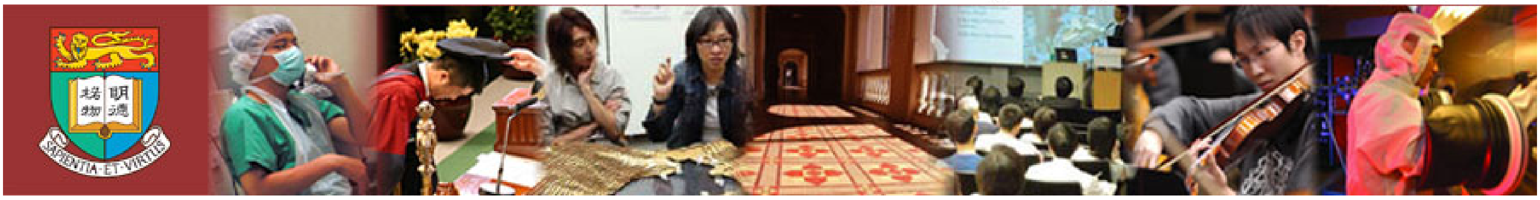

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Citation	
Issued Date	2008
URL	http://hdl.handle.net/10722/173655
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Reading Aloud Real and Pseudo-characters: One System or Two Systems

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A dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2008

Abstract

Using data from two dyslexic participants with contrasting reading abilities and 20 controls, the current study aimed to investigate whether pseudo-character reading is, like alphabetic scripts, mediated by the non-lexical mechanism (Coltheart, Curtis, Atkins & Haller, 1993) or, alternatively, by the lexical mechanism (Ding, Taft & Zhu, 2004), which also mediates real word reading. The results found that real and pseudo-character reading co-varied, thereby supporting the lexical mediation account.

Additionally, the current study also aimed to investigate the representation of freestanding phonetic radicals (i.e. radicals that are themselves characters, e.g., 舌) and non-freestanding phonetic radicals (i.e. non-character radicals, e.g., 敫), which are thought to be represented separately in the Lexical Constituency Model (Perfetti & Tan, 1999) but at the same level in the Interactive Activation Model (IAC) (Ding et al., 2004). The findings from the study replicated those by Law, Weekes and Wong (2006), which favored the IAC model.

Over the decades, cognitive neuropsychological research comparing the performance of different sub-types of acquired dyslexic individuals and normal subjects in the reading of real and orthographically legitimate pseudo-words has resulted in the proposals of various theoretical models of word and character reading. In particular, double dissociation between reading real and pseudo-words, consistent and inconsistent words found in acquired dyslexic patients in alphabetic scripts such as Italian and English has often been cited as evidence to suggest two mechanisms (i.e. the lexical mechanism and the non-lexical mechanism) being responsible for reading aloud in a dual-route model (Coltheart, Curtis, Atkins & Haller, 1993). However, despite the importance of studying pseudo-word reading in the dyslexic population, only a few studies of relevance were undertaken in Chinese.

From what is known in alphabetic scripts according to the dual-route model, the two mechanisms responsible for reading are 1) the lexical mechanism including lexical routes that map whole orthography to whole phonology either via or bypassing the semantic system and 2) the non-lexical mechanism (also called a sub-lexical route) that assembles sub-lexical components in orthography to phonology via the rule-based grapheme-to-phoneme correspondence (GPC) system (e.g., reading words such as ‘chap’ is assembled from /tʃ/ for the digraph ‘ch’, /æ/ for ‘a’ and /p/ for ‘p’) (Coltheart et al., 1993). Given the different characteristics of the lexical and non-lexical mechanisms, they play different roles in reading. That is, the frequency sensitive lexical routes are optimized for high frequency regular real words (e.g., mean) and exceptional real words (e.g., colonel) whereas the non-lexical route is responsible for regular real words and pseudo-words (e.g., kean) (Paap & Noel, 1991).

Although the dual-route model is often used to explain reading in alphabetic scripts, whether the non-lexical route or sub-lexical processing exists as language universal entities is debatable (Luo, Zhao, Wang, Xu & Weng, 2007). One orthographic system that is *prima facie* incompatible with the above model is Chinese. Unlike its alphabetic counterparts, Chinese is a logographic writing system with relatively opaque character-to-sound correspondence (Lee et al., 2005). Specifically, a Chinese character corresponds to a morpheme, and a character's sub-character constituents such as radicals and strokes do not specify the segmental phonology of the character, unlike the case with letters or syllables in alphabetic languages. Therefore, reading real Chinese characters is considered by some to be achieved through holistic and direct mapping of a character from print to phonology (i.e. via the lexical routes) rather than by rule-based sub-lexical decomposition into sub-character constituents (Chen & Yung, 1989). Because of this difference, a sub-lexical GPC is thought to be nonexistent in Chinese, rendering the reading model of Chinese fundamentally different from that of alphabetic languages (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). It also follows that without the involvement of a GPC rule, the reading of pseudo-characters and the reading of real-characters via sub-lexical means in Chinese should be impossible theoretically.

In reality, however, the Chinese script is not totally opaque, therefore implying the possibility of sub-lexical reading (Chen, 1996). Although the subcomponents of a Chinese character such as a stroke do not correspond to the segmental features of the whole character, around 80% of all Chinese characters are phonograms (also called phonetic compounds) with the phonetic radical inside offering probabilistic cues to the characters' pronunciation (e.g., 羅 /lo4/ as in 囉 /lo1/, 攞 /lo2/, 鑼 /lo4/ etc.) (Chen, 1996). According to the reliability of the cues offered by the phonetic radical to the whole-character pronunciation, Fang et al. (1986) categorized Chinese characters into several types. When the cues given by the phonetic radical matches the pronunciation of the whole character regardless of tonal differences, the character is classified as regular (e.g., 羅 /lo4/ as in 囉 /lo1/, 攞 /lo2/, 鑼 /lo4/ etc.). By contrast, when the cues given by the phonetic radical do not parallel the pronunciation of the whole character (e.g., 舌 /sit3/ as in 話 /wa6/), it is classified as irregular. In addition to regularity, an alternative way to classify Chinese characters is by consistency (Lee, Tsai, Chung, Tzeng, & Hung, 2005; Jared, McRae & Seidenberg, 1990). If the summed frequencies of a character's orthographic neighbors sharing the same phonetic radical and the same pronunciation (i.e. friends) are greater than the summed frequencies of orthographic neighbors having the same phonetic radical but dissimilar pronunciations (i.e. enemies), a character is classified as consistent (also called high dominance) and otherwise as inconsistent (also called low dominance). In fact, skilled readers in Chinese can often derive the pronunciations of most phonograms and pseudo-characters correctly from the phonetic radical according to either regularity or consistency (Wu, Zhou & Shu, 1999). Therefore, the internal structure of Chinese real and pseudo characters can be decomposed and read at least in theory via sub-lexical processing of the cues from phonetic radicals.

Indeed, a sizeable body of empirical evidence using different paradigms from normal subjects shows that sub-lexical processing and pseudo-character reading is possible in Chinese. For instance, illusory conjunction of radicals during the reading of Chinese characters was used to support the idea of sub-lexical processing in Chinese (Fang & Wu, 1989). Additionally, using a priming paradigm, Zhou and Marslen-Wilson (1999) showed that the reading of a character automatically activates the phonological and semantic representations of the phonetic radical, thereby further supporting the presence of sub-lexical processing in Chinese. Data from chronometric studies also found that the consistency level of phonetic radicals affected both the naming latencies and accuracy during the reading aloud of real (Lee et al., 2006; Lee, 2000; Wu et al., 1999; Fang et al., 1986) and pseudo compound characters (Lee et al., 2005; Peng, Yang & Chan, 1994; Fang et al., 1986). The consistency effect demonstrated in the studies implied that the phonetic radical, which is a sub-character component, was processed sub-lexically and had an effect on the reading aloud of characters (Lee et al., 2005).

In addition to literature on normal subjects, reports by Butterworth and Yin (1992, 1991) pointed out that surface dyslexic individuals were able to read pseudo-characters in Chinese. A more recent study by Law, Weekes and Wong (2006) even found consistency effect during both real and pseudo-character reading by two participants with mild surface dyslexia, which was consonant with patterns exhibited by normal subjects as reported in Lee (2000).

In sum, the evidence summarized above supports the notion of sub-lexical processing and pseudo-character reading in Chinese. What remains unclear, however, is how sub-lexical processing and pseudo-character reading is mediated in Chinese. Theories abound with regard to this question. Some believe that the writing system of Chinese is, to a certain extent, in accordance with the dual route account mentioned earlier. Supporters for such a claim proposed that a lexical mechanism is responsible for real word reading whereas a *separate* rule-governed non-lexical mechanism, analogous to GPC rules in alphabetic scripts, exclusively enables sub-lexical processing of real words and pseudo-character reading in Chinese (Bi, Han, Weekes & Shu, 2007; Wu et al., 1999). If this dual-route hypothesis holds, one can expect to find evidence of dissociation between the reading of real and pseudo characters where either the lexical mechanism or the non-lexical route is selectively damaged.

In contrast to this dual-route model, there exists a connectionist model called multi-level interactive activation model (IAC) (Taft & Zhu, 1997) whereby the reading of both real and pseudo-characters in Chinese are mediated by a *singular* lexical mechanism without recourse to a non-lexical route (Bi et al., 2007; Lee et al., 2005). In this model, the presentation of both real and pseudo characters activates a number of visually similar real characters (i.e., orthographic neighbors) and their respective pronunciations via the same lexical mechanism. These candidate pronunciations in turn compete against each other with the predominant one winning (i.e., consistency effect) (Jared et al., 1990). Since a unitary lexical mechanism is assumed to mediate both real and pseudo characters, this model should predict association rather than dissociation between real and pseudo character reading when the shared lexical mechanism is damaged.

In addition to the debate on whether pseudo-character reading in Chinese is achieved via a separate non-lexical route or via the same lexical route as real characters, the level of representation of the phonetic radical is also open to question (Perfetti & Tan, 1999; Taft & Zhu, 1997). In Chinese, phonetic radicals can be classified into two types according to their dependency. The first type is called free-standing phonetic radicals (Lee et al., 2005) in that they can exist as legitimate whole-characters in their own rights. For example, the phonetic radical 舌 (/sit3/ tongue) is a legitimate character by itself (i.e. a simple character) and can also be found in phonograms such as 話 (/wa6/ to speak), 活 (/wut6/ to live) and 刮 (/kwat3/ to scratch). On the other hand, non-freestanding radicals (e.g., 敫) can never exist alone and are parasitic upon phonograms (e.g., 激, 徼 and 邀 etc.) (Lee et al., 2005).

Two competing models have been proposed to account for the representation of these two types of phonetic radicals in Chinese. According to Ding, Taft and Zhu (2004), Ding, Peng & Taft (2004) and Taft and Zhu (1997) in their multi-level IAC model, both freestanding and non-freestanding radicals are represented at the same radical level. However, freestanding radicals, in addition to being represented at radical level, also have redundant representation higher in the hierarchy at character level. In contrast, the lexical constituency model (Perfetti & Tan, 1999) proposed that freestanding phonetic radicals are represented in the same location as any real character in a character orthographic subsystem whereas non-freestanding radicals are represented separately in a non-character orthographic sub-system. Unlike the interactive activation model, no hierarchical relationship exists between the representations in the lexical constituency model.

Therefore, using data from dyslexic individuals, the current study aimed to shed light on the Chinese reading model with special reference to the ongoing debate on the mediation of pseudo-character reading and the level of representation of phonetic radicals in Chinese. Additionally, the current research also aimed to address the limitations in the previous studies of relevance. For instance, although Butterworth and Yin (1991) compared the performance on pseudo-character reading and real character reading of surface and deep dyslexic subjects in Chinese, the stimuli presented were small in quantity and were not manipulated on variables such as consistency and radical dependency (i.e. freestanding radical and non-freestanding radical). Law et al. (2006), by contrast, manipulated the consistency value of the stimuli and compared the performance between the naming of characters with freestanding and non-freestanding radicals presented alone and presented in compound pseudo-characters. However, a limitation of the research was that its participants were homogenous. In particular, the two brain-injured subjects in the study had similar reading performance such that the performance of dyslexic individuals with poorer reading ability was still unknown. With such a homogenous pool of participants, no double dissociation could be found. In addition, how different the dyslexic participants performed from normal participants was not known because the study did not include normal controls for comparison.

Given the shortcomings of the previous research, the present study extended the work of Law et al., (2006) and recruited two brain-injured subjects with contrasting reading and naming performance to investigate if the two subjects would perform differently or similarly in the reading of real and pseudo-characters. Also, normal participants matched in age and education with the dyslexic counterparts were included as controls. For the stimuli, the dominance ratios of the characters were manipulated to examine the presence of a consistency effect. Additionally, radical dependency (i.e. free/non-freestanding) and presentation (i.e. presented alone or in pseudo-compounds) were also manipulated to examine their effects on reading.

Several hypotheses on the reading performance could be made based on different theoretical reading models. If both real and pseudo characters were mediated by a unitary lexical mechanism as proposed by Ding, Taft and Zhu (2004), association would occur between the reading of these two types of characters. Specifically, one would predict that the participant with superior reading and naming ability would read both real and pseudo characters as well as the normal controls. On the other hand, the participant with a more severe form of dyslexia would have poorer performance in both real and pseudo-character naming and a diminished consistency effect commensurate with his deficits (Jefferies, Ralph, Jones, Roy, Bateman & Patterson, 2004). However, if pseudo and real characters were mediated by two separate mechanisms as put forward by the dual-route model (Bi et al, 2007; Coltheart et al., 1993), dissociation between real and pseudo-character reading would be found within a participant in case of selective damage to one of the mechanisms.

Similarly, dissociation or association is predicted to also exist in the reading of freestanding radicals and non-freestanding radicals based on different reading models. In the lexical constituency model (Perfetti & Tan, 1999), because freestanding radicals (e.g., 舌) are represented separately from non-freestanding radicals (e.g., 敫), dissociation might be found between the reading of these two kinds of radicals. In contrast, because the IAC model (Ding et al., 2004; Taft, Liu & Zhu, 1999; Taft, Zhu & Peng, 1999; Taft & Zhu, 1997) proposed that freestanding phonetic radicals and non-freestanding radicals are represented at the same radical level, the reading performance between them should be comparable.

Moreover, consistency effect is predicted in the response distribution of pseudo-character reading (Lee et al., 2005; Jared et al., 1990). In particular, in reading high dominance freestanding and non-freestanding stimuli where the summed frequencies of friends exceed those of the enemies, the response is predicted to bias towards the pronunciation of the friends (i.e. dominant pronunciation). In contrast, a bias towards the pronunciation of the enemies (i.e. alternative pronunciation) is predicted in reading low dominance non-freestanding stimuli where the summed frequencies of enemies exceed those of the friends.

Finally, the interactive activation model (Ding, Peng & Taft, 2004; Taft, Zhu & Peng, 1999; Taft & Zhu, 1997) predicted a bias towards the pronunciation of the phonetic radical (e.g., 舌 /sit3/) rather than the dominant pronunciation (e.g., 話 /wa6/) during the reading of a low dominance pseudo-compound (e.g., ) with a freestanding radical. The reason for the prediction is that freestanding radicals are represented twice (i.e. one at radical level and another redundantly at character level). In the face of strong mutual inhibition among the multiple activated candidate pronunciations at character level (e.g. 話 /wa6/, 活 /wut6/, 恬 /tim3/ etc.) (Law et al., 2006; Ding et al., 2004), the pronunciation at the lower radical level is favored.

Method

Participants

A total of 22 participants took part in the study. They included two brain-injured participants with contrasting reading abilities and 20 normal controls with no prior history of brain injury.

The two Cantonese speaking brain-injured participants, FSY and LSK, were right-handed and were at least 1 year post-onset during the study. A battery of initial language and cognitive assessments by Law et al., (2006) was administered prior to the study as the inclusion criteria. The assessment results showed that FSY, a 57-year-old female with 2 years of secondary education, presented with mild anomia, mild dyslexia and relatively preserved reading; LSK, a 34-year-old male with 6 years of secondary education, suffered from severe anomia and severe dyslexia. Since both dyslexic participants, especially LSK, showed difficulties in oral naming but relatively intact semantic access, the underlying deficits are suspected to be in the semantic lexical route between the phonological output lexicon and the semantic system. The results of their initial assessments are presented in Appendices A and B.

To compare the performance of the dyslexic participants with their normal counterparts, 10 normal participants matched in age and education level were recruited as controls for *each* dyslexic participant. For FSY, her controls included 7 females and 3 males with a mean age of 53.3 (*SD* = 2.54) and a mean of 2.7 years of secondary education (*SD* = 0.67). For LSK, his controls included 9 females and 1 male with a mean age of 36.1 (*SD* = 2.23) and a mean of 4.7 years of secondary education (*SD* = 0.48).

Materials

A total of 336 stimuli used in Law et al. (2006) were included in the present study, which consisted of three experiments.

Experiment 1 included 198 real compound characters (i.e., constructed with a semantic and a phonetic radical) and real simple characters (i.e., constructed with a phonetic radical) adapted from Lee et al. (2005). The list of stimuli used in Experiment 1 is summarized in Appendix C.

Experiment 2 included 76 freestanding phonetic radicals as stimuli. They were divided into two subsets: 1) 38 freestanding radicals presented alone (i.e. real simple characters) and 2) the same set of 38 freestanding phonetic radicals presented in legally constructed pseudo-compounds.

Experiment 3 included 62 non-freestanding phonetic radicals as stimuli. They were also divided into two subsets, which consisted of 1) 31 non-freestanding pseudo characters presented alone and 2) the same 31 non-freestanding phonetic radicals presented in legally constructed pseudo-compounds. The list of stimuli used in all Experiments 2 and 3 is summarized in Appendix D.

The purpose of including real characters in Experiments 1 and 2 was to compare the differential reading abilities of the participants. Freestanding and non-freestanding pseudo-characters were featured in Experiments 2 and 3 respectively to investigate the effect of radical dependency on reading performance and to contrast the participants' abilities in pseudo-character reading.

To investigate the effect of dominance rating (i.e., consistency) on character reading, each subset of stimuli in Experiment 2 and 3 was further split into halves into high and low dominance according to the consistency value calculated by Law et al. (2006). This consistency value was obtained by measuring the ratio of friends (i.e. the summed token frequencies of homophonic characters in an orthographic neighborhood regardless of tone) to enemies (i.e. the summed token frequencies of heterophonic characters within a neighborhood regardless of tone). Specifically, characters that have a high dominance rating have a high friends-to-enemies ratio and vice versa. For pseudo-characters (e.g., ), their dominance ratings were derived from the consistency value of the real characters in the orthographic neighborhood (e.g., 話). Illustrative examples of how the consistency value was computed are presented in Table 1.

Table 1

Illustrative examples showing the computation of the consistency value

	Phonetic radical	**Neighborhood of the phonetic compounds**									
		Dominant pronunciation (i.e. friends)	**Alternative pronunciations (i.e. enemies)**								
Orthographic neighbor	舌	話	活	聒	括	颳	刮	舔	恬	甜
Character-based token frequency	20	681	630	1	224	7	48	2	4	59
Pronunciation	sit	wa	wut	kwut		gwat		tim		
Pronunciation-based token frequency	20	681	630	225		55		65		
Consistency value	= Summed frequencies of friends / Summed frequencies of enemies									

Procedures

The three experiments were conducted in a quiet room in each participant's home. Each stimulus had a size of 3.5 cm x 3.5 cm and was presented individually in black on a piece of A4 paper.

Each participant was required to read aloud the stimuli in the three experiments, which were carried out sequentially in four blocks. These four blocks were sequenced in such a way that pseudo-characters were always presented before the real counterparts. The purpose of this sequence was to prevent the participants from predicting the pronunciations of pseudo-characters by using clues from prior exposure to real-character reading. Block 1 included the pseudo-compound characters in Experiments 2 and 3. The second block featured the non-free-standing phonetic radicals presented alone as pseudo-characters in Experiments 3. The third block consisted of the freestanding radicals presented alone as real characters in Experiment 2 while the fourth block included the 198 real characters in Experiment 1. The stimuli within each block were randomized.

In each trial, the response of the participant was transcribed online into Jyutping (LSHK, 1993). Each response was audio-recorded on a Macintosh laptop for offline re-transcription and response analysis.

Results

Results are presented first for real-character reading in Experiments 1 and 2, then for pseudo-character reading in Experiments 2 and 3, followed by the response distribution in pseudo-character reading, and finally for the reliability measurement.

Real-character reading

To reflect the participants' differential reading abilities, the participants' percentage accuracies in real-character reading in Experiments 1 and 2 were computed by dividing the number of accurate responses by the number of stimuli in the respective experiment. The performance on real character reading in Experments 1 and 2 is summarized in Figure 1.

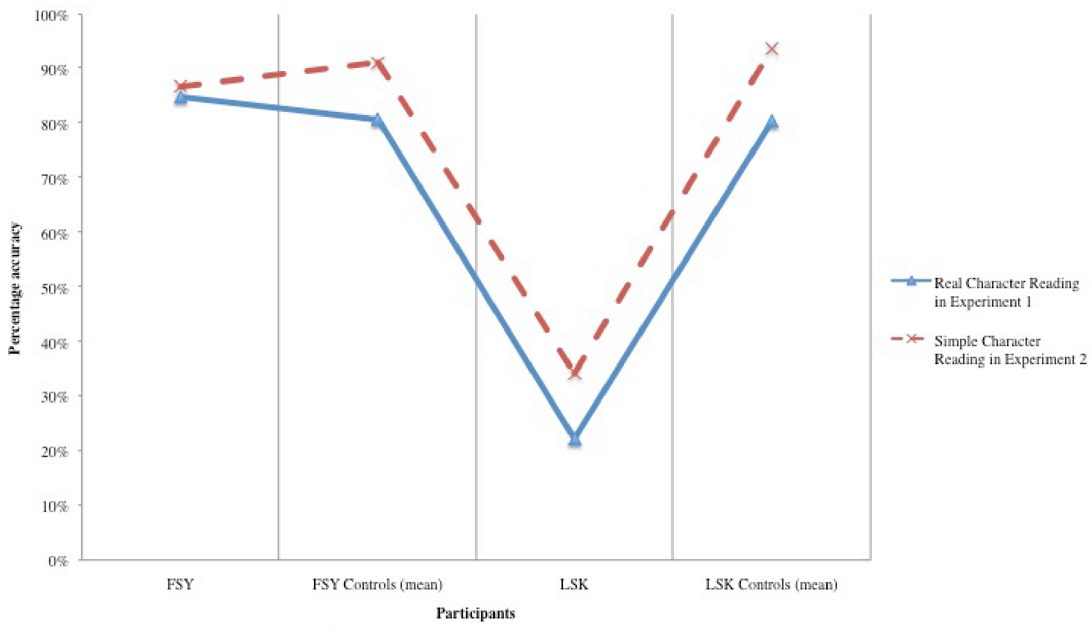


***Figure 1*. Performance on real-character reading in Experiments 1 and 2**

From the figure, it can be seen that FSY's real word reading ability as reflected by both experiments was near normal resembling her own controls. On the other hand, LSK's performance was markedly inferior when compared to his controls.

Pseudo-character reading

In addition to the abilities in real-character reading, the performance of the participants on pseudo-character reading was also compared to examine whether association or dissociation exists between the readings of real and pseudo characters. The method of comparison was by calculating the proportion of legitimate responses to illegitimate responses. The criteria for response categorization, which was adapted from Fan (2007) and Law et al. (2006), are presented in Table 2. Figure 2 below summarizes the percentage of legitimate responses during the reading of different types of pseudo-characters in Experiments 2 and 3.

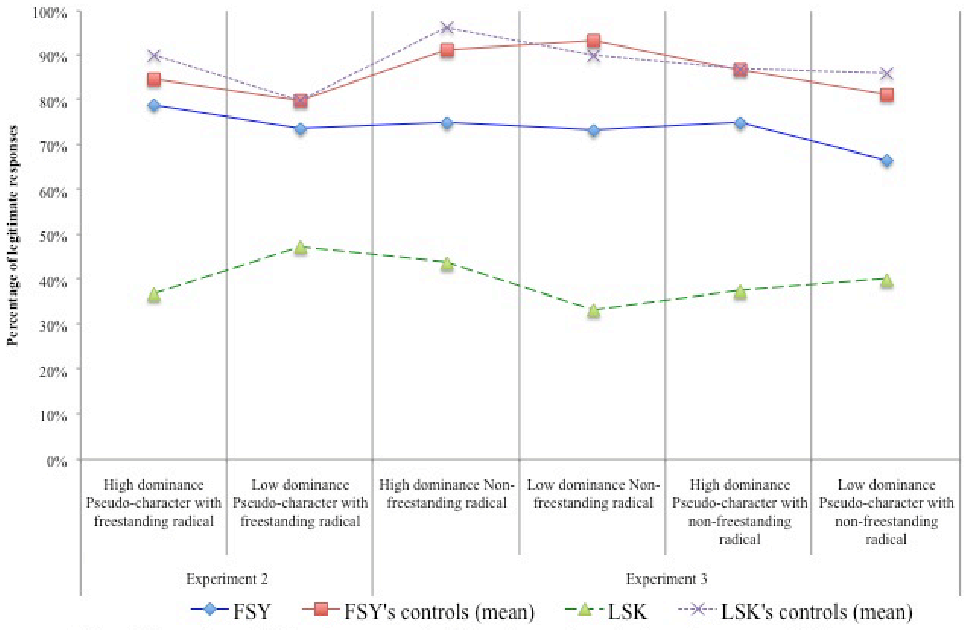


Figure 2. **Percentage of legitimate responses in different types of pseudo-characters across subjects**

Figure 2 showed that FSY's pseudo-character reading was similar to her normal controls. Her near-normal performance on pseudo-character reading correlated with her preserved abilities in real-character reading. LSK's performance on pseudo-character reading was inferior, which correlated with his own poor performance on real-character reading.

A one-tailed chi-square test with Yate's correction (see Table 3) was performed to examine whether the difference between the number of legitimate responses in dyslexic and the normal participants was significant. The results showed that LSK's indeed performed significantly more poorly than his controls in pseudo-character reading. On the other hand, no significant difference was found between FSY's and the controls' pseudo-character reading performance.

Table 2

Criteria for Response Categorization in Pseudo-character Reading

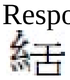
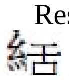
Response types	Definitions	Examples
Legitimate response		
Dominant	Reading aloud according to the dominant pronunciation in the family, which has the highest pronunciation-based token frequency	Response:  / gaam2/ from Dominant pronunciation: 減 /gaam2/
Alternative and phonetic radical based (PR-based)	Reading aloud according to the non-dominant pronunciation in the family, which is also the same as the pronunciation of the phonetic radical (applicable only to the reading of low dominance freestanding radicals presented alone or presented in pseudo-compounds)	Response:  /haam/ from Radical & non-dominant pronunciation: 咸 /haam4/
Alternative but non-phonetic radical (non-PR) based	Reading aloud according to the any non-dominant pronunciation in the family, which is different from the pronunciation of the phonetic radical	Response:  /zaam1/ from Non-dominant & non-radical pronunciation: 箴 /zaam1/
Illegitimate responses		
Phonetic radical based (PR-based)	Reading aloud according to the phonetic radical, whose pronunciation which is not present in the family (applicable only to the reading of low dominance freestanding radicals presented alone or presented in pseudo-compounds)	Response:  /sit/ from Phonetic radical pronunciation: 舌 /sit3/
Circumlocution	Reading aloud by giving semantically relevant definitions	Response:  /jung6 lai4 sik6 je3/, literally, 'for eating'
Semantic	Reading aloud by pronouncing a semantically related word	Response:  /ga1/ based on 減 /gaam2/, meaning 'minus' from semantically related 加 /ga1/, meaning 'plus'
Orthographically similar	Reading aloud by pronouncing another character which is not present in the family but is visually similar to the pseudo-character	Response:  /git/ Orthographically similar: 結 /git3/
Unrelated	Reading aloud a pseudo-character with a pronunciation which is orthographically, semantically and phonologically unrelated to any characters in the family	Response:  /jan/ from Unrelated pronunciation: 人 /jan4/, meaning person
No response	No pronunciation was given	-

Table 3

Results of the One-tailed Chi-square Test Comparing the Numbers of Legitimate Responses in Different Pseudo-character Reading Tasks

	FSY vs. controls		LSK vs. controls	
	Yate's chi-square (*df* = 1)	Yate's *p*-value (one-tailed)	Yate's chi-square (*df* = 1)	Yate's *p*-value (one-tailed)
Experiment 2				
Pseudo-characters with freestanding radicals (High)	< 0.00	NS	11.57	***
Pseudo-characters with freestanding radicals (Low)	< 0.00	NS	4.37	*
Experiment 3				
Non-freestanding radicals (High)	0.57	NS	10.50	***
Non-freestanding radicals (Low)	0.96	NS	10.19	***
Pseudo-characters with non-freestanding radicals (High)	0.16	NS	8.29	**
Pseudo-characters with non-freestanding radicals (Low)	0.24	NS	6.81	**

Note. (High) = High dominance; (Low) = Low dominance; * = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$; NS = Not significant ($p \geq 0.05$)

Response distribution for Experiments 2 and 3

The response distribution for Experiments 2 and 3 was analyzed to investigate whether it varied as a function of the independent variables (i.e., dominance ratio of characters, types of participants, dependency of radicals). The overall response distribution of pseudo-character reading across the participants is summarized in Figure 3.

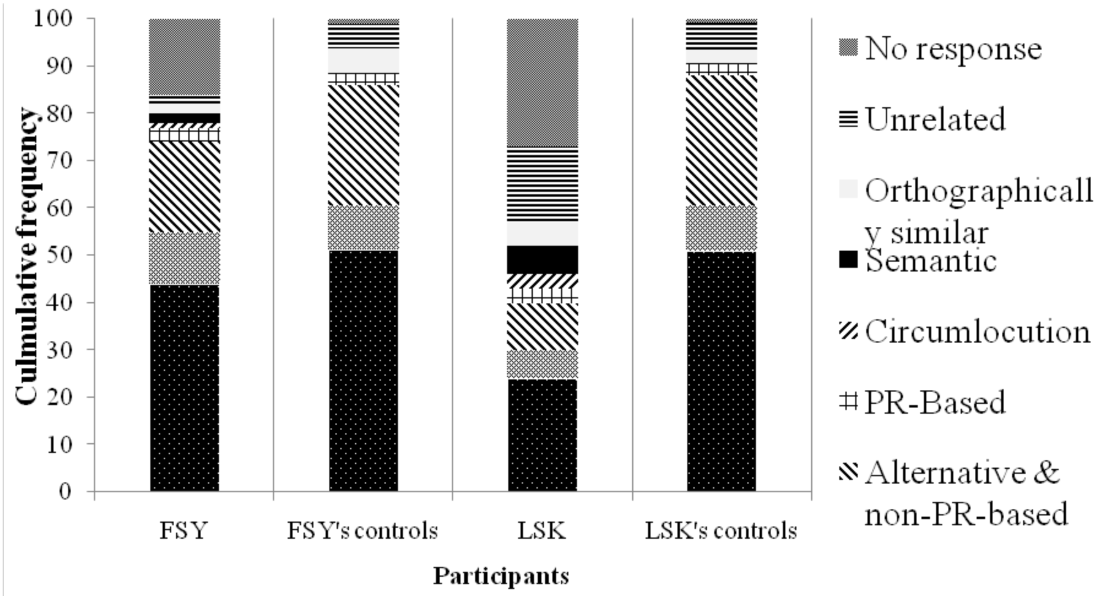


***Figure 3*. Stacked column chart showing overall composition of response types in pseudo-character reading**

The summary in Figure 3 showed that the composition of legitimate responses did not vary as a function of the participants. That is, both dyslexic and normal participants had dominant pronunciation as the prevalent response type within legitimate responses followed by non-phonetic radical based alternative pronunciations and finally by phonetic-radical based alternative pronunciations.

However, Figure 3 also showed that unlike the case of legitimate responses, the overall distribution for illegitimate responses varied as a function of the types of participants. For the two groups of control participants, their patterns of response were generally comparable with unrelated or orthographically similar responses constituting the highest proportion of illegitimate responses. However, for both LSK and FSY, ‘no response’ was the predominant illegitimate response type. They also made considerably more semantic errors than both control groups. Furthermore, the dyslexic participants also made circumlocutory responses, which were non-existent in both control groups. In fact, more of these semantically based illegitimate responses were found in LSK than in FSY. This also correlated with their differential reading abilities.

In addition to the overall response distribution presented in Figure 3, the response distributions for each sub-type of pseudo-characters are summarized in Tables 4 and 5 to examine if the distributions varied as a function of the dominance ratings of the stimuli. As predicted, the dominance ratings did have an effect on the composition of the legitimate responses in FSY and the controls. That is, in reading high dominance freestanding and non-freestanding pseudo-characters, the responses of all the participants biased towards the dominant pronunciation in preference to the alternative pronunciations. However, the reverse pattern was noted for reading low dominance non-freestanding pseudo-characters. As for reading low dominance freestanding pseudo-characters, the participants especially favored PR-based pronunciations rather than the alternative or dominant pronunciations. Nevertheless, this oscillating pattern of response bias for freestanding stimuli was less prominent for LSK. In fact, for non-freestanding stimuli, LSK did not show a response bias according to the dominance rating. In particular, the dominant pronunciation prevailed in both high and low dominance conditions under legitimate responses.

Table 4

Distribution of Responses in Reading Pseudo-characters in Experiment 2

Freestanding radicals presented in pseudo-compounds							
Participants (Dominance rating)		FSY (High)	FSY (Low)	LSK (High)	LSK (Low)	Controls (High)	Controls (Low)
Response type		Frequency (Percentage)					
Legitimate responses	Dominant	15 (79%)	2 (11%)	7 (37%)	3 (16%)	16.6 (87%)	2.3 (12%)
	Alternative & non-PR-based	0 (0%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)	3.4 (18%)
	Alternative & PR-based	N/A	11 (58%)	N/A	6 (32%)	N/A	9.5 (50%)
Illegitimate responses	PR-Based	N/A	3 (16%)	N/A	3 (16%)	N/A	2.4 (13%)
	Circumlocution	0 (0%)	0 (0%)	2 (11%)	0 (0%)	0 (0%)	0 (0%)
	Semantic	0 (0%)	0 (0%)	3 (16%)	1 (5%)	0 (0%)	0.1 (1%)
	Orthographically similar	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0.95 (5%)	0.55 (3%)
	Unrelated	0 (0%)	0 (0%)	5 (26%)	1 (5%)	1.05 (6%)	0.7 (4%)
	No response	4 (21%)	2 (11%)	2 (11%)	5 (26%)	0.4 (2%)	0.05 (0%)
Total number of stimuli		19	19	19	19	19	19

Note. Because of the similarity exhibited by the two control groups, data on their performance were collapsed for simplicity.

Table 5

Distribution of responses in reading pseudo-characters in Experiment 3

		Non-freestanding radicals presented alone						Non-freestanding radicals presented in pseudo-compounds					
Participants (Dominance rating)		FSY (High)	FSY (Low)	LSK (High)	LSK (Low)	Controls (High)	Controls (Low)	FSY (High)	FSY (Low)	LSK (High)	LSK (Low)	Controls (High)	Controls (Low)
Response type		Frequency (Percentage)											
Legitimate responses	Dominant	9 (56%)	5 (33%)	4 (25%)	3 (20%)	11.25 (70%)	5.1 (34%)	10 (63%)	3 (20%)	3 (19%)	4 (27%)	10.95 (68%)	4.95 (33%)
	Alternative & non-PR-based	3 (19%)	6 (40%)	3 (19%)	2 (13%)	3.75 (23%)	8.65 (58%)	2 (13%)	7 (47%)	3 (19%)	2 (13%)	2.95 (18%)	7.6 (51%)
Illegitimate responses	Circumlocution	1 (6%)	0 (0%)	0 (0%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Semantic	1 (6%)	0 (0%)	1 (6%)	1 (7%)	0 (0%)	0.05 (0%)	1 (6%)	0 (0%)	0 (0%)	0 (0%)	0.05 (0%)	0 (0%)
	Orthographically similar	0 (0%)	2 (13%)	1 (6%)	2 (13%)	0.3 (2%)	0.45 (3%)	0 (0%)	0 (0%)	2 (13%)	0 (0%)	0.85 (5%)	0.95 (6%)
	Unrelated	0 (0%)	0 (0%)	3 (19%)	0 (0%)	0.65 (4%)	0.75 (5%)	1 (6%)	1 (7%)	3 (19%)	4 (27%)	1.05 (7%)	1.3 (9%)
	No response	2 (13%)	2 (13%)	4 (25%)	6 (40%)	0.05 (0%)	0 (0%)	2 (13%)	4 (27%)	5 (31%)	5 (33%)	0.15 (1%)	0.2 (1%)
Total number of stimuli		16	15	16	15	16	15	16	15	16	15	16	15

Note. Because of the similarity exhibited by the two control groups, data on their performance were collapsed for simplicity

Finally, to examine whether association or dissociation existed in reading freestanding and non-freestanding pseudo-characters (see Figure 2), a chi-square test was performed to compare the number of legitimate responses of all the participants when reading stimuli with these two types of radicals. The results from the chi-square test revealed no significant difference in the number of legitimate responses during freestanding and non-freestanding character reading in FSY, $\chi^2(1) = 0.046$, $p = .828$, FSY's controls, $\chi^2(1) = 0.789$, $p = .374$, LSK, $\chi^2(1) = 0.141$, $p = .707$ and LSK's controls, $\chi^2(1) = 0.035$, $p = .851$. In other words, association was noted between freestanding and non-freestanding character reading.

Reliability measurement

Inter-rater reliability measurement was performed by another trained-rater on 10% of the data from each participant to ensure that the scoring procedures and response categorizations were reliable. The results showed that the inter-rater reliability was 97.6% for transcription and 96.7% for response categorization.

Summary of findings

In all four groups of participants, the performance on real character reading co-varied with the performance on pseudo-character reading.

The type of participants had an effect on the composition of illegitimate responses in pseudo-character reading in that LSK and FSY's distributions of illegitimate responses were different from the controls. Also, semantically related and circumlocutory illegitimate responses were found exclusively in LSK and FSY.

The type of participants had no significant effect on the composition of legitimate responses in pseudo-character reading. However, the dominance ratio of the stimuli had an effect on the composition of legitimate responses with a bias towards the dominant pronunciation in both freestanding and non-freestanding high dominance characters, a bias towards the alternative pronunciations in non-freestanding low dominance characters and a bias towards the PR-based pronunciation in freestanding low dominance character. Nevertheless, for LSK, the bias was shown in low dominance freestanding pseudo-characters only.

Finally, the dependency of the radicals (i.e. being freestanding versus non-freestanding) did not have an effect on the performance on pseudo-character reading.

Discussion

Several important implications were derived from the present study. First, the study found, for the first time, association between the performance on real and pseudo-character reading in Chinese dyslexic participants. This finding serves as converging evidence to suggest that pseudo-characters, like real characters, are mediated by a shared lexical mechanism. In other words, damage to this singular lexical mechanism would result in comparable deficits in both real and pseudo-character reading, which was indeed demonstrated in the case of FSY and LSK. Specifically, since the lexical mechanism of FSY was only mildly damaged, her performance on both real and pseudo character reading were also, to a similar degree, mildly affected. On the other hand, the more severe damage to the lexical mechanism of LSK led to more severe deficits of a similar scale in both pseudo and real character readings. To summarize, the view of a singular lexical mechanism underpinning character reading can explain the association between real and pseudo-character reading abilities without recourse to hypothesizing extra damage to a separate GPC correspondence as proposed by the dual-route model.

The study also presented another piece of evidence suggesting that pseudo-character reading is mediated by the lexical mechanism rather than by a separate GPC rule. During pseudo-character reading, the dyslexic participants, FSY and especially

LSK, gave semantically related and circumlocutory responses. These semantically-based illegitimate responses in pseudo-character reading could not have resulted from reading via the GPC mechanism because it simply maps orthography to phonology without processing the character’s semantic features (Coltheart et al., 1993). Therefore, to account for these semantically-based illegitimate responses, the dyslexic participants in the study must have utilized an impaired semantic lexical route, which is a lexical mechanism that processes semantic features, during pseudo-character reading. The fact that LSK made even more semantically-based illegitimate responses than FSY further corroborates the involvement of their differentially impaired lexical mechanisms in pseudo-character reading.

In sum, the findings of association between real and pseudo-character reading and the presence of semantic-related responses in the dyslexic participants are in favor of the lexical mediation account for pseudo-character reading. The adoption of this lexical account has significant implications for Chinese reading models. One implication is that the dual-route model (Coltheart et al., 1993), which puts forward two separate routes for real and pseudo-word reading in alphabetic scripts, is therefore not applicable to the case of Chinese. In contrast to the dual-route model, however, the interactive activation competition model (IAC) (McClelland & Rumelhart, 1981) adapted by Taft and Zhu (1999) can sufficiently explain the association between real and pseudo character reading found in this study because this model had provisions for a shared lexical mediation for both real and pseudo characters. In addition, the IAC model also allows the activation of semantic representations during pseudo-character reading (Coltheart et al., 2001). This property of IAC can account for the semantically-based illegitimate responses made by FSY and LSK when their impaired semantic representations were unduly activated in pseudo-character reading.

Another notable finding in the current study was that consistency, which was manipulated by the dominance rating in the study, played a role in pseudo-character reading. This finding was in accord with the conclusion from previous studies (Lee et al., 2005; Jared et al., 1990). In fact, the effect of dominance rating on response bias in FSY and the controls replicated the findings by Law et al. (2006).

Among the Chinese reading models, the IAC model adapted by Taft and Zhu (1999) and consistency effect (Lee et al., 2005; Jared et al., 1990) can best account for the relationship between dominance rating and response bias. In this model, after the pseudo-character is presented (e.g., 絬), the features from the lowest stroke level converge (e.g., ㇀, ㇖ and ㇑ etc.) and activate the radical (e.g. 舌) at the intermediate level of the orthographic lexicon. From the radical level, the activation is sent upward to multiple competing characters in the orthographic neighborhood (e.g., 舌 /sit3/, 話 /wa6/, 活 /wut6/, 恬 /tim3/ etc.). All of these candidates at character level will subsequently activate their corresponding phonological representations (i.e. dominant pronunciation /wa6/ or alternative pronunciations /wut6/, /tim3/ etc.) in the phonological output lexicon. Whether the dominant pronunciation or one of the alternative pronunciations is selected depends on the relative strength of the activation they receive from their candidates at character level. In the case of high dominance stimuli where the strength of friends (i.e. dominant pronunciation) exceeds that of the enemies (i.e. alternative pronunciation), a bias towards the dominant pronunciation occurs. For non-freestanding low dominance stimuli, however, because there are more enemies activating the alternative pronunciations than there are friends activating the dominant pronunciation, the alternative pronunciation prevails. Finally, for low dominance freestanding stimuli, there is great competition among the candidates at character level and they inhibit each other (Law et al., 2006; Ding et al., 2004). As a result of the mutual inhibition among these candidate characters, the freestanding phonetic radical, which has redundant representations at both the character and the radical level, is favored (Law et al., 2006). The radical then connects to its phonological representation directly, thereby resulting in a bias towards the phonetic radical based pronunciation. In short, the IAC model and consistency effect can explain the effect of dominance rating on response bias during the reading of different pseudo-characters.

However, the response bias according to dominance rating in non-freestanding stimuli was non-existent in LSK. That is, the dominant pronunciation was favored both in high and low dominance conditions for LSK. The reason could be that dominant pronunciations are more resistant than alternative pronunciations to damage. The resilience of the dominant pronunciation can be attributed to frequency effect, which predicts the preservation of high frequency characters or pronunciations in a lexicon (Hillis, 2001). Since a dominant pronunciation has, by definition, a higher summed frequency than an alternative pronunciation, it is less susceptible to degradation and therefore prevailed in both high and low dominance ratings in LSK.

Finally, the current study also yielded insight into the representation of radicals in Chinese. The finding that the dependency of the radical (i.e. being freestanding or non-freestanding) does not affect the pseudo-character reading performance implies that both freestanding and non-freestanding radicals are represented at the same level, which is in line with the IAC (Taft & Zhu, 1999). In other words, the alternative Lexical constituency model (Perfetti & Tan, 1999), which proposes separate representations of freestanding and non-freestanding radicals, falls short of explaining the association between the readings of these two types of radicals.

Moreover, the fact that all participants could give legitimate responses to non-freestanding radicals presented alone is also incompatible with the Lexical constituency model, which specifies that non-character units (i.e. non-freestanding radicals) have no connection with the phonological lexicon (Perfetti & Tan, 1999).

In conclusion, the study showed a correlation between abilities of real and pseudo-character reading in dyslexic participants with contrasting reading abilities, suggesting that a single lexical mechanism mediates both types of characters. Accordingly, the applicability of the traditional dual-route model to Chinese is called into question. Secondly, the effect of dominance rating on response bias during pseudo-character reading lent support to the IAC model. Thirdly, the fact that no dissociation was observed between the reading of freestanding and non-freestanding radicals suggested that these two types of radicals were represented at the same level. Additionally, non-freestanding radicals were also pronounceable, implying their connection to the phonological representations via character units. In these regards, the IAC model is more tenable than the lexical constituency model.

Finally, although association was observed in real and pseudo character reading and in freestanding and non-freestanding radical reading, we note that our evidence can be seriously challenged by future observation of dissociation which is more compelling in addressing issues about functional independence of reading mechanisms (Shallice, 1988).

Acknowledgements

The author would like to express gratitude to Dr. Sam Po Law and the participants in this study. Sincere thanks are extended to his family and friends who helped with subject recruitment and inter-rater reliability measurements.

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Appendices

Appendix A showing the initial assessment results of FSY

Assessment	Subscale	Score	Total Score	% Accuracy
	Initial Assessment			
Cantonese Aphasic Battery (CAB)	Spontaneous speech	8	10	80.0
	Fluency	10	10	100.0
	Auditory verbal	60	60	100.0
	Auditory word recognition	58	60	96.7
	Sequential commands	80	80	100.0
	Repetition (syllable)	100	100	100.0
	Object naming	55	60	91.7
	Word fluency	10	20	50.0
	Sentence completion	10	10	100.0
	Responsive Speech	10	10	100.0
	AQ (syndrome)	92.8	Anomic	
Screener 1-4	Repetition	30	30	100.0
	Oral Naming Nouns	29	30	96.7
	Oral Naming Verbs	10	10	100.0
	Written Naming Nouns	15	30	50.0
	Written Naming Verbs	3	10	30.0
	Reading Aloud Nouns	29	30	96.7
	Reading Aloud Verbs	N/A	10	N/A
	Writing to Dictation Nouns	16	30	53.3
	Writing to Dictation Verbs	0	10	0.0
	Auditory Comprehension	20	20	100.0
	Reading Comprehension	19	20	95.0
	Direct Copying	15	15	100.0
	Delayed Copying	13	15	86.7
Verbal Memory	CALVT – Immediate Recall	19	75	25.3
	CALVT – Delayed Recall	5	15	33.3
	CALVT – Delayed Recognition	15	15	100.0
Working Memory	Digit Span Forward (seq.)	6	16	37.5
	Digit Span Forward (span)	7	16	43.8
	Digit Span Backward (seq.)	2	16	12.5
	Digit Span Backward (span)	3	16	18.8
Semantic Access	Birmingham Object Recognition Battery (BORB)	22	23	95.7
	Pyramid and Palm Tree Test (PPTT)	25	37	94.6
Attention	Balloon Test A (time)	60s		
	Balloon Test B (time)	153s		
	Balloon Test A (correct)	20	20	100.0
	Balloon Test B (correct)	20	20	100.0
Visuospatial Function	Minimal Feature View	23	25	92.0
	Foreshortened View	22	25	88.0
	Item Match	31	32	96.9
	Extended Assessment			
Snodgrass	Snodgrass Oral Naming	172	217	79.3
	Snodgrass Reading Aloud	215	217	99.1
Word-Picture Matching	Written Word Picture Matching	121	126	96.0
	Spoken Word Picture Matching	125	126	99.2
Immediate Auditory Discrimination		38	40	95.0
Synonym Judgment (Auditory)		47	60	
Nonverbal Intelligence	**TONI-3 Form A**	**Raw**	**Quotient**	**Percentile**
		10	72	3.0
Executive Function	**Behavioral assessment of dysexecutive functions (BADS)**	Total Profile	Standardized	Age-corrected
		9	56	53 (Impaired)

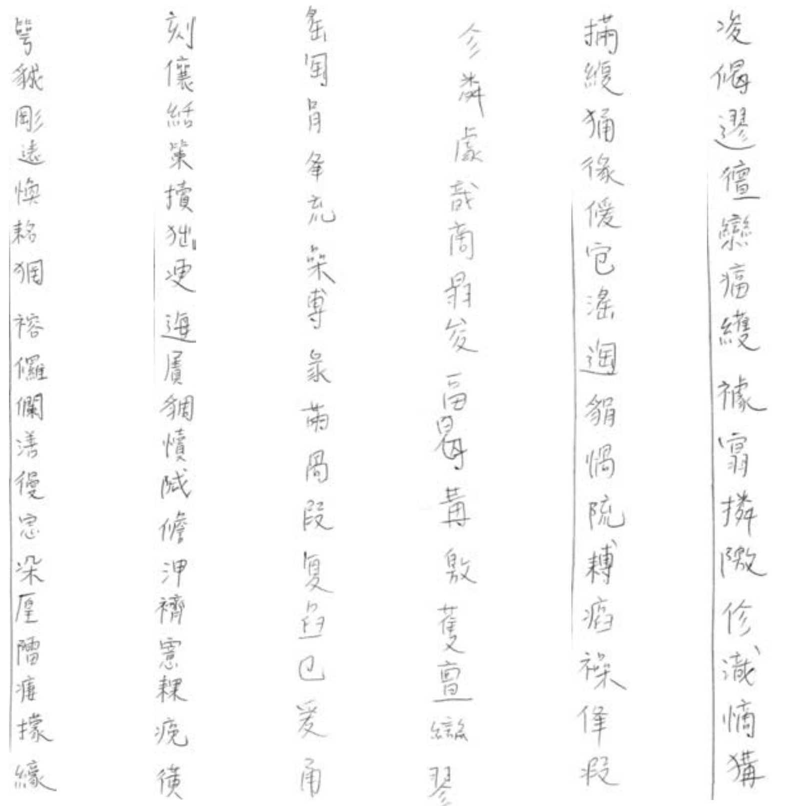
Appendix B showing the initial assessment results of LSK

Assessment	Subscale	Score	Total Score	% Accuracy
	Initial Assessment			
Cantonese Aphasic Battery (CAB)	Spontaneous speech	8	10	80.0
	Fluency	8	10	80.0
	Auditory verbal	11	60	18.3
	Auditory word recognition	44	60	73.3
	Sequential commands	28	80	35.0
	Repetition (syllable)	54	100	54.0
	Object naming	36	60	60.0
	Word fluency	2	20	10.0
	Sentence completion	6	10	60.0
	Responsive Speech	2	10	20.0
	AQ (syndrome)	57	Wernike’s	
Screener 1-4	Repetition	26	30	86.7
	Oral Naming Nouns	20	30	66.7
	Oral Naming Verbs	5	10	50.0
	Written Naming Nouns	14	30	46.7
	Written Naming Verbs	1	10	10.0
	Reading Aloud Nouns	23	30	76.7
	Reading Aloud Verbs	8	10	80.0
	Writing to Dictation Nouns	14	30	46.7
	Writing to Dictation Verbs	0	10	0.0
	Auditory Comprehension	18	20	90.0
	Reading Comprehension	19	20	95.0
	Direct Copying	15	15	100.0
	Delayed Copying	11	15	73.3
Verbal Memory	CALVT – Immediate Recall	18	75	24.0
	CALVT – Delayed Recall	6	15	40.0
	CALVT – Delayed Recognition	10	15	66.7
Working Memory	Digit Span Forward (seq.)	3	16	18.8
	Digit Span Forward (span)	4	16	25.0
	Digit Span Backward (seq.)	2	16	12.5
	Digit Span Backward (span)	2	16	12.5
Semantic Access	Birmingham Object Recognition Battery (BORB)	23	23	100.0
	Pyramid and Palm Tree Test (PPTT)	37	37	100.0
Attention	Balloon Test A (time)	89s		
	Balloon Test B (time)	149s		
	Balloon Test A (correct)	20	20	100.0
	Balloon Test B (correct)	20	20	100.0
Visuospatial Function	Minimal Feature View	24	25	96.0
	Foreshortened View	24	25	96.0
	Item Match	32	32	100.0
	Extended Assessment			
Snodgrass	Snodgrass Oral Naming	102	217	47.0
	Snodgrass Reading Aloud	128	217	59.0
Word-Picture Matching	Written Word Picture Matching	120	126	95.2
	Spoken Word Picture Matching	123	126	97.6
Immediate Auditory Discrimination		38	40	95.0
Synonym Judgment (Auditory)		46	60	76.7
Nonverbal Intelligence	**TONI-3 Form A**	**Raw**	**Quotient**	**Percentile**
		31	100	50.0
Executive Function	**Behavioral assessment of dysexecutive functions (BADS)**	Total Profile	Standardized	Age-corrected
		13	75	70 (Broderline)

Appendix C showing the stimuli used in Experiment 1

佇	屜	梭	濫	簌	謬
佔	峰	棄	瀝	算	護
佩	幽	棒	灑	篡	贍
侃	弄	棕	焚	糖	趾
假	弔	棗	熔	絆	跤
傘	患	棧	燈	網	踝
傷	悽	檀	燐	綴	蹄
儕	憐	椤	燦	緘	躡
冷	愎	榻	爐	織	躲
印	愕	構	爽	繭	輓
卵	慢	樣	犒	聒	輔
厚	愎	橫	犢	胞	返
叩	憔	椤	猙	胤	透
咄	憶	殃	猿	胰	週
咒	懇	殄	獨	膛	遊
售	懷	殞	獰	膳	邀
啕	懺	殤	珍	臊	醺
喙	抽	毒	珠	茶	釜
噱	捐	毓	珮	虱	鉀
嚎	掐	氾	瑙	蝗	銅
垢	探	泰	瑣	蝠	銘
壺	掬	浪	璨	蠟	鋼
夙	揀	浸	環	蠶	錶
奔	描	涓	甩	蠻	鎖
套	換	涕	疏	詐	鑲
姻	握	混	皂	評	鑼
娛	援	游	睦	誌	陶
娟	搖	湮	睫	語	階
婪	撲	溥	朦	誠	鞍
媒	擂	滴	硬	誦	飛
孽	攔	滿	磚	誨	饌
寒	暖	漬	禍	諂	駭
寬	桅	漾	突	謁	驅

Appendix D showing the stimuli used in Experiments 2 and 3

Experiment 2				Experiment 3			
Freestanding phonetic radicals presented alone		Freestanding phonetic radicals presented in pseudo-compounds		Non-freestanding phonetic radicals presented alone		Non-freestanding phonetic radicals presented in pseudo-compounds	
Dominance rating							
High	Low	High	Low	High	Low	High	Low
咢	蜀						
岡	舌						
曼	賣						
朵	詹						
雷	襄						
蒙	亥						
豪	咸						
皇	周						
志	黃						
善	責						
羅	免						
容	每						
表	果						
成	意						
闌	甲						
妻	柬						
啚	齊						
名	更						
奐	出						
N = 19	*N* = 19	*N* = 19	*N* = 19	*N* = 16	*N* = 15	*N* = 16	*N* = 15

Note. Low dominance rating in Experiment 2 refers to a dominance value of < 0.1 and high dominance rating refers to a dominance value of 1.0. Low dominance rating in Experiment 3 refers to a dominance value of 0.5 – 0.75 and high dominance rating refers to a dominance value of ≥ 0.85.