HP of Chinese characters marks expert-level character recognition, here we hypothesize that writing experience enhances character recognition performance by modulating the perceptual system, allowing readers to identify Chinese characters more analytically (Tso et al., 2011). The modulating effect of writing experience on our perception of Chinese characters has never been studied before in Children who are learning to read and write Chinese characters. Here, we investigate whether children in upper grades perceived characters less holistically than children in lower grades in an elementary school where the Chinese language is taught. We also examine their Chinese reading and writing performance to see what can predict Children's reduced HP of Chinese characters. We predict that upper-grade children (who should have better Chinese literacy than lower-grade children) will process Chinese characters more analytically (i.e., less holistically) than children in lower grades. Because of the direct relationship writing experiences have with reduced HP (Tso et al., 2011), we hypothesize that children's reduction in HP can be predicted by writing performances across grades. Since writing performance also strongly correlates with reading abilities in Chinese (see e.g., Guan et al., 2011; McBride-Chang et al., 2011; Tan et al., 2005), we hypothesize that HP mediates between Chinese reading and writing abilities in children. More specifically, we predict that writing experience leads to reduced holistic processing in Chinese characters, which in turn enhances reading abilities in Chinese (Fig. 1)

Tso and colleagues (2011) also suggested that writing experience may facilitate reading Chinese characters in an unfamiliar font, as Limited-writers had difficulty reading words in the Feng font (a font that mimics handwriting and was unfamiliar to the participants) whereas this effect in Writers was minimal. Hence here we also examine the possible effect of enhanced Chinese writing proficiency on naming characters and words in familiar and unfamiliar fonts.

---

[1] Although some studies have proposed that writing enhances graphomotor memory of Chinese characters, which in turn facilitates reading (e.g., Tan et al., 2005; Tse et al., 2010). Yet, this hypothesis has not been statistically tested.

Fig. 1. Predicted mediation effect of reduced holistic processing between Chinese writing and reading performance.

Methods

Participants
56 first grade (mean age = 5.88 years, SE = .051), 73 third grade (mean age = 7.90, SE = .056), and 88 fifth grade (mean age = 9.89, SE = .047) Chinese children from an elementary in Hong Kong participated in our study. They were all Cantonese native-speaking and were all receiving regular Chinese language curriculum at school. All of them had normal or corrected-to-normal vision.

Procedures

Test for holistic processing
To test for HP effects, we adopted procedures from Hsiao and Cottrell (2009). 160 pairs of medium to high frequency Chinese characters in Ming font were chosen; 80 pairs had a top-bottom configuration and 80 pairs had a left-right configuration[2] (Fig. 2). The frequency information of the Chinese characters was obtained from Ho and Kwan (2001). The top-down and left-right characters were matched in stroke number and frequency. In each trial, children were presented with two characters and instructed to attend to only half (either top or bottom for top-bottom characters, or left or right for left-right characters) of each character and judge whether they were the same or different. Forty pairs were presented in each of the four conditions (Fig. 3a): *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 (e.g., the top halves were the same while the bottom halves were different). We adopted this paradigm to avoid response biases that may occur in the partial composite design in which the irrelevant halves would always be
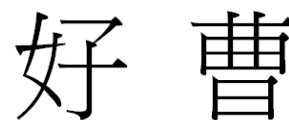

Fig. 2. Examples of Chinese characters with left-right configuration (left) and top-bottom configuration (right).

different (see Gauthier & Bukach, 2007; Robbins & McKone, 2007; Richler, Cheung, & Gauthier, 2011).

---

[2] Both left-right and top-bottom are common Chinese character structures. Left-right is a more dominant structure than top-bottom in the Chinese lexicon.

In each trial, after 1,000 ms of central fixation, participants were cued with a symbol that indicated which half of each character they should attend to. 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, children 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 3b). Accuracy was collected. 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.
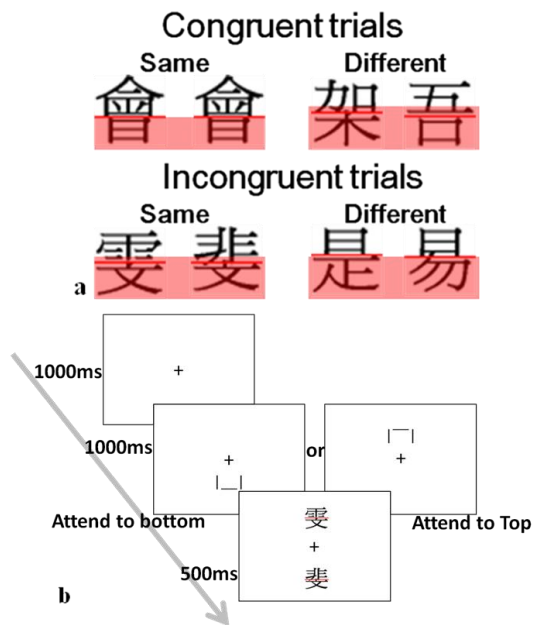

Fig. 3. Illustration of stimulus pairs in the complete composite paradigm and trial sequences (for top-bottom characters). In (a), the attended components are shaded in red. In (b), a 1,000 ms central fixation cross precedes each trial, followed by a cue either below or above the cross to indication which half (top or bottom) of the characters participants should attend to in the following display.

Tests for reading and writing performance:
Four tests were administered: 1. Character naming task, 2. Word naming task, 3. Character copying task, and 4. Word dictation task. Tasks 1 and 2 assessed participant's reading ability, while Tasks 3 and 4 assessed their copying and word recalling/writing ability respectively.

Reading tests:
1. Character naming task:
Children were presented with 60 Chinese characters one at a time. Half of the stimuli were presented in Ming font (a commonly used font type; Fig. 4a) and the other half were presented in Feng font (an unfamiliar font type that simulates handwriting; Fig. 4b). They were instructed to read aloud the characters as quickly and as accurately as possible. The characters were arranged from high to low frequency (frequency information for primary students was obtained from Leung & Lee, 2001). The trials stopped after 5 consecutive errors made. Each trial started with a central fixation cross for 500ms, followed by the character presentation. The screen turned blank after a child had responded and the experimenter pressed a button to record the accuracy and to start the next trial. Their response time was measured as the time difference between the stimulus onset and the onset of the pronunciation, detected by a microphone.

2. Word naming task:
Children read aloud 30 two-character words arranged from high to low frequency (frequency information for primary students was obtained from Leung & Lee, 2001) as quickly and accurately as possible. Half of the stimuli were presented in Ming font and the other half were presented in Feng font. The procedure was the same as that of the character naming task. The response time was measured as the time difference between the stimulus onset and the onset of the pronunciation of the first character.

Fig. 4. Examples of a Chinese character in Ming font (a) and Feng font (b).

Writing tests:
3. Character copying task:
Children copied 30 characters (10 real characters, 10 pseudo-characters, and 10 Korean characters) as quickly and as accurately as possible. The Chinese characters were randomly selected from the characters used in task 1. The pseudo-characters were orthographically legal but non-sense characters. Each trial started with a central fixation cross for 500 ms, followed by the character presentation. Each time, after a child had copied a character, the experimenter pressed a button immediately and the screen turned blank to start the next trial. Their response time was recorded.

4. Word dictation task:
Children wrote down 30 two-character words (the same words used in task 2) 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 corresponding 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 rate was recorded.

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

Results

Repeated-measures ANOVA was used to investigate HP effects (congruency: congruent vs. incongruent trials x grade: Grade 1 vs. Grade 3 vs. Grade 5). We found a significant effect of grade ($F(2, 213) = 25.090$, $p < 0.001$), a significant effect of congruency ($F(1, 213) = 268.319$, $p < 0.001$), and an interaction between congruency and grade ($F(1, 213) = 11.376$, $p < 0.001$). The main effect of congruency suggests that across grades, children process Chinese characters holistically. While the main effect of grade showed that the performance level increased with grade, the interaction between grade and congruency suggests that children processed Chinese characters with varying levels of congruency effect across grades (Fig. 5).
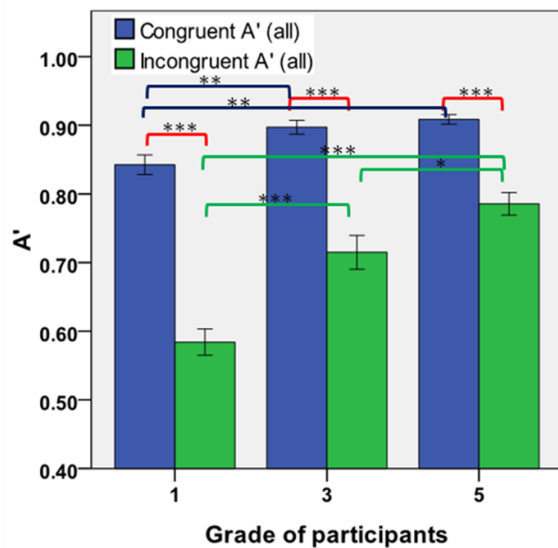

Fig. 5. *A'* of congruent and incongruent trials for first, third and fifth graders in the holistic processing task (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

Pairwise post-hoc t-tests showed that A' in congruent trials was larger than in incongruent trials in first ($t(55) = 12.01$, $p < .001$), third ($t(72) = 7.838$, $p < .001$) and fifth graders ($t(86) = 8.439$, $p < .001$). In congruent trials, first graders had a smaller A' than third ($t(127) = 3.226$, $p < .01$) and fifth graders ($t(141) = 4.576$, $p < .001$) while third and fifth graders did not differ statistically in A' ($t(158) = .994$, n.s.). In incongruent trials, first graders had a smaller A' than third ($t(127) = 3.991$, $p < .001$) and fifth graders ($t(141) = 7.878$, $p < .001$), and third graders had a smaller A' than fifth graders ($t(158) = 2.450$, $p < .05$). We also conducted pairwise post-hoc t-tests on the A' difference between incongruent and congruent trials (i.e., Holistic A') between children in the 3 grades. We found that first graders had a larger Holistic A' than third graders ($t(127) = 2.334$, $p < .05$)] and fifth graders ($t(141) = 5.401$, $p < .001$), while third graders had a larger Holistic A' than fifth graders ($t(158) = 2.230$, $p < .05$). These results suggest that HP of Chinese characters in children was reduced as they reached higher grades (see Fig. 5).

Chinese proficiency tests

Pearson's correlation regression analysis showed a positive correlation between grade and character-naming accuracy ($r^2 = .602$, $p < .001$), word-naming accuracy ($r^2 = .512$, $p < .001$) and dictation accuracy ($r^2 = .707$, $p < .001$); and a negative correlation between grade and character-naming response time ($r^2 = .269$, $p < .001$), word-naming response time ($r^2 = .347$, $p < .001$) and character-copying response time ($r^2 = .620$, $p < .001$). These results suggest that children had better Chinese reading and writing proficiency as they reached higher grades.

Font familiarity effect on character and word naming

Repeated-measures ANOVA (font: Ming vs. Feng x grade) was used for the analysis on character-naming response time. We found a main effect of font ($F(1,181) = 16.9$, $p < .001$) and a main effect of grade ($F(2,181) = 37.01$, $p << .001$), but no interaction effect was found between font and grade ($F(2,181) = .348$, n.s.).

For word-naming response time, we found a main effect of font ($F(1,177) = 17.1$, $p < .001$) and a main effect of grade ($F(2,177) = 59.6$, $p << .001$). We also found an interaction

Table 2. Hierarchical regression analysis among holistic processing and reading and copying performance

Predicted Variable:	Holistic A'	
Age vs. Character Naming (RT & Accuracy)		
Steps	**Variables**	**Δr^2**
1	Age	.110***
2	Character Naming	.037*
1	Character Naming	.141***
2	Age	.005
Age vs. Word Naming (RT & Accuracy)		
1	Age	.099***
2	Word Naming	.056**
1	Word Naming	.147***
2	Age	.008
Age vs. Copying (RT)		
1	Age	.104***
2	Copying	.001
1	Copying	.067***
2	Age	.038**
Age vs. Dictation (Accuracy)		
1	Age	.155***
2	Dictation	.014[1]
1	Dictation	.118***
2	Age	.011

[1] $p < 0.1$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

effect between font and grade (F(2,177) = 3.894, p < .05). We then performed pairwise post-hoc t-tests on the response time difference between Ming font words and Feng font words among children in the 3 grades. We found that first graders had a larger font effect in response time than third graders (t(109)=1.941, p = .055) and fifth graders (t(117) = 2.192, p < .05) while third and fifth graders did not differ statistically (t(128) = .135, n.s.). These results suggest that word-naming performances depended greatly on font familiarity in lower grades than in upper grades. This font-grade interaction was not found in character-naming.

Hierarchical Regression Analysis

We investigated how HP could be uniquely predicted by literacy level by partialing out the variance due to age. As summarized in Table 2, HP was predicted uniquely by reading and writing performance and vice versa. The variance of HP can be significantly explained by reading and dictation performances, but not copying performance, when partialing out the variance due to age.

Mediation Analysis

We conducted a mediation analysis to test the mediation effect of HP between dictation accuracy and word naming accuracy[3]. Regression analysis revealed that Holistic A' predicted word naming accuracy ($\beta = -.265, p < .01$). A Sobel mediation test showed that Holistic A' significantly mediated the relationship between dictation accuracy and word naming accuracy ($z = 2.403, p < .05$). The mediator effect of Holistic A' was partial as the direct effect of dictation accuracy and word naming accuracy remained statistically significant, $\beta = .635, p < .001$ (Fig. 6).
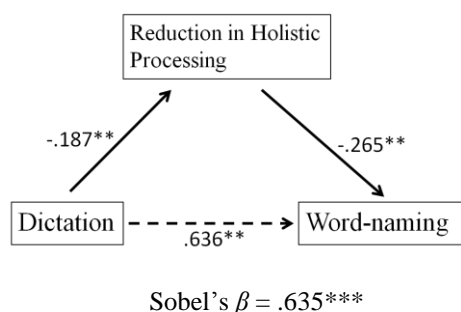

Sobel's $\beta = .635^{***}$

Fig 6. Partial mediation effect of reduced holistic processing on dictation and word naming performances (*p <0.05; **p <0.01; ***p <0.001).

Discussion

Our study showed that children in upper grades processed Chinese characters less holistically than children in lower grades. Further analyses showed that this effect could not be solely accounted for by age. Consistent with Hsiao and Cottrell's (2009) findings, better Chinese reading and writing proficiency strongly predicted reduced HP. Because elementary schools in Hong Kong do not explicitly teach children Chinese character radicals (Ho et al., 2003), their reduction in HP in upper grades is more likely the result of enhanced Chinese literacy.

Previous studies had reported a close relationship between Chinese writing and reading performance. Yet, the underlying mechanism remained unclear (e.g., Guan et al., 2011; McBride-Chang et al., 2011; Tan et al., 2005; Tse et al., 2010). In our study, the mediation analysis suggests that HP is a significant mediator of dictation accuracy and word naming accuracy (Fig. 6). This result is consistent with our hypothesis that the HP effect in Chinese character recognition is predicted by writing performance (i.e., the ability to recall and write down Chinese characters), and in turn predicts word reading performance (Fig. 1). Perhaps writing experience enhances the ability to analyze the orthographic structures and components of Chinese characters in children, which leads to reduced HP (i.e., more analytic) as suggested in Tso and colleagues' (2011) study. Consistent with previous findings that suggest our sensorimotor learning influences our perception (He et al., 2003; James & Atwood, 2009; Longcamp et al., 2003), we show how writing performance can be associated with reduced HP in Chinese character recognition. In addition, we show that this change in the perception of Chinese characters (reduced HP) can in turn modulate reading performance. This study is also the first to report on the developmental trajectory of HP of Chinese characters in children.

Our results also revealed that children were better at recognizing Chinese characters and words in a familiar font (Ming) than in an unfamiliar font (Feng); this effect of font familiarity was more prominent in first graders than third and fifth graders. ANCOVA analysis showed that the group difference in the font familiarity effect became insignificant when dictation accuracy was set as a covariate (F(2,172) = 1.84, n.s.). This suggests that writing experience, measured as the ability to recall and write characters here, facilitates reading words in an unfamiliar font (Tso et al., 2011). Further investigation, however, is needed to see whether this effect is due to a particular dimension or general improvement in literacy.

As future work, we will obtain information of HP of Chinese characters from non-Chinese speaking children that do not receive the local Chinese curriculum as a control group. We speculate that the pattern of their holistic processing of Chinese characters will not drop as much as Chinese-learning children as they do not learn to write Chinese explicitly.

In conclusion, our study provides an information processing account of the relationship between writing and reading ability in Chinese children. We show that children learning to read and write Chinese characters processed Chinese characters with reduced HP as they reached upper grades; this reduction in HP may be facilitated by writing experience and may in turn enhance word reading ability.

---

[3] This mediation pathway with word-naming accuracy as the first and dictation accuracy as the final step was not significant.

References

Bukach, C. M., Gauthier, I., & Tarr, J. M. (2006). Beyond faces and modularity: The power of an expertise framework. *Trends in Cognitive Sciences, 10*, 156-166.

Chan, D. W., Ho, C. S.-H., Tsang, S.-m., Lee, S.-h., & Chung, K. K. H. (2006). Exploring the reading-writing connection in Chinese children with dyslexia. *Reading and Writing, 19*, 543-561.

Chen, Y. P., Allport, D. A., & Marshall, J. C. (1996). What are the functional orthographic units in Chinese word recognition: The stroke or the Stroke pattern? . *Q. J. Exp. Psychol-A, 49*, 1024-1043.

Gauthier, I., & Bukach, C. (2007). Should we reject the expertise hypothesis? *Cognition, 103*, 322-330.

Ge, L., Wang, Z., McGleery, J. P., & Lee, K. (2006). Activation of face expertise and the inversion effect. *Psychological Science, 17*, 12-16.

Guan, C. Q., Liu, Y., Chan, D. H. L., Ye, F., & Perfetti, C. A. (2011). Writing strengthens orthographic and alphabetic-coding strengthens phonology in learning to read Chinese. *Journal of Educational Psychology, 103*(3), 509-522.

He, A. G., Tan, L. H., Tang, Y., James, A., Wright, P., & Eckert, M. A. (2003). Modulation of neural connectivity during tongue movement and reading. *Human Brain Mapping, 18*, 222-232.

Ho, C. S., & Kwan, T. W. (2001). Hong Kong, Mainland China & Taiwan: Chinese character frequency-A trans-regional, diachronic survey. Retrieved December 30, 2011, from Character Frequency: http://arts.cuhk.edu.hk/Lexis/chifreq/

Ho, C. S., Ng, T., & Ng, W. (2003). A radical approach to reading development in Chinese: The role of semantic radicals and phonetic radicals. *Journal of Literacy Research, 35*, 849-878.

Hsiao, J. H., & Cottrell, G. (2009). Not all visual expertise in holistic, but it may be leftist: The case of Chinese character recognition. *Psychological Science, 20*(4), 455-463.

Hsiao, J. H., & Shillock, R. (2006). Analysis of a Chinese phonetic compound databse: Implications for orthographic processing. *Journal of Psycholinguistic Research, 35*, 405-426.

James, K. H., & Atwood, T. P. (2009). The role of sensorimotor learning in the perception of letter-like forms: Tracking the causes of neural specialization for letters. *Cognitive Neuropsychology, 26*, 91-110.

Leung, M. T., & Lee, A. W. Y. (2001). The Hong Kong corpus of primary school Chinese. Paper presented at the 9th meeting of the International Clinical Phonetics and Linguistics Association. Hong Kong.

Longcamp, M., Anton, J. L., Roth, M., & Velay, J. L. (2003). Visual presentation of single letters activates a premotor area involved in writing. *NeuroImage, 19*, 1492-1500.

McBride-Chang, C., Chung, K. K. H., & Tong, X. (2011). Copying skills in relation to word reading and writing in Chinese children with andwithout dyslexia. *Journal of Experimental Child Psychology, 110*, 422-433.

McKone, E., Kanwisher, N., & Duchaine, B. C. (2007). Can generic expertise explain special processing for faces? *Trends in Cognitive Sciences, 11*, 8-15.

Richler, J. J., Cheung, O. S., & Gauthier, I. (2011). Beliefs alter holistic face processing ... if response bias is not taken into account. *Journal of Vision, 11*(13):17, 1–13.

Richler, J. J., Wong, Y. K., & Gauthier, I. (2011). Perceptual expertise as a shift from strategic interference to automatic holistic processing. *Current Directions in Psychological Science, 20*(2), 129-134.

Robbins, R., & McKone, E. (2007). No face-like processing for objects of expertise in three behavioural tasks. *Cognition, 103*, 34-79.

Shu, H. (2003). Chinese writing system and learning to read. *International Journal of Psychology, 38*, 274-285.

Siok, W. T., Perfetti, C. R., Jin, Z., & Tan, L. H. (2004). Biological abnormality of impaired reading is constrained by culture. *Nature, 431*, 71-76.

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments & Computers, 31*, 137-149.

Tan, L. H., Spinks, J. A., Eden, G. F., Perfetti, C. A., & Siok, W. T. (2005). Reading depends on writing, in Chinese. *PNAS, 102*, 8781-8785.

Tse, H. M., Kwan, D. P., & Ho, C. S. (2010). *Should dyslexic children stop copying? Exploring the relationship between word reading, copying and dictation*. Paper presented at the Annual International Academy for Research in Learning Disabilities Conference.

Tso, R. V. Y., Au, T. K., & Hsiao, J. H. (2011). *The influence of writing experiences on holistic processing in Chinese character recognition*. Paper presented at the Thirty-Third Annual Conference of the Cognitive Science Society, Boston.

Wong, A. C., & Gauthier, I. (2006). An analysis of letter expertise in a levels-of-categorization framework. *Visual Cognition, 15*, 854-879.