The Influence of Writing Experiences on Holistic Processing in Chinese Character Recognition

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Abstract

Holistic processing has been shown to be a behavioral marker of face recognition and object recognition in experts. We tested Chinese literates who can read and write Chinese characters (Writers) and Chinese literates whose reading performance far exceeded their writing ability (Limited-writers). We found that Writers perceived Chinese characters less holistically than Limited-writers. In addition, the holistic processing effect was found to be dependent of writing experiences rather than reading and copying performances. This effect may be due to Chinese Writers exhibiting a better awareness of the orthographic components of Chinese characters than Limited-writers. While Hsiao and Cottrell (2009) showed that reduced holistic processing is a marker of visual expertise in Chinese character recognition, our findings further suggest that such reduction is related to writing experiences in Chinese. This study is also the first to report on the Chinese reading population that has far poorer writing performance than reading performance.

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

Introduction

Holistic processing has been found to be a marker of expertise in face recognition as well as for object recognition (e.g. Bukach, Gauthier, & Tarr, 2006; Gauthier & Buhach, 2007; Wong, Palmeri, & Gauthier, 2009; although some argued that it is specific to face recognition; see e.g., McKone, Kanwisher, & Duchaine, 2007). Chinese characters, with their many shared visual properties with faces (McCleery et. al., 2008), had been hypothesized to induce a similar holistic processing effect in expert readers. Yet the expertise marker for Chinese character recognition is reduced holistic processing (Hsiao & Cottrell, 2009).

It is understandable why Chinese characters were thought to induce holistic processing in Chinese readers. The Chinese reading system is logographic. While words in alphabetic languages such as English are linear in structure, consisting of series of letters in varying lengths, Chinese characters have a more homogenous configuration and each character is considered as a grapheme that maps onto a morpheme (Shu, 2003; Wong & Gauthier, 2006). The basic units of a Chinese character are strokes, which combine to form more than a thousand different stroke patterns in the Chinese writing system (Hsiao & Shillcock, 2006). Recognizing Chinese character means recognizing different constituent units formed by different combinations of stroke patterns and a typical literate recognize 3,000 to 4,000 Chinese characters (Hsiao & Cottrell, 2009). Chinese characters are recognized regardless of variation in font, similar to face recognition regardless of difference facial expressions (Hsiao & Cottrell, 2009), and experts recognize Chinese characters individually like faces (Wong & Gauthier, 2006).

However, the reason why experienced Chinese readers have a reduced holistic processing effect compared with novices in perceiving Chinese characters (Hsiao & Cottrell, 2009) may be because Chinese readers are sensitive to the internal constituent components of Chinese characters and have the ability to ignore the overall configural information (Ge, Wang, McCleery, & Lee, 2006). In contrast, these internal constituent components of Chinese characters do not look easily separable to novices who lack the orthographic sensitivity that expert readers possess to distinguish individual features and components in Chinese characters (Chen, Allport, & Marshall, 1996; Ho, Ng, & Ng, 2003; Hsiao & Cottrell, 2009).

Chinese children have better orthographic awareness as they progress to higher grades (Ho, Ng, & Ng, 2003). One explanation has to do with motor programming through extensive copying and reading at school (Tan, Spinks, Eden, Perfetti, & Siok, 2005). Tan et al. (2005) identified that copying performance significantly predicts reading ability, while a more recent study further demonstrated a significant correlation between dictation and reading performance (Ho et al., 2006). Both copying and dictation were shown to predict reading performance because children may consolidate orthographic structures of Chinese characters with graphomotor memory of strokes as they copy the stroke sequence (Tan et al., 2005; Tse, Kwan, & Ho, 2010). Other research also suggested that our writing experience plays an important role in shaping the neural representation specialized for reading (e.g., James & Atwood, 2008; Longcamp Anton, Roth, & Velay, 2003). He et al. (2003) showed that a neural pathway linking the Broca's area and the supplemental motor area was activated during silent reading of Chinese pinyins (Romanized transcriptions of Mandarin pronunciation) in an fMRI study. Siok, Perfetti, Jin and Tan (2004) identified the left middle frontal gyrus, an area just anterior to the premotor area, was activated in normal but not dyslexic Chinese readers when reading. These results consistently suggest a close relationship between the development of sensory-motor integration through writing practice and the development of reading skills.

However, there exist some Chinese readers who have high reading proficiency with writing ability far poorer than their reading performance. These readers are usually from international schools or foreigners living in Chinese speaking countries who learned to read Chinese from the environment, or overseas Chinese immigrants who acquired reading Chinese from the mass media. These readers thus are a counter-example of the claim that writing skills are required in learning to read Chinese. Yet, there is virtually no existing literature that investigated such a Chinese community on their reading abilities and behavior. This discrepancy between reading performance and writing performance in Chinese is possible because writing in Chinese is more complex and resource-demanding than writing in alphabetic languages (Tse, Kwan, & Ho, 2010). When recalling an English word to write, remembering the 26 letters in the alphabet together with the combination corresponding to its sounds is much simpler than writing Chinese characters, in which one has to retrieve more than a thousand pieces of script information from long term memory. Given the higher cognitive load when producing a Chinese character, it is possible that the above-mentioned limited-writing Chinese community use a more efficient strategy, recognizing the holistic structure similarly to face recognition, as they do not need to analyze the constituent structures of Chinese characters for writing. Nevertheless, it remains unclear whether their Chinese reading performance is comparable to native readers who received intensive character writing training, and whether different cognitive processes are involved in Chinese reading between these two groups of readers.

Here we aim to investigate the reading and writing performance differences between proficient Chinese readers who know how to write (i.e. Writers) and those with substantially poorer writing performance (i.e. limited-writers). In addition, we examine whether writers perceive characters less holistically than limited-writers, and whether the reduced holistic processing effect is related to their reading and writing performance. Since writing practice may enhance orthographic awareness of characters and de-emphasize configural information in character recognition, we predict that writers may be more sensitive to components and less sensitive to configural information than limited-writers, and consequently recognize characters with reduced holistic processing.

Methods

Participants
34 Cantonese native-speaking Chinese readers (14 males and 20 females) from Hong Kong participated in our study. They had similar (college) education background. Half of them had always attended conventional local schools and reported to have fluent reading and writing proficiency (i.e. Writers), while the other half had either studied overseas or in an international school and had not received formal Chinese lessons that prepared them for the local public Chinese examinations (i.e. Limited-writers). All Limited-writers

reported being capable of reading Chinese characters but with far poorer writing ability. Their average age was 21.06 (S.E. = .39) and all of them had normal or corrected-to-normal vision.

Procedures

Test for holistic processing
To test for holistic processing effects, procedures were adopted from Hsiao and Cottrell (2009). 80 pairs of medium to high frequency Chinese characters in Ming font having a top-bottom configuration as adopted by Hsiao and Cottrell (2009) were chosen. Participants were asked to attend to only half (either top or bottom) of each character on any given trial. Twenty pairs were presented in each of the four conditions (Fig. 1): *same in congruent trials, different in congruent trials, same in incongruent trials and different in congruent trials*. A complete composite paradigm (Gauthier & Bukach, 2007) was adopted so that in congruent trials, the attended and irrelevant halves of the Chinese characters 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 (i.e. one halves were the same while the others were different). We adopted this experimental design to avoid response biases that may occur in the partial composite design in which the irrelevant halves of the Chinese characters would always be different (Robbins & McKone, 2007; see Gauthier & Bukach, 2007). The stimuli were of relatively low contrasts to enhance the difficulty of this task to avoid ceiling effects.

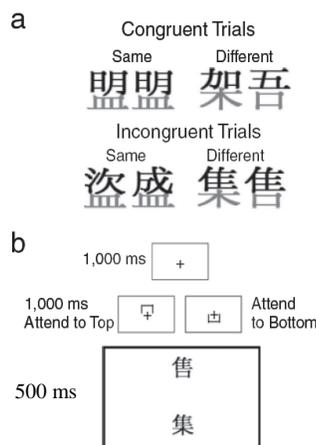In each experimental trial, participants were cued with a

Fig. 1. Illustration of stimulus pairs in the complete composite paradigm and trial sequences (Hsiao & Cottrell, 2009, p. 456). In (a), the attended components are shaded in grey in this example for trials when attended halves are the bottom halves. 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.

symbol that indicated which half (top or bottom) of each character they should attend to, after 1,000 ms of central fixation, in judging whether the pair of word part was the same. The pair of characters was then presented, with one above and one below the initial fixation point. During the 500 ms presentation time, participants looked at each character once and responded as quickly and accurately as possible, pressing a button to judge if the character parts were the same or different. Accuracy and reaction time were collected. If the participants judged characters holistically, they should make more error and respond more slowly in the incongruent trials compared with the congruent trials. We measure participants' holistic processing effect D' as:

$$D' = d'_{congruent} - d'_{incongruent}$$

Where d' is the discrimination sensitivity measure of the congruent and incongruent trials. We also measure the response time difference between incongruent trials and congruent trials (i.e. holistic Response Time).

Fig. 1 illustrates how the stimuli appeared in each condition and summarizes the events that occurred in each trial.

Tests for reading and writing performance:
Four tests were employed to obtain data on participants' reading and writing ability:
1. Character naming task
2. Word naming task
3. Character copying task
4. Word dictation task.

Task 1 and 2 tested participant's reading ability while task 3 and 4 tested their Character copying and word recalling ability respectively. Two-character words were presented in Task 2 and the same words were given in task 4 instead of characters to reduce ambiguity due to homophonic characters in the Chinese lexicon. Task 4 was compared with Task 2 to examine the discrepancy between word naming and word recalling as both tasks used the same words.

Reading tests:

1. Character naming task:
   Participants were presented with 84 high frequency Chinese characters of similar visual complexity one at a time and asked to read aloud as quickly and as accurately as possible (the characters had an average frequency of 443.3 (S.E. = 45.4) and stroke number of 10.9 (S.E. = .16)). The information of the stimuli's frequencies and stroke numbers was obtained from the database from Humanities Computing and Methodology Programme at the Chinese University of Hong Kong (Kwan, 2001). In each trial, participants first fixated on a screen with a fixation cross at the center for 500 ms, followed by the presentation of the character. After they had responded, the screen turned blank and the experimenter pressed a button to record the accuracy and to start the next trial. Their response time and accuracy rate were recorded.

2. Word naming task:
   Participants read aloud 40 high frequency two-character words (average frequency = 194.7, S.E. = 19.6) as quickly and accurately as possible. The information of the stimuli's frequency and stroke number was obtained from the database

of Taiwan Ministry of Education (1997). In each trial, participants first fixated on a screen with a fixation cross at the center for 500 ms, followed by the presentation of the character. After they had responded, the screen turned blank, and the experimenter pressed a button to record the accuracy and to start the next trial. Their response time and accuracy rate were recorded.

Writing tests:

3. Character copying task:
   Participants copied 60 characters (20 real characters, 20 pseudo-characters, and 20 Korean characters) as quickly and as accurately as possible. The Chinese characters were high frequency characters that were randomly selected from the characters used in task 1 with an average frequency of 348 (S.E. = 65.9) and average stroke number of 10.7 (S.E. = .48). The pseudo-characters were orthographically legal but non-sense characters. In each trial, participants first fixated on a screen with a fixation cross at the center for 500 ms, followed by the presentation of the character. After they had copied each character, they pressed a button on the response box immediately and the screen turned blank. Then the experimenter pressed a button to record the accuracy and to start the next trial. Their response time was recorded.

4. Word dictation task:
   Participants wrote down 40 two-character words as quickly and as accurately as possible when they heard each word said in a female voice presented by a computer. In each trial, participants first fixated on a screen with the words "Get ready" for 500 ms. After hearing the word, participants immediately pressed a button to indicate whether they could recall the word, or another button if they could not, before they started writing. The experimenter then 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

One-way ANOVAs were used for the analysis. The results showed that Writers and Limited-writers did not differ in their word naming accuracy [$F(1, 32) = 0.995$, n.s.; Fig. 2(a)], suggesting that both groups had high Chinese reading proficiency. Nevertheless, Writers had significantly shorter response times in word naming than Limited-writers [$F(1, 32) = 12.365$, $p < 0.01$; Fig. 2(b)]. In character naming, Writers outperformed Limited-writers in both accuracy [$F(1, 32) = 5.23$, $p < 0.05$; Fig. 2(c)] and response time [$F(1, 32) = 14.45$, $p < 0.01$; Fig. 2(d)]. Writers also had shorter response times in the character copying task than Limited-writers [$F(1, 32) = 15.39$, $p < 0.01$; Fig. 2(e)]. In the dictation task, Writers were significantly more accurate than the Limited-writers [$F(1, 32) = 140.15$, $p < 0.01$; Fig. 2(f)]. As for holistic processing effects, a significant difference was found in the response time difference between the incongruent and congruent trials (i.e. holistic Response Time) between the two groups [$F(1, 32) = 13.61$, $p < 0.01$; Fig. 2(g)]. Writers perceived Chinese characters less holistically than Limited-writers. A marginal
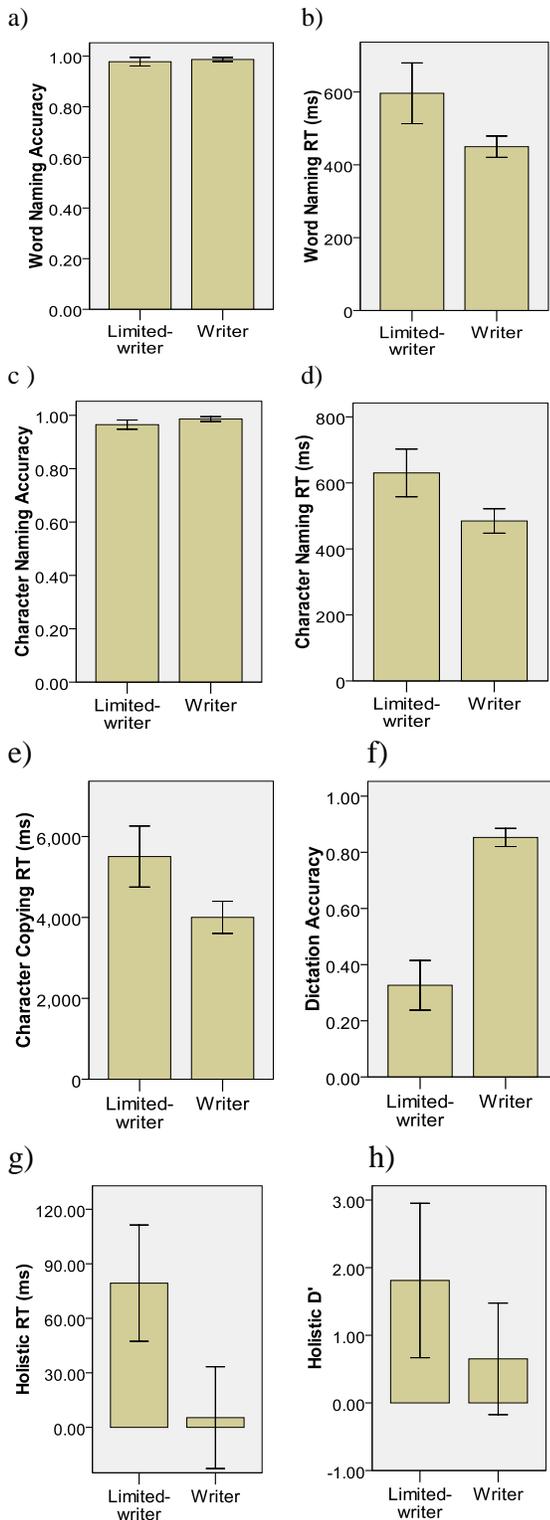
Fig.2. Bar charts showing the word naming accuracy (a) and response time (b); character naming accuracy (c) and response time (d); character copying response time (e); dictation accuracy (f); holistic Response Time (g); and holistic D' (h) in Limited-writers and Writers

effect in holistic D' was also observed [F(1, 32) = 3.044, p < 0.1; Fig. 2(h)].

Analysis of Covariates

To examine whether the difference in holistic processing between Writers and Limited-writers was due to their difference in reading or copying performance rather than writing experience, we analyzed the holistic response time difference between Writers and Limited-writers by putting the variables of reading and writing performances as covariates (ANCOVA). We found that the effect of writing experiences on holistic processing was still significant when either character naming response time [F(1, 32) = 4.759, p < 0.05], character naming accuracy [F(1, 32) = 7.637, p < 0.05], word naming accuracy [F(1, 32) = 12.17, p < 0.01], or character copying response time [F(1, 32) = 5.201, p < 0.05] was put as a covariate, and a marginal effect was found when word-reading response time was put as a covariate [F(1, 32) = 2.953, p < 0.1]. However, when dictation accuracy was used as a covariate, the effect became insignificant [F(1, 32) = .059, n.s.]. These effects suggest that the difference in holistic Response Time between Writers and Limited-writers was due to their writing experiences and performance in the dictation task (i.e. the ability to recall and write down characters), instead of their reading or copying performances.

Copying Task:

To further understand the performance of Writers and Limited-writers in the copying task, we investigated their copying performance for real Chinese characters, pseudo-characters and Korean characters separately. The results showed that Writers copied significantly faster for real characters [$F(1,32) = 15.39$, $p = .003$], Korean characters [$F(1,32) = 10.257$, $p = .003$] and pseudo-characters [F(1,32) = 14.706, $p = .001$] than Limited-writers, as summarized in Fig. 3. These results suggest that writers are able to generalize their Chinese character copying ability to copying novel characters that have similar structures (i.e. Korean characters in this case).

Discussion

In the current study, we tested the reading and writing performance of Writers and Limited-writers and examined which variables uniquely predict holistic processing. We found that Limited-writers processed Chinese characters more holistically than Writers. Further analyses showed that this effect could be accounted for by their performance difference in the dictation task, but could not be accounted for by their differences in any of the reading performance measures, including character and word naming accuracy and response times. This result suggests that the holistic processing effect in Chinese character recognition is dependent on writing experience, or more specifically, the ability to recall and write down Chinese characters rather than reading performance.

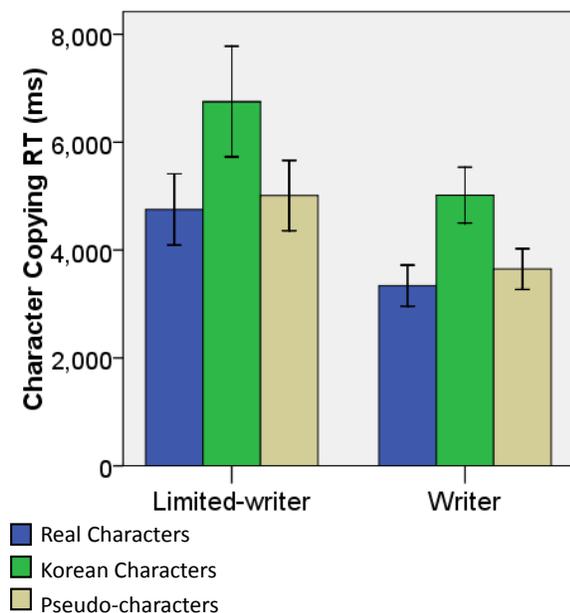Analyzing the constituents and stroke information probably facilitates recalling and writing down Chinese

Fig.3. Bar chart showing the copying response time for real characters, Korean characters and pseudo-characters in Limited-writers and Writers

characters substantially. Such ability can be honed by extensive writing experience. This perhaps explains why the Writers in this study not only outperformed the Limited-Writers in the dictation task, but also in the task involving Korean characters. Note that each Korean (hangul) character typically consists of several phonetic symbols arranged in configurations commonly found in Chinese characters. The Writers' ability to analyze Chinese characters may have generalized to Korean characters, thereby reducing their holistic processing of Korean characters as well.

Reading performance in Chinese has generally been shown to be similar among good and poor readers when copying performance in Chinese was controlled (Tan et. al, 2005; Tse, Kwan, & Ho, 2010). This phenomenon suggests a close relationship between reading and copying performance. Thus, in a separate analysis, we analyzed reading performance difference (response time in character naming) between Writers and Limited-writers with character copying performance (response time) as a covariate. We found that the effect of writing experiences on character naming response time was still significant even when character copying response time was used as a covariate ($p < .05$). Our finding suggests that reading performances may not depend on copying ability. Moreover, both Writers and Limited-writers scored similar accuracy in the word naming task while Limited-writers performed much poorer in the dictation task than Writers, despite the same words were used in the two tasks. This further suggests that word reading accuracy in Chinese is not related to the ability to recall and write down characters (assessed in the dictation task), though

Limited-writers had slower naming time for Chinese words compared to Writers.

Complementing Hsiao and Cottrell (2009)'s study, we found that holistic processing uniquely depended on writing experiences, or more specifically, the ability to recall and write Chinese characters, by focusing on a little noticed population of Chinese readers with limited writing ability. Since orthographic sensitivity and writing/copying performance had been shown to strongly predict reading ability (Tan et al., 2005; Tse, Kwan, & Ho, 2010), our study may implicate a different Chinese character recognizing strategy employed by Chinese readers who have limited writing experience. Further investigation can examine a possible causal relationship between Chinese writing performance and holistic processing preferably with age-matched and reading-level matched participants.

In conclusion, our study is the first to report on the community of Chinese readers with limited writing ability and to suggest a close relationship between writing performance and holistic processing in Chinese character recognition.

Acknowledgments

References

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

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

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

Ho, C. S., Chan, D., Tsang, S. and Lee, S. (2000). *The Hong Kong Test of Specific Learning Difficulties in Reading and Writing*. Hong Kong: Hong Kong Specific Learning Difficulties Research Team.

Ho, C. S., Ng, T., & Ng, W. (2003). A 悲adical?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. W. (2009). Not all visual expertise is holistic, but it may be leftist: The case of

Chinese character recognition. *Psychological Science , 20*, 455-463.

Hsiao, J. H., & Shillcock, 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 sensoritmotor learning in the perception of letter-like forms: Tracking the causes of neural specialization for letters. *Cognitive Neuropsychology, 26*, 91-110.

Kwan, T. W. (2001) Hong Kong, Mainland China & Taiwan: Chinese character frequency-A trans-regional, diachronic survey. *Character Frequency*. Retrieved December 30, 2010 from http://arts.cuhk.edu.hk/Lexis/chifreq/

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.

McCleery, J. P., Zhang, L., Ge, L., Wang, Z., Christiansen, E. M., Lee, K., & Cottrell, G. W. (2008). The roles of visual expertise and visual input in the face inversion effect: Behavioral and neurocomputational evidence. *Vision Research, 48*, 703-715.

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

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.

Taiwan Ministry of Education. (1997). 八十六年常用語詞調查報告書. Retrieved December 30, 2010 from http://www.edu.tw/files/site_content/M0001/86news/ch2.html?open

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.-Y., Kwan, D. P.-L., & Ho, C. S.-H. (2010). *Should dyslexic children stop copying? Exploring the relationship between word reading, copying and dictation*. Poster presented at the 35th Annual International Academy for Research in Learning Disabilities Conference in Taipei, Jan 12-15, 2011.

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

Wong, A. C., Palmeri, T. J., & Gauthier, I. (2009). Conditions for face-like expertise with objects: Becoming a ziggerin expert-but which type? *Psychological Science, 20*, 1108-1117.