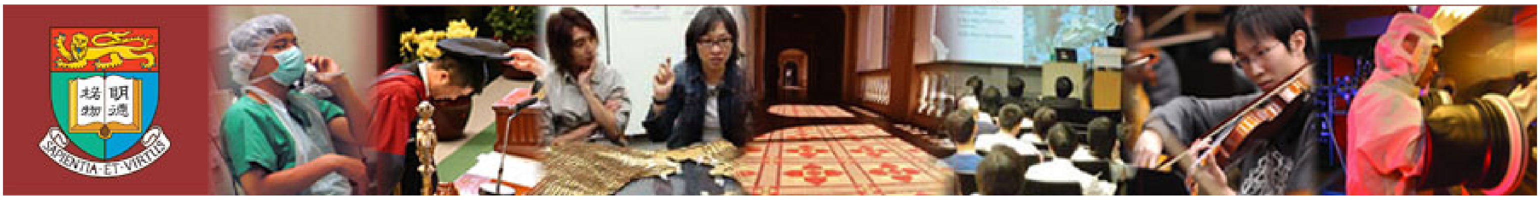

Reading without Meaning:

The Case of Cantonese Developmental Hyperlexia

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Abstract

This study addressed the issue of whether oral reading of Chinese is mediated by semantics in children with hyperlexia. A Cantonese child with hyperlexia (C.C.H.), 19 chronological age-matched (CA), and 19 mental age-matched (MA) controls were assessed on their semantic knowledge and oral reading of words and characters. Despite having an underdeveloped lexical-semantic system, the oral reading scores of words and single characters of C.C.H. was comparable to his CA and MA controls. He showed better oral reading of the words he knew than those he did not and significantly poorer reading of bisyllabic words containing homographic heterophonic characters, of which correct pronunciation could only be disambiguated by the word context. Importantly, similar to his CA and MA peers, low-frequency, low-imageability and irregular characters, which required more semantic support for phonological retrieval, were named poorer during character reading. The observations support the Parallel Distributed Processing model of reading (PDP: Plaut, McLelland, Seidenberg, & Patterson, 1996), which argues that successful oral reading in Chinese hyperlexia is semantically associated.

Key words: Cantonese developmental hyperlexia; Parallel Distributed Processing model

Reading without Meaning: The Case of Cantonese Developmental Hyperlexia

Reading and comprehension are thought to be two inseparable processes; it is believed that children learn the sound and meaning of a word at the same time. However, evidence from 'reading without meaning' abilities of children with hyperlexia challenges this view. 'Reading without meaning' refers to the ability to read words without understanding of those words. Hyperlexia is a disorder characterized by the development of advanced oral reading ability despite cognitive, social and language impairments (Silberberg & Silberberg, 1967). Children with hyperlexia were reported to be able to read at a very young age before any formal instruction, possess a strong preoccupation with reading and is generally associated with other developmental disorders, most often autistic spectrum disorder and intellectual disability (Aram, 1997; Siegel, 1993). The 'reading without meaning' pattern of hyperlexia is of particular interest in the debate of whether reading and semantics are developmentally independent and for its implications for models of reading. Reading models such as the Dual Route Cascaded model and the Parallel Distributed Processing model have tried to explain how reading can be achieved without modulation to meaning.

Oral reading and semantics can be two independent processes in the Dual Route Cascaded model of reading (DRC model: Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The model delineated two primary routes in oral reading. One is the lexical-semantic route, which links the orthographic input lexicon to the phonological output lexicon via semantics. Another is the non-lexical route, which decodes unfamiliar regular words and non-words by grapheme-phoneme conversion (GPC) rule. A third direct lexical route has been proposed to account for the reading pattern of individuals with semantic impairment. This route maps between orthography and phonology bypassing semantics and enables reading without understanding of word meaning. Both the non-lexical route and the direct lexical route can be considered as the non-semantic route. However, the presence of a non-lexical route is controversial in Chinese as Chinese characters do not carry any information of the phoneme nor tone, the GPC rule in alphabetic languages is not applicable in Chinese. Nevertheless, there could be still some clues to help oral reading. Over 80% of the Chinese characters are phonetic compounds, which contain components that provide clues to the sound of the character (phonetic radical) and the meaning of the character (semantic radical). The phonetic radical of a regular phonetic compound provides reliable cue to the pronunciation of the whole character (e.g., the phonetic 其 others, */kei4/*[1] is a reliable sound cue for 棋 chess, */kei4/)*, while the phonetic radical of irregular ones cannot (e.g., the phonetic 民 people, */man4/* cannot provide a sound cue for 眠 sleep, */min4/*). As most of the phonetic radicals are existing characters with their own meanings in Chinese, assembling pronunciation from phonetic radicals was arguably a lexical process instead of being non-lexical (Law, Wong, & Chiu, 2005). Given the impossibility of non-lexical reading in Chinese, Law et al. (2005) and Weekes, Chen, and Yin (1997) argue that reading of Chinese characters is dependent on the direct lexical route in case of semantic deficits. They found adults with semantic deficits achieved successful oral reading regardless of character frequency, regularity and imageability. Such insensitivity to psycholinguistic variables could not be a result of semantic mediation but demonstrated oral reading via the direct lexical route.

Studies of developmental hyperlexia showing dissociations between semantics and oral reading also lend support to the presence of a direct lexical route. Siegel (1984) and Aram, Rose, and Horowitz (1984) had showed that this dissociation was evident early in childhood by demonstrating the ability of children with hyperlexia to read English words without comprehension. However, almost all words read correctly without comprehension were regular words. It is argued that the findings of these studies are not sufficient to support the presence of a direct lexical route as successful oral reading of regular English words can be explained by the use of GPC rule. A more recent study from Castle et al. (2010) reported that two children with hyperlexia read high-imageability irregular English words as accurate as their age-matched controls even with an impaired semantic system. Su, To, & Weekes (2011) also reported accurate reading of high-imageability Chinese characters in a child with hyperlexia. These studies concluded that intact reading in children with hyperlexia was achieved via the use of direct lexical route given that irregular words do not follow GPC rules and non-lexical processing is arguably absent in Chinese. However, unlike adult aphasic studies, the effects of psycholinguistic variables of frequency, imageability and regularity were not fully investigated in children studies, and especially the effects of imageability. Given that the two children studies only included words that are highly imageable, it is still unclear whether reading of low-imageability words could be read equally well via the direct lexical route. If reading of low-imageability words is impaired, the direct lexical route alone will be inadequate in explaining such sensitivity to imageability effect.

Opposing prediction from the Parallel Distributed Processing model (PDP: Plaut, McLelland, Seidenberg, & Patterson, 1996) believes that semantics plays a role in oral reading of irregular words, particularly those low in frequency and low in imageability. Two pathways work in connections. The phonological pathway links orthography to phonology via the interconnections between orthographic and phonological units, which supports reading of high-frequency and regular characters. The semantic pathway maps between orthography and phonology via semantics, which supports reading of low-frequency irregular characters. Therefore, semantic deficit cannot leave reading of low-frequency irregular characters intact. The effects are expected to be more exaggerated for low-imageability characters because they have fewer number of semantic features than high-imageability ones for phonological activation (Plaut & Shallice, 1993). Therefore, regularity effects (i.e., better reading of regular than irregular characters), frequency effects (i.e., better reading of high-frequency than low-frequency characters) and imageability effects (i.e., better reading of high-imageability than low-imageability characters) will be evident in the reading performance of an individual with semantic deficit given that the integrity of the semantic memory predicts oral reading accuracy.

Evidence of association between semantics and reading of particular types of words, i.e., low-frequency, low-imageability and irregular words, in adults with comprehension loss has been explained using the PDP model (Weekes, 2000; Weekes & Chen, 1999). Another line of evidence supporting the need of semantic information during reading come from the reading out of context errors of adults with semantic deficits in reading homographic heterophones, which refers to orthographically identical characters that have more than one pronunciation depending on different intraword contexts, e.g., 便利 (convenient, /*bin6* *lei6*/) and 便宜 (cheap, /*pin4* *ji4*/) (Law, 2004). However, studies of developmental hyperlexia have not investigated these psycholinguistic factors and homographic heterophones in reading as in the study of Castle et al. (2010) and Su et al. (2011).

The two models of reading make different predictions on the reading pattern of individuals with semantic impairment. The DRC model predicts oral reading can be intact irrespective of character frequency, regularity and imageability, while the PDP model predicts poor oral reading of low-frequency, irregular and low-imageability characters in case of impaired semantics. Given the reports from previous studies, it is still inconclusive to understand whether oral reading of children with hyperlexia is dependent on semantic information due to several reasons: (a) most of the literatures investigating the relationship between semantics and oral reading were based on adults with brain injuries or semantic dementia. However, disruption in the mature semantic system in adults may have a different effect in reading compared with a developing semantic system in children (David, 1984). (b) Children studies usually assumed no semantic involvement in oral reading whenever there is semantic deficit, and explained any successful oral reading using non-semantic reading routes. Therefore, the amount of lexical-semantic knowledge required for correct word reading, frequency effect, regularity effect and especially imageability effect were usually not considered. (c) Few developmental studies have contrasted reading and semantic development of hyperlexic individuals with their age-matched and mental age-matched peers to establish a reference for fair comparison. Given the paucity of information, in this study we aim to examine the semantic contribution to reading in greater detail by investigating whether oral reading is semantically mediated in children with hyperlexia.

Given the aim of this study, individual with hyperlexia is expected to show good oral reading ability despite an underdeveloped semantic system. It is hypothesized that if oral reading is not semantically mediated in hyperlexics, then the hypelexic individual will show intact character reading irrespective of their frequency, imageability and regularity features. Homographic heterophones will be read correctly without taking the intraword context into consideration. A pattern of dissociation between oral reading and semantics would support the postulation of a direct-lexical route in the DRC model. On the contrary, if oral reading is semantically mediated, then characters that typically need more semantic support (i.e., low-frequency, irregular, low-imageability characters) for phonological activation is expected to be more impaired than those require less support. Homographic heterophones cannot be read correctly without understanding the intraword context. This pattern of association between oral reading and semantics would lend support to the PDP model.

Method

Participants

C.C.H. is a Cantonese-speaking boy aged 8 years and 11 months with a non-verbal IQ age of 7.5 years based on the Ravens Colored Progressive Matrices (Raven, Raven, & Court, 1998). He studied in Primary 3 in a special school for mild-moderate intellectual disability in Hong Kong. He was diagnosed with Autistic Spectrum Disorder and mild intellectual disability. No other sensory impairment was reported. He could comprehend 4-element commands and was able to use 2-element utterances. Teachers reported poor social skills.

C.C.H. was selected for this study according to the criteria of (a) advance oral reading ability, and (b) inferior verbal comprehension ability (Nation, 1999). Parents reported other features of developmental hyperlexia described in the literature (Aram, 1997), including character reading skills emerged at the same age as his first word at 4 years and 6 months with no prior formal instruction and a pre-occupation for lyrics that appeared on television.

Two control groups of normally-developing individuals were recruited from a local mainstream primary school. Nineteen Grade Two students (M_{age} = 7.58 years, SD = 0.23 years; 15 females, 4 males) matched in non-verbal IQ age with C.C.H. were selected into the mental age (MA) control group. Another nineteen Grade Three students (M_{age} = 8.51 years, SD = 0.26 years, 8 females, 11 males) matched in chronological age with C.C.H. were selected into the chronological age (CA) control group. All participants received education in Hong Kong since Grade One and reported to have normal vision and hearing.

An additional 35 native Cantonese speaking university students aged from 21-27 (M_{age} = 22.5 years, SD = 1.44 years; 15 male; 20 female) with normal vision and hearing were recruited to provide imageability ratings of the characters in the Hong Kong Graded Character Naming Test (HKGCNT; Leung, Lai, & Kwan, 2008)

Materials

Intelligence test. Ravens colored progressive matrices (RCPM; Raven et al., 1998) was a standardized test used to measure the children's non-verbal intelligence. The test comprised three sets of 12 items, each item consists of a target matrix with one missing part. Children were asked to select the part that best completes the matrix from six alternatives. The test was scored referenced to the norms for children in Taiwan (Raven et al., 1998).

Picture-picture matching test. The test was a 23-item picture to picture matching semantic relatedness test. Three line drawings were presented on a computer screen with the target item (e.g., 椅子 chair) positioned above the other two distractor pictures (e.g., 檯 table vs.鐘 clock). The distractor drawings were positioned below the target picture, with one to the left and the other to the right. Children were asked to select from the two distractors the picture that was related in meaning to the target picture (i.e., 檯 table). Items were selected from the Pyramid and Palm Trees Test (PPTT: Howard & Patterson, 1992) and the Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993; see Appendix A) according to the criteria that (a) the items were identified by Cantonese adults with more than 75% correct (Law & Yeung, 2010), and (b) the written words of the items were taught in Primary one (P1) to Primary three (P3). For two PPTT items with the unrelated distractor words not learned by P3, the unrelated distractor was replaced by another item from the same semantic category using pictures in the PPTT set (i.e., 蘿蔔 carrot was used to replace 洋蔥 onion and 修女 nun was used to replace 市長 mayor).

Word-word matching test. The test was a 23-item written word to written word matching semantic relatedness test (see Appendix A), which was the written word version of the picture-picture matching test. Presentation layout and instructions to select the semantically related target were identical to the picture-picture matching test, except the three pictures on the computer screen were replaced with three written words.

Spoken word comprehension test. The test contained 65 forced choice spoken word-picture matching items from standardized Hong Kong Cantonese Receptive Vocabulary Test (HKCRVT: Lee, Lee, & Cheung, 1996). Four pictures were presented on a computer screen. Upon the presentation of the spoken word, the children were asked to select the target picture (e.g., 車 car, /*ce1*/) that matched the presented spoken word amongst a semantic distractor picture (an object semantically related to the target, e.g., 船 boat, */syun4/*), a phonological distractor picture (an object phonologically similar to the target, e.g., 遮 umbrella, /*ze1*/) and an unrelated distractor picture (an object that is neither phonologically nor semantically related to the target, e.g., 眼鏡 eye glasses, /*ngan3 geng2*/).

Written word comprehension test. The test contained 65 forced choice written word-picture matching items using the written forms of the targets from HKCRVT (see Appendix B). A written word was placed at the centre of a computer screen surrounded by a target picture, a semantic distractor, a phonological distractor and an unrelated distractor picture. Children were asked to select the target picture that matched the written word.

Word reading test. The test comprised 65 written forms of the targets in the standardized HKCRVT (Lee et al., 1996). Presentation of the words was randomized for each participant. The children were required to read aloud the words appeared on the computer screen. The score of this task was used to make a direct comparison with the HKCRVT word- picture matching scores to examine the pattern of reading without meaning.

Contextual word reading test. This test comprised of 40 bisyllabic words that were paired to have 20 target characters, see Appendix C. Each of the 20 target characters were homographic heterophonic characters that differed in tone between the two bisyllabic words (e.g., 更加 more, /*gang3 gaa1*/, 更改 change, /*gang1 goi2*/). The items were selected from the Lexical Items with English Explanations for Fundamental Chinese Learning in Hong Kong Schools (Hong Kong, China, 2009) based on the criteria that they were taught in Primary 1 to Primary 3 in local schools. Half of the target characters appeared in the first character and the other half appeared in the second character. Presentation of the words to be read aloud was randomized for each child. The children were asked to read aloud the individual word presented on the computer screen.

Character reading test. Hong Kong Graded Character Naming Test (HKGCNT; Leung et al., 2008) was administered to test the children's single character oral reading ability. HKGCNT Grade 2 was administered to C.C.H. and the MA control, whereas HKGCNT Grade 3 was administered to C.C.H. and the CA control. Children were asked to read aloud the character that appeared on the screen one at a time. The items to be read aloud for each grade consists of 150 single Chinese characters of varying grade appropriate frequency levels, character complexity and regularity, see Appendix D. Mean imageability ratings of the characters (ranging from 1 to 5 with increasing numbers reflecting greater difficulty to imagine a pictorial representation of the character) was independently collected from the university students as shown in Appendix D. The first half of the characters with the highest imageability rating was group as high imageability (Grade 3, M =3.78, SD =0.95, Range: 2.67-5.00; Grade 2, M = 3.63, SD = 1.12, Range: 2.67-4.81), whereas the second half of the characters with the lowest imageability rating was grouped as low imageability (Grade 3, M = 1.83, SD = 0.93, Range:1.14-2.67; Grade 2, M = 1.93, SD = 1.02, Range:1.24-2.62).

Procedure

C.C.H. was assessed over a 2-week period. He completed the non-verbal IQ (RCPM), character reading (HKGCNT) and comprehension measures (HKCRVT) in the first session for screening purpose, he then completed the remaining tests in the second session. The control children finished all the tests in a single session. Total testing period lasted for 1.5 hr for each child. Order of test administration was randomized using repeated Latin Squares design. Tests were carried out in the classrooms of the children's schools. All the tests were computerized using E-Prime 2.0 and administered on a laptop. Any reading responses given were recorded for accuracy by the experimenter, and a record of vocal responses were stored for later checking. For the intelligence test and semantic tests, the experimenter entered C.C.H.'s response onto the computer. The control participants were instructed to enter their response (i.e., the selected picture number) onto the computer themselves. The imageability rating questionnaires were carried out in the Prince Philip Dental Hospital.

Scoring for oral reading tests

The number of correct items was scored and self-correction was included as a correct response. In the rare instances when children offered two responses, they were asked to decide on the final answer. For the word reading tests, an item was regarded as correct only when both characters in a word was read correctly. The response of the children was first scored on site, and later re-scored by another judge, the investigator, based on the audio recording. Inter-rater reliability was good for the oral reading tasks of HKCRVT (Pearson's correlation = .96, $p < .0001$), homographic heterophones (Pearson's correlation = .82, $p < .0001$) and HKGCNT (Pearson's correlation = .96, $p < .0001$). Therefore, only the scores from the investigator were reported.

Results

The results section is organized in a way to address the role of semantics in oral reading of children with hyperlexia by examining a) whether word oral reading can be independent of meaning and b) whether character oral reading is affected by psycholinguistic variables.

Overall Performance

Table 1.

Mean Performance Scores of C.C.H. and the Control Groups on a range of reading and semantic tasks

Test		C.C.H.	MA Control	CA Control	Max Score
Age (year; month)		8;11	7;7** (2.76 m)	8; 6 (3.12 m)	
Intelligence	RCPM	26	28.4 (4.66)	30.2 (3.63)	36
Semantic Relatedness	(i) Picture-picture matching	16	20.3 (1.95) *	21.4 (1.30) ***	23
	(ii) Word-word matching	16	20.2 (1.42) **	21.4 (0.96) ***	23
Comprehension	(i) Spoken word-picture matching (HKCRVT)	54	62.6 (1.95) ***	63.2 (1.46) ***	65
	(ii) Written word-picture matching (HKCRVT)	55	62.2 (2.01) **	61.2 (3.88)	65
Word Reading	(i) HKCRVT written words	60	60.4 (3.23)	61.7 (2.54)	65
	(ii) Homographic heterophones	19	30.0 (4.19) *	33.6 (2.83) ***	40
Character Reading	(i) HKGCNT Grade 2	108	113.1 (18.78)		150
	(ii) HKGCNT Grade 3	99		114.1 (13.28)	150

Note. MA, mental age- matched; CA, chronological age- matched, RCPM, Ravens Colored Progressive Matrices; HKCRVT, Hong Kong Cantonese Receptive Vocabulary Test; HKGCNT, Hong Kong Graded Character Naming Test; Standard deviations are given in parentheses.

$*p < .05$. $**p < .01$. $***\ p < .001$.

Table 1 displays the scores for the semantic relatedness tasks and the word-picture matching tasks of C.C.H. and the control groups. The scores were compared statistically using the modified *t* test of Crawford and Howell (1998) to show whether there was a significant difference between the scores of C.C.H. and the control groups. The result confirmed that C.C.H. showed a highly significant impairment relative to the MA and CA controls in all semantic tests, word-word matching, MA: $t(18) = -2.86$, $p = .005$; CA: $t(18) = -5.45$, $p < .001$, picture-picture matching, MA: $t(18) = -2.16$, $p = .045$; CA: $t(18) = -4.06$, $p = .001$, spoken word-picture matching, MA: $t(18) =-4.31$, $p < .001$; CA: $t(18) = -6.12$, $p < .001$, and written word–picture matching, MA: $t(18) = -3.47$, $p = .003$, except that C.C.H. did not significantly differ from the CA control in the written word-picture matching task, *t*

(18) = -1.55, *p* = .14. The lack of significant difference between C.C.H. and the CA control in the written word- picture matching task was due to the extremely low score of a CA control participant, who performed 3.37 *z*- score (48/65) below the mean. These results together indicate that C.C.H. showed a significantly poorer performance on comprehension and semantic tests in both visual and auditory modalities than the controls. On the other hand, C.C.H. showed comparable oral reading performance to MA and CA controls on the HKCRVT written words, MA, $t(18) = -.11$, $p = .91$; CA, (18) = - .65, $p = .26$, and HKGCNT characters, MA, $t(18) = -.26$, $p = .80$; CA, $t(18) = -1.11$, $p = .28$, see Table 1. For oral reading of bi-syllabic words containing homographic heterophones, C.C.H. however performed significantly poorer than the MA controls, $t(18) = -2.55$, $p = .02$, and CA controls, $t(18) = -5.02$, $p < .001$. Overall, C.C.H. was impaired in semantic and comprehension tasks, but his oral reading skills were comparable to the controls except in the reading of homographic heterophones, which suggest a 'reading without meaning' pattern.

Word Reading and Comprehension

Oral reading and comprehension of HKCRVT words. In this section I move to examine into more detail the relationship between reading abilities and comprehension abilities by first comparing the reading score and the comprehension score of HKCRVT.

Table 2.

Difference in Performance between Oral Reading and Comprehension on HKCRVT

	Oral reading minus spoken comprehension	Oral reading minus reading comprehension
C.C.H.	6	5
MA	-2.26 (3.51)*	-1.79 (2.76)*
CA	0.53 (4.27)*	-1.47 (3.06)

Note. HKCRVT, Hong Kong Cantonese Receptive Vocabulary Test; MA, mental age matched control; CA, chronological age matched control; Standard deviations are given in parentheses.**p* < .05 in comparison to C.C.H.'s performance.

Table 2 shows the difference of scores between HKCRVT word-picture matching and word oral reading task. A positive score indicates better oral reading skills than comprehension skills, whereas a negative score indicates better comprehension skills than oral reading skills. Table 2 shows that C.C.H. had better oral reading performance than the two comprehension tasks. On the other hand, the MA and CA controls showed an opposite pattern of better comprehension performance than oral reading, although the difference between oral reading and spoken comprehension was small for the CA control. Analysis using modified *t* test confirmed that C.C.H. showed a significantly greater difference between oral reading and spoken comprehension scores compared to the CA control, $t(18) = 2.38$, $p = .029$, and MA control, $t(18) = 2.29$, $p = .034$. C.C.H. also showed a significantly greater difference between oral reading and reading comprehension than the MA control, $t(18) = 2.40$, $p = .028$, and a marginally greater difference compared to the CA control, $t(18) = 2.06$, $p = .054$. These analyses showed that C.C.H. was able to read aloud more words than he could comprehend in written or spoken form. An opposite pattern was evident for the control groups, they were able to comprehend more words than the ones they could read aloud.

Table 3.

Comparison between Oral Reading of Known words and Unknown words in the HKCRVT test

	Spoken word-picture matching				Written word-picture matching			
	Known words		Unknown words		Known words		Unknown words	
	N	Correctly read	*N*	Correctly read	*N*	Correctly read	*N*	Correctly read
C.C.H.	54	52 (96.3 %)	11	8 (72.7 %)	55	53.0 (96.4 %)	10	7 (70 %)
MA	62.6	58.1 (92.8 %)	2.4	2.3 (95.8 %)	61.1	58.4 (95.6 %)	2.8	2 (71.4 %)
CA	63.2	60 (94.9%)	1.8	1.6 (88.9 %)	62.2	58.8 (94.5 %)	3.9	3.2 (82.1 %)

Note. HKCRVT, Hong Kong Cantonese Receptive Vocabulary Test; MA, Mental age matched control; CA, Chronological age matched control; Percentage scores are given in parentheses.

An item specific analysis of HKCRVT words was conducted to verify whether known words (i.e., words correctly matched with the corresponding pictures in the word-picture matching tasks) were read better than unknown words (i.e., words incorrectly identified with the corresponding pictures in the word-picture matching tasks). This may suggest whether C.C.H.'s ability to read was related to the corresponding semantic knowledge.

Table 3 shows that both C.C.H. and the control groups were generally able to read aloud a greater proportion of words they knew the meaning of than ones that were unknown words in both spoken and written word- picture matching tasks. Fisher's Exact test confirmed that the difference between known and unknown words determined by both spoken and written word- picture matching tasks was significant only for C.C.H. (Spoken, p = .031; Written, p = .023), but not the MA control (Spoken, p = 1; Written, p = .22) nor the CA control (Spoken, p = 1; Written, p = .23). The results showed that C.C.H. was able to read aloud more accurately the words he knew than ones he did not know. While for the control groups, known words did not show a significant advantage in oral reading.

Oral reading and comprehension of homographic heterophones. Reading of bi-syllabic words containing homographic heterophones was investigated to examine if correct reading of these words required comprehension of intraword context.

Table 4.

Analysis of Errors on Homographic Heterophones Reading Task of C.C.H. and the Control Groups

Error Type	C.C.H.	MA Control	CA Control
Total bi-syllabic word error	21	10.0 (4.19)*	7.40 (2.83)***
Total homographic heterophonic character error	20	9.32 (3.71)*	6.00 (2.56)***
ROC errors	15	7.42 (1.98)**	5.11 (2.00)***
Visual errors	1	0.21 (0.42)	0.00 (0.00) [a]
Word-related errors	1	0.16 (0.37)	0.21 (0.71)
Others	3	0.00 (0.00) [a]	0.11 (0.32)***
Did not know	0	0.16 (0.71)	2.06 (0.47)***

Note. MA, Mental age matched; CA, Chronological age matched; ROC, Reading out of Context; Standard deviations are given in parentheses; [a] t test was unable to run due to zero value.
*p < .05. **p < .01. *** p < .001.

As reported in the *Overall Performance* section, C.C.H. read aloud bisyllabic words containing homographic heterophones significantly poorer than both controls. Table 4 shows that a majority of the errors came from the homographic heterophonic characters for all participants. Modified t test showed that C.C.H. made more homographic heterophonic character errors than MA controls, *t*(18) = 2.81, *p* = .012 and CA controls, *t*(18) = 5.33, *p* < .001. The homographic heterophonic character errors were categorized into ROC (reading out of context) errors, where the error differs from the target character in tone but is still a legitimate alternative pronunciation of the character, e.g., 難民 refugee, /*naan6 man4*/ → /*naan4 man4*/ as in 難題 difficult problem /*naan4 tai4*/; visual errors (e.g., 興建 construction /*hing1 gin3*/ → /*jyu5 gin3*/ as in 與建 is a non-word); word-related errors (e.g., 稱讚 praise, /*cing1 zaan3*/ →讚賞 praise, /*zaan3 soeng2*/); others (e.g., 更加 even more, /*geng3 gaa1*/ → /*bai3 gaa1*/where 拜加 is a non-word) and did not know. The comparison across groups showed that C.C.H. made significantly more ROC errors than the controls, MA, *t*(18) =3.73, *p*= .002; CA, *t*(18) =4.8, *p* < .001, and more errors that were categorized as others than the CA control, *t*(18) = 8.80, *p* <. 001. However, C.C.H. made significantly less did not know response than the CA control, *t*(18) = -4.27, *p* <. 001.

Character Reading and Semantic Mediation

The above analyses showed that despite better oral reading of HKCRVT words than the corresponding comprehension performance, C.C.H.'s reading of known words was better when compared to unknown words. His reading of homographic heterophones was worse than the controls and more reading of out context errors was demonstrated. In this latter section, the issue of whether there is semantic mediation for character reading is addressed.

Effects of psycholinguistic variables. As hypothesized in the introduction, if semantics is not necessary for oral reading, psycholinguistic features of frequency, regularity and imageability will not affect oral reading performance. On the other hand, if semantics is required, characters that require more semantic information for phonological activation (i.e., low-frequency, irregular, low-imageability characters) will be particularly difficult for C.C.H. To examine these psycholinguistic effects on character reading, error scores were selected for analyses rather than accuracy scores to link closer to the later *Error Pattern Analysis* section.

Table 5.

Percentage of Oral Reading Errors across Frequency, Imageability and Regularity of C.C.H. *and the Control Groups on Hong Kong Graded Character Naming Test*

	C.C.H.	MA Control						C.C.H.	CA Control					
	%	*M*	*SD*	*df*	*F*	η_ρ^2	*p*	%	*M*	*SD*	*df*	*F*	η_ρ^2	*p*
Frequency				2,36	82	.82	<.001***				1.34, 24	103	.85	.001**
High	10.0	3.79	5.0					12.2	4.51	3.5				
Mid	23.6	26.8	17.5					30.8	24.0	9.7				
Low	53.3	45.2	18.4					59.2	43.4	15.4				
Imageability				1,18	7.7	.30	.01*				1,18	30.9	.63	<.001***
High	25.3	21.8	11.5					28.0	17.1	7.0				
Low	30.7	27.5	14.9					40.0	30.8	11.2				
Regularity				1,18	0.1	.01	.78				1,18	29.6	.62	<.001***
Regular	29.4	29.9	17.2					20.0	23.2	12.5				
Irregular	40.9	26.6	14.1					50.8	31.6	10.4				

Note. MA, Mental age matched; CA, Chronological age matched.

*p < .05. **p < .01. ***p < .001.

Frequency (High-, medium-, low-frequency) X Imageability (high- , low-imageability) X Regularity (regular, irregular) repeated-measures three-way analysis of variance (ANOVA) was conducted on the percentage error score of HKGCNT Grade 2 of the MA control and Grade 3 of the CA control. Mauchly's test indicated the assumption of sphericity had been violate for the main effect of frequency for CA control, $\chi^2(2) = 11.73$, $p = .003$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε =.67). Table 5 shows that for both control groups, there was significant main effect of character frequency, with more errors made when reading low-frequency characters compared to medium frequency characters, MA, $F(1, 18) = 45.7$, $p < .001$, $\eta_\rho^2 = .72$; CA, $F(1, 18) = 91.81$, $p < .001$, $\eta_\rho^2 = .84$, and high frequency characters, MA, $F(1, 18) = 125.1$, $p < .001$, $\eta_\rho^2 = .87$; CA, $F(1, 18) = 121.88$, $p < .001$, $\eta_\rho^2 = .87$. A significant main effect of imageability was also found for both control groups, with more errors for characters that were low in imageability than high in imageability. Interestingly, significant main effect of regularity was found only in the CA control, with more errors made on irregular than regular characters, but not for the MA control, who showed comparable number of errors in irregular and regular characters. [2]

Within-subject item-specific analysis using the unstandardized difference test of Crawford and Garthwaite (2005) examined whether the magnitude of difference between C.C.H.'s error scores on frequency, imageability and regularity differed significantly from the controls. Result showed that C.C.H. did not differ from both control groups in the main effect of frequency, both showed more errors in low- than medium-frequency characters, MA, $t(18) = 1.10$, $p = .29$; CA, $t(18) = 1.01$, $p = .30$, and medium- than high-frequency characters, MA, $t(18) = .66$, $p = .52$; CA, $t(18) = .11$, $p = .91$. C.C.H. also did not differ from both control groups in the main effect of imageability, both showed more errors in low- than high-imageability characters, MA, $t(18) = .061$, $p = .95$; CA, $t(18) = .28$, $p = .78$. However, significant regularity effect was found for C.C.H. when compared to the CA control, $t(18) = 2.33$, $p = .032$, and marginally for the MA control, $t(18) = 1.96$, $p = .065$, suggesting that C.C.H. demonstrated more errors on irregular than regular characters, and the difference was more pronounced when compared to the CA control group. Generally, C.C.H. demonstrated effects of imageability and frequency at similar magnitude to his CA and MA controls, and larger regularity effect than both control groups.

Between- subject analysis using modified *t* test compared C.C.H.'s error score for each character type with the controls. Results showed that C.C.H. made significantly more errors in irregular- high imageability- high frequency characters (11.1%) and irregular-high imageability-medium frequency characters (58.3%) than the MA control ($M = 1.16\%$, $SD = 3.47$), $t(18) = 2.80$, $p = .012$, and CA controls ($M = 23.74\%$, $SD = 12.5$), $t(18) = 2.69$, $p = .015$, respectively. All other comparisons between C.C.H. and the control groups were not significant (all *p*'s > .05, see Appendix E).

Error pattern analysis. In the above analyses, the psycholinguistic factors were found to affect oral reading accuracy. The error pattern analysis in this section may have the potential to reveal the oral reading strategies of C.C.H.

Table 6.

Analysis of Oral Reading Errors of C.C.H. and the Control Groups on HKGCNT

	Grade 2			Grade 3			
	C.C.H.	MA Control		C.C.H.	CA Control		
Error Type	%	%	*SD*	%	%	*SD*	Example
Regularization	22.0	11.6	6.0	27.7	11.8	7.6	液 /*jik6*/→ 夜 /*je6*/
Phonetic analogy	34.3	15.7	10.1	25.5	11.3*	5.2	枯 /*ku1*/→ 姑 /*gu1*/
Semantic analogy	0.0	2.4	3.3	0.0	1.5	2.0	鮨 /*kei4*/→ 鱗 /*leon4*/
Logographeme analogy	4.9	5.0	4.1	2.1	2.2	2.4	岳 /*ok6*/→ 屈 /*wat1*/
Visually related	9.8	2.2*	2.6	4.3	0.5**	1.0	式 /*sik1*/→ 武 /*mou3*/
Word-related	4.9	6.7	4.4	2.1	6.8	6.4	浴 /*juk6*/→ 缸 /*gong1*/
Semantic-related errors	0.0	4.6	4.6	0.0	5.7	6.5	櫃 /*kwai6*/→ 箱 /*soeng1*/
Tonal	0.0	1.7	2.9	2.1	2.6	3.0	奮 /*faan3*/→ 墳 /*faan4*/
LARC	0.0	0.8	1.9	0.0	0.8	1.8	嗜 /*kei4*/→ 老 /*lou3*/
Did not know	0.0	22.6	26.4	0.0	35.5	28.5	
Ambiguous	7.3	12.0	7.2	12.8	5.7	3.0	斯 /*si1*/→ 其/棋 /*kei4*/
Others	19.5	15.0	8.2	23.4	10.6	8.3	屈 /*wat1*/→ /*lik1*/
Total number of errors	41.0	36.9	19.3	47.0	35.9	13.3	

Note. HKGCNT, Hong Kong Graded Character Naming Test; MA, Mental age matched; CA, Chronological age matched; LARC, Legitimate Alternate Reading of Component.
$*p < .05$. $** p < .01$.

I adopted the error classification system of Ho and Bryant (1997) with the addition of semantic analogy, logographeme analogy, LARC[3] (Legitimate Alternate Reading of Component), tonal, visually related and ambiguous errors. Table 6 shows the error distribution of C.C.H. and the control groups in the HKGCNT reading task. The major types of errors made by C.C.H. were (a) regularization error, where the sound of the phonetic radical was used for the pronunciation of the whole character; (b) phonetic analogy error, where the character was pronounced as another character that share the same phonetic component; and (c) visually related error, where the character was pronounced as another character that shared similar orthography (see Appendix G, for the classification criteria of the remaining error types). C.C.H. demonstrated a greater percentage of these three error types than both control groups. Modified *t* test showed that C.C.H. did not demonstrate significantly more regularization, $t(18) = 1.70$, $p = .11$, and phonetic analogy errors, $t(18) = 1.80$, $p = .089$, than the MA control, but marginally significant more regularization errors, $t(18) = 2.04$, $p = .056$, and significantly more phonetic analogy errors, $t(18) = 2.66$, $p = .016$, than the CA control. Given that both regularization and phonetic analogy errors are considered phonetic-related errors (Ho & Bryant, 1997), when both types of errors were combined, C.C.H. (Grade 2, 56.1%; Grade 3, 53.2%) showed significantly more phonetic-related errors than both the MA ($M = 27.3\%$, $SD = 11.7$), $t(18) =2.41$, $p = .027$, and CA controls ($M = 23\%$, $SD = 11.8$), $t(18) = 2.49$, $p = .023$. The percentage of the visually related errors made by C.C.H. was also significantly greater than both the MA, $t(18) = 2.85$, $p = .01$, and CA, $t(18) = 3.70$, $p = .002$, controls. No significant difference was found (all *p*'s > .05) between C.C.H. and the control groups in other types of errors.

In general, the analysis showed that psycholinguistic variables affected C.C.H.'s oral reading accuracy. Low-frequency, low-imageability and irregular characters were most error prone and the error types were primarily phonetic and visually related errors.

Discussion

This study reported a case of Cantonese hyperlexia with semantic deficit but comparable oral reading ability as the typically developing children in word and character reading. This resembled the general reading pattern reported in other hyperlexic children (Castle et al., 2010; Siegel, 1993; Su et al., 2011) and semantic dementia patients (Law et al., 2005; Weekes et al., 1997). However, examining into more detail the reading performance and error pattern of C.C.H. showed that the previous view of hyperlexia was over-simplified. The findings of this study are summarized into several key observations: (a) C.C.H. read more words than he could comprehend and read known words more accurately than unknown words; (b) Homographic heterophones could not be read as accurately as the controls, and most were read out of context; (c) Psycholinguistic variables of frequency, regularity and imageability affected oral reading; and (d) Phonetic and visually related errors characterized the oral reading errors of C.C.H.. I now discuss the implications of these findings for addressing the issue of whether reading is semantically mediated in children with hyperlexia.

The first finding showed that C.C.H. read more words than he could comprehend. This pattern was consistent with other hyperlexia children studies (Aram et al., 1984; Castle et al., 2010). Interestingly, after looking closer into the items, C.C.H. showed more accurate reading of known words than unknown words. Semantic knowledge is believed to have played a role in the reading process of C.C.H. to give such pattern of performance. This finding was in contrast to the result of Castle et al. (2010), in which the two children with hyperlexia, JY and AD, showed comparable reading ability of known and unknown words. The use of a more stringent criterion for known words, which required an oral definition score of 2 or above (max score =3) in Castle et al. (2010)'s study can account for the discrepancy. It is suspected that an oral definition score of 1 had already demonstrated some semantic knowledge of the word, given the limited expressive language of the two children. When I carried out the Fisher's Exact test again with an oral definition score of 1 or above as the criterion for known words, both JY and AD showed significantly better in reading known than unknown words (Fisher's Exact: $p < .001$). Using this less stringent criterion then mirrored the pattern found in C.C.H.'s performance because oral definition task, which required expressive language ability and no choices were available, was inherently more demanding than the word-picture matching task we used. Therefore, given that C.C.H.'s reading performance was better for words he knew, it is argued that word reading still relied on a certain degree of semantics despite an impoverished semantic system.

The second finding demonstrated that C.C.H. was impaired in reading of homographic heterophones. These types of words were particularly impaired despite C.C.H.'s reading ability of words and characters in HKCRVT and HKGCNT was as proficient as typically developing readers. The result was consistent with the prediction according to the PDP model that reading of homographic heterophones could not be read accurately with an impaired semantic system and would result in Reading Out of Context errors. C.C.H. read a majority of the target characters out of context, meaning that he read most of the words at a single syllable level with a legitimate alternative pronunciation without considering the intraword context. It is believed that the homographic heterophonic character will activate the syllable units corresponding to the possible pronunciations of the character, e.g., 難 will activates both the phonological representations of the characters in 難民(refugee, /*naan6* *man4*/ and 難題 (difficult problem, /*naan4* *tai4*/). The two phonological representations will compete with each other for production. Without understanding of the intraword context to resolve the conflict at the phonological output representation, ROC error resulted (Law et al., 2005). Given the frequency effects in HKGCNT, I suspect the higher frequency phonological representation will be selected as output due to the greater efficiency of orthography to phonology conversion for high-frequency characters than low-frequency ones (Plaut et al., 1996). This however would warrant further investigation as information on frequency of exposure to the homographic heterophonic characters was lacking. It could also be argued that C.C.H. may not be familiar to these words in a special school, where the curriculum did not emphasize on literacy skills. This might have possibly contributed to the poor performance in homographic heterophones, rather than due to an inability to read using word context. Despite this potential confound, effort had been made on selecting words from Grade 1 to Grade 3 in Hong Kong primary schools in order to make the word list as familiar as possible. Furthermore, C.C.H.'s ability to read HKGCNT characters at a level of typically developing children would be the best evidence that familiarity should not be a constraint for his reading of homographic heterophones, but semantic knowledge was.

These two findings on word reading demonstrated that semantics played a key role in word oral reading. The result was consistent with the literatures showing an association between oral reading and semantics (Patterson et al., 1994; Weekes, 2000; Weekes & Chen, 1999). These studies also predicted the presence of regularity, frequency and imageability effects on C.C.H.'s character oral reading. C.C.H.'s sensitivity to psycholinguistic variables was contradictory to the predictions based on direct lexical route of the DRC model (Coltheart et al., 2001), but was predicted in the PDP model (Plaut et al., 1996). As delineated in the PDP model, with a poorer semantic system, the mapping between orthography to phonology is still intact to support reading of regular characters. However, irregular characters are more error prone as the mapping between orthography to phonology of irregular characters requires input from semantics, especially the lower frequency ones (Plaut et al., 1996). There were more errors in low-frequency characters as it takes a longer time for semantic information to enter into the orthography to phonology conversion before reaching a stable pattern of phonological activation (Plaut et al., 1996). The more errors in low-imageability characters than high-imageability ones could be accounted for by their difference in richness of semantic representations. Low-imageability characters were associated with fewer sensory referents and fewer semantic features, hence they require more input from the semantic system before settling into a stable phonological representation

(Plaut & Shallice, 1993). The need for more semantic input for irregular, low-frequency and low-imageability characters explained C.C.H.'s poorer reading of these characters.

In the above, lexical-semantic knowledge was found to be involved in oral reading of C.C.H. However, the effects of semantic impairment on reading pathways were still unclear. The error pattern of C.C.H. may provide a better understanding of his reading pathways. 8.89% (4/45), 31.1% (14/45) and 44.5% (20/45) of C.C.H.'s phonetic-related errors were from irregular high-, medium- and low-frequency characters respectively. The PDP model predicted a different pathway for irregular character of high frequency and low frequency. The high-frequency irregular characters could be read via the phonological pathway, while the low-frequency irregular characters should be read via the semantic pathway (Plaut et al., 1996). It is believed that if reading proceeded via the semantic pathway, C.C.H.'s errors on irregular characters would not be so prevalent in lower frequency characters. The observation of more errors from irregular low-frequency characters suggests reliance on reading via the phonological pathway without mediation from semantics. Computation of phonological output from a character will activate both the pronunciation of the whole character and the pronunciation of the phonetic radical. The two phonological representations compete with each other for an irregular character (Plaut et al., 1996). The radicals were usually of higher frequencies as they appeared as character components in different characters repeatedly (Zhou & Marslen-Wilson, 1997) and the chance of having a relatively higher frequency component was even greater for low-frequency characters. Without constraint from semantics in the phonological pathway, the one reaches a stable phonological representation faster (i.e., the higher frequency component) will be selected as output, resulting in regularization errors as reported in previous hyperlexia studies (Aram, 1997; Aram, et al., 1984) and other studies involving adults with semantic deficits (Patterson

& Hodges, 1994; Weeks & Chen 1999). For phonetic analogy errors, the lower frequency characters were more prone to error in a similar vein as the regularization errors, as the higher frequency analogous character would be selected as output without input from semantics.

It could be argued that the regularization errors resulted from reading via the non-lexical pathway (i.e. grapheme-to- phoneme conversion) as in the DRC model. However, all of the phonetic radicals in this experiment were real characters with their own meanings, e.g., 跑 run, /*paau2*/, and whose phonetic radical, 包 bag, /*baau1*/, has different pronunciation and meaning. In this regard, regularization of Chinese characters is considered as a lexical process instead of non-lexical (Law, Weekes, Wong, & Chiu, 2009). This contrasts to the use of non- lexical reading pathway to explain the regularization errors in English hyperlexia studies (Aram, 1997; Aram et al., 1984). However, the present study cannot rule out the possibility of non-lexical processing in hyperlexia, and warrants further investigation on reading of pseudocharacters with non-freestanding radicals (i.e., sublexical units that cannot exist as real characters). The ability to give plausible pronunciation of the characters reflects knowledge of print to sound mapping derived from previous exposure to characters that share the same phonetic radical. This would rule out the possibility of non-lexical processing and confirm the lexical nature of Chinese character reading (Law et al., 2009).

The error patterns shed light on the reading strategies employed by C.C.H. to achieve comparable reading performance to his age-matched peers. The presence of more visually related errors than the controls showed the possibility of learning some characters logographically (i.e., memorize the character as a whole without decomposing into components) (Ho & Bryant, 1996). This suggests that C.C.H. read a small portion of the characters based on rote memory. And the larger number of regularization and phonetic analogy errors of C.C.H. reflects the use of regularity and analogy rules in oral reading, suggesting that he was aware of the function of the phonetic radicals in oral reading (Ho & Bryant, 1997). C.C.H. used regularity rule more extensively than the typically developing children resulting in a greater regularity effect. Use of regularity and analogy rule was found to help second and third graders in Hong Kong read up to 60% the characters of their grade correctly (Leung, 2010), which showed that a major portion of C.C.H.'s oral reading could be explained by the use of these strategies. Development of these rules was believed to emerge from exposure to a large amount of characters for typically developing children as teachers in Hong Kong do not teach the rules explicitly (Ho & Bryant, 1997). C.C.H.'s preoccupation for lyrics on television might have contributed to the larger print exposure. Generating reading rules from print exposure was justifiable within the PDP framework in which learning is shaped by the amount and frequency of word exposure (Plaut et al., 1996).

Although this study was based on a single case, it has elucidated important findings that set it as the cornerstone for future studies. Future studies may examine children with hyperlexia from a range of semantic abilities to study the effect of differing degree of semantic knowledge on reading. Greater effects of character frequency, regularity and imageability would be expected in children with more severe semantic deficit. This would further support the role of semantics in oral reading. The presence of non-lexical processing in children with hyperlexia will be also an area of interest as mentioned above.

The case of hyperlexia in this study showed that with an underdeveloped semantic system, oral reading of unknown words, words that require understanding of the word context, irregular, low-frequency, and low-imageability characters were at a disadvantage. This association of lexical-semantic knowledge and oral reading lends support to the PDP model that successful oral reading in Chinese hyperlexia is semantically associated despite having an impoverished semantic system.

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Footnotes

[1] Phonetic transcriptions are given in *jyutping*, a Romanization system for Cantonese developed by the Linguistic Society of Hong Kong. The number represents the tone of the character.

[2] Although significant interactions effects were found, they are only reported in Appendix F given that the findings from the main effects were already sufficient to understand the control's character reading in relation to C.C.H.

[3] LARC errors included the regularization errors (Law, 2004; Weekes & Chen, 1999) and reading out of context errors (Law, 2004; Law et al., 2005) in a number of Chinese dyslexia studies.

Appendix A

Word-word Matching Semantic Relatedness Test Items

Trial No.	Target	Distractor1	Distractor2	MA Control *M*	MA Control *SD*	CA Control *M*	CA Control *SD*
Practice Trial 1	鞋	腳	手	-	-	-	-
Practice Trial 2	紅綠燈	巴士	飛機	-	-	-	-
Practice Trial 3	梳	腳	頭髮	-	-	-	-
1	小丑	獅子	狗	63.16	0.50	84.2	0.37
2	電池	電燈	電筒	73.68	0.45	94.7	0.23
3	枕頭	床	椅子	100.00	0.00	94.7	0.23
4	老鼠	狗	貓	100.00	0.00	100	0.00
5	樹	蘿蔔	蘋果	94.74	0.23	100	0.00
6	火柴	電燈泡	蠟燭	84.21	0.37	94.7	0.23
7	戒指	手指	拇指	89.47	0.32	94.7	0.23
8	雞	蟲	蛇	100.00	0.00	78.9	0.42
9	木材	斧頭	鋸	47.37	0.51	52.6	0.51
10	魚	貓	狗	89.47	0.32	100	0.00
11	鎖	單車	汽車	63.16	0.50	94.7	0.23
12	小路	手	腳	89.47	0.32	100	0.00
13	面具	小丑	修女	78.95	0.42	100	0.00
14	郵票	信封	書	94.74	0.23	100	0.00
15	車	路軌	馬路	73.68	0.45	84.2	0.38
16	椅子	枱	鐘	100.00	0.00	94.7	0.23
17	箭	槍	弓	73.68	0.45	94.7	0.23
18	頭髮	帽子	戒指	100.00	0.00	100	0.00
19	火車	馬路	路軌	84.21	0.37	94.7	0.23
20	蛋	貓頭鷹	雞	100.00	0.00	100	0.00
21	骨頭	狗	貓	100.00	0.00	100	0.00
22	襪	鞋	帽	100.00	0.00	100	0.00
23	皮帶	褲	恤衫	84.21	0.37	84.2	0.37

Note. MA, mental age matched; CA, Chronological age matched; Underlined items are the correct answers

Appendix B

HKCRVT Written word- Picture Matching Written Items

Trial No.	Target	Trial No.	Target	Trial No.	Target
Practice Trial 1	波	21	燈	44	夜晚
Practice Trial 2	車	22	食	45	危險
Practice Trial 3	鞋	23	電器	46	一半
1	筆	24	水果	47	一齊
2	飽	25	交通燈	48	清潔
3	梳	26	讀書	49	多
4	床	27	切	50	滿
5	瞓覺	28	鐘	51	修理
6	牛	29	吹	52	服裝
7	刀	30	雪櫃	53	帆船
8	喊	31	直昇機	54	送
9	櫈	32	涼	55	洗澡
10	跌倒	33	羊	56	鄰居
11	龜	34	鼓	57	追
12	的士	35	魔術師	58	熱鬧
13	裙	36	毛蟲	59	呔
14	狗	37	長	60	愉快
15	消防車	38	熱	61	守秩序
16	梳化	39	濕	62	量度
17	雞	40	蟹	63	郊外
18	開心	41	企鵝	64	文具
19	肥	42	清道夫	65	寵物
20	貨櫃車	43	一枝		

Note. HKCRVT, Hong Kong Cantonese Receptive Vocabulary Test

Appendix C

Contextual Word Reading (Homographic Heterophone) Items

Number	Homographic Heterophone pair	
1	地上 /*dei6 soeng6*/	上學 /*soeng3 hok6*/
2	得分 /*dak1 fan1*/	分子 /*fan6 zi2*/
3	播種 /*bo3 zung2*/	種植 /*zung3 zik6*/
4	答應 /*daap3 jing3*/	應該 /*jing1 goi1*/
5	照相 /*ziu3 soeng3*/	相處 /*soeng1 cyu3*/
6	暑假 /*syu2 gaa3*/	假如 /*gaa2 jyu4*/
7	高興 /*gou1 hing3*/	興建 /*hing1 gin3*/
8	應當 /*jing1 dong1*/	當做 /*dong3 zou6*/
9	需要 /*seoi1 jiu3*/	要求 /*jiu1 kou4*/
10	對稱 /*deoi3 cing3*/	稱讚 /*cing1 zaan3*/
11	為了 /*wai6 liu3*/	為主 /*wai4 zyu2*/
12	更加 /*gang3 gaa1*/	更改 /*gang1 goi2*/
13	中心 /*zung1 sam1*/	中毒 /*zung3 duk6*/
14	倒轉 /*dou3 zyun3*/	倒霉 /*dou2 mui4*/
15	會員/*wui2 jyun4*/	會見/*wui6 gin3*/
16	擔子/*daam3 zi2*/	擔心 /*daam1 sam1*/
17	轉變 /*zyun2 bin3*/	轉動 /*zyun3 dung6*/
18	難看 /*naan4 hon3*/	難民 /*naan6 man4*/
19	重新 /*cung4 san1*/	重量 /*cung5 loeng6*/
20	看見 /*hon3 gin3*/	看守 /*hon1 sau2*/

Note. Target characters are underlined.

Appendix D
Hong Kong Graded Character Naming Test (HKGCNT) Items

Table 1.

HKGCNT Grade 2 items with Imageability Ratings

Character	Imageability	Character	Imageability	Character	Imageability	Character	Imageability	Character	Imageability
河	4.81 (0.51)	尋	2.24 (1.34)	尼	1.71 (0.90)	啼	2.71 (1.27)	碰	3.19 (1.03)
掃	3.90 (0.89)	箭	4.48 (0.98)	針	4.38 (1.12)	淹	3.81 (0.87)	病	3.57 (1.29)
奮	1.48 (0.60)	怎	1.62 (1.02)	涼	2.52 (1.08)	空	3.43 (1.25)	我	3.57 (1.63)
積	1.62 (0.80)	何	1.43 (0.81)	腐	2.43 (0.93)	向	2.10 (1.22)	鮨	2.35 (1.50)
儲	2.52 (1.40)	讚	2.76 (1.04)	森	3.52 (1.17)	豬	4.52 (0.87)	鴨	4.62 (0.92)
側	2.57 (1.08)	品	1.81 (1.08)	筆	4.52 (1.08)	跌	3.33 (1.28)	枯	3.00 (1.22)
九	3.81 (1.29)	略	1.43 (0.68)	古	2.00 (1.00)	唱	3.57 (1.16)	志	1.52 (0.68)
悔	1.86 (0.91)	紫	4.1 (1.34)	跑	4.00 (1.05)	欄	4.10 (0.94)	粗	3.57 (1.16)
盪	3.19 (1.03)	尖	4.38 (0.80)	設	1.62 (0.80)	擲	3.48 (1.25)	警	3.24 (1.22)
善	1.43 (0.81)	聚	3.05 (1.07)	叢	3.29 (0.96)	措	1.52 (0.68)	憂	3.10 (1.22)
喉	4.24 (0.89)	軟	3.33 (1.20)	愛	3.00 (1.18)	式	1.43 (0.68)	櫃	4.19 (1.12)
認	1.48 (0.68)	舍	3.33 (1.20)	律	1.81 (0.98)	祖	2.14 (1.31)	治	1.62 (0.67)
圃	1.86 (1.15)	背	4.10 (0.89)	讓	2.00 (1.10)	付	2.29 (1.27)	乎	1.33 (0.58)
計	2.33 (1.11)	踩	3.62 (1.24)	武	2.67 (1.43)	斯	1.24 (0.44)	客	3.24 (1.14)
預	1.57 (0.75)	暑	2.38 (1.07)	手	4.81 (0.87)	就	1.29 (0.46)	跳	4.00 (1.10)
良	1.86 (1.20)	暫	1.57 (0.98)	披	2.86 (1.11)	後	2.43 (1.29)	茶	4.48 (0.87)
級	2.52 (1.12)	李	1.81 (1.17)	縮	2.76 (1.18)	村	3.76 (1.09)	程	1.52 (0.81)
蓆	4.24 (0.77)	板	3.57 (1.03)	時	2.52 (1.21)	悲	3.19 (1.29)	液	3.10 (1.41)
柑	4.38 (1.07)	詩	3.19 (1.40)	領	2.48 (1.54)	身	4.00 (1.22)	拇	1.89 (1.15)
係	1.67 (1.02)	佔	1.81 (0.81)	日	4.00 (1.34)	汗	4.43 (0.75)	滅	2.67 (1.15)
仗	2.62 (1.36)	巴	1.57 (0.98)	反	2.57 (1.29)	岳	1.95 (1.20)	荻	1.70 (1.08)
茄	4.10 (0.94)	鴉	3.81 (1.12)	挺	2.76 (1.18)	蚪	2.67 (1.46)	檢	1.90 (1.04)
橘	4.05 (1.24)	訓	2.29 (1.19)	浴	3.71 (1.10)	兵	3.86 (1.01)	脾	3.10 (1.34)
蒼	1.67 (0.86)	執	2.33 (1.24)	傳	2.43 (1.21)	恰	1.52 (0.75)	換	2.33 (1.35)
利	1.90 (1.22)	物	2.38 (1.02)	棄	2.57 (1.36)	累	2.86 (1.24)	玻	1.48 (0.87)
土	3.95 (1.28)	烈	1.95 (0.86)	移	2.67 (1.24)	敗	2.71 (1.31)	謙	1.67 (0.91)
塵	4.29 (0.90)	子	3.24 (1.48)	容	1.76 (0.83)	靠	2.38 (1.12)	荊	2.90 (1.26)
浮	3.38 (1.20)	擴	2.14 (1.15)	伐	2.38 (1.50)	馬	4.76 (0.70)	陳	1.33 (0.91)
幫	2.19 (1.17)	缺	2.19 (1.17)	足	4.52 (0.81)	語	2.10 (1.14)	尊	1.52 (1.03)
稚	1.71 (0.72)	桶	4.1 (1.26)	后	2.81 (1.25)	鍛	1.38 (0.59)	似	2.00 (1.18)

Note. Standard deviations are given in parentheses.

Table 2.

HKGCNT Grade 3 Items with Imageability Ratings

Character	Imageability	Character	Imageability	Character	Imageability	Character	Imageability	Character	Imageability
蓄	3.24 (1.29)	第	1.29 (0.66)	壺	4.57 (0.60)	跌	4.14 (0.93)	死	4.05 (1.34)
賣	3.29 (1.17)	碧	1.90 (1.12)	俱	2.14 (1.31)	米	4.90 (0.31)	十	3.62 (1.57)
謝	3.14 (1.25)	箭	4.90 (0.22)	替	1.71 (0.79)	養	2.95 (1.15)	問	3.10 (1.27)
榮	1.43 (0.83)	豫	1.43 (0.68)	柚	4.19 (1.11)	甘	2.05 (1.05)	烘	2.86 (1.19)
蛔	1.65 (1.06)	唐	1.33 (0.75)	詞	3.00 (1.29)	家	3.86 (1.07)	銳	2.33 (1.27)
似	2.19 (1.11)	叭	2.62 (1.35)	究	1.24 (0.55)	欺	2.19 (1.16)	留	1.90 (1.19)
睹	2.71 (0.86)	皂	4.14 (0.89)	橋	4.95 (0.22)	丁	1.52 (0.83)	晴	3.86 (1.21)
送	3.67 (1.18)	餘	1.86 (1.09)	氟	1.90 (1.19)	遺	1.86 (0.72)	艇	4.67 (0.47)
味	2.71 (1.16)	填	2.81 (1.18)	婆	4.76 (0.55)	盪	3.24 (1.21)	喧	2.57 (1.31)
台	3.00 (1.12)	哺	2.43 (1.19)	誠	1.67 (1.03)	肅	1.43 (0.69)	措	1.19 (0.41)
悠	1.86 (0.93)	磨	3.57 (1.10)	個	2.19 (0.91)	四	3.76 (1.29)	喚	2.14 (0.88)
晃	2.10 (0.97)	翻	3.33 (1.14)	料	1.76 (0.77)	題	2.14 (1.20)	圖	4.14 (1.11)
傻	3.19 (0.95)	不	3.19 (1.52)	刀	4.95 (0.22)	伙	1.71 (0.97)	各	1.24 (0.44)
及	1.38 (0.81)	娃	4.33 (0.81)	鎮	3.33 (1.53)	讀	3.43 (1.39)	碳	4.38 (0.75)
略	1.52 (0.83)	贊	1.76 (0.95)	塑	2.90 (1.43)	乘	2.86 (1.33)	弛	1.71 (0.91)
巡	3.10 (1.02)	庭	2.67 (1.08)	棄	2.67 (1.42)	屈	2.00 (1.19)	昔	1.14 (0.37)
甲	2.62 (1.10)	突	2.00 (0.97)	荃	1.38 (1.10)	序	1.52 (1.00)	蓮	3.57 (1.14)
薯	4.14 (0.99)	曹	1.14 (0.49)	劍	4.90 (0.31)	佳	1.86 (0.91)	妥	1.43 (0.00)
鄭	1.29 (0.80)	倦	3.19 (0.95)	荊	3.14 (1.28)	錶	5.00 (0.00)	堂	2.57 (1.14)
模	2.52 (1.39)	遜	2.19 (1.32)	城	3.90 (1.10)	持	2.14 (0.93)	愧	1.43 (0.83)
撥	2.95 (1.23)	瞎	3.62 (1.14)	否	2.19 (1.12)	斜	3.81 (1.06)	雀	4.67 (0.55)
博	2.19 (1.09)	史	1.86 (0.97)	毫	2.90 (1.19)	鳥	4.90 (0.31)	凳	4.86 (0.67)
窗	4.90 (0.31)	余	1.24 (0.79)	成	1.43 (0.83)	波	5.00 (0.00)	積	2.24 (1.13)
嗜	1.57 (0.82)	挑	2.76 (1.15)	獨	2.48 (1.24)	很	1.48 (0.76)	飛	4.19 (0.95)
瀉	3.62 (0.93)	松	3.05 (1.39)	薦	1.62 (0.88)	盜	3.10 (1.09)	娥	2.71 (1.34)
飼	2.95 (0.92)	嘉	1.24 (0.55)	廠	4.05 (0.85)	瞧	2.62 (0.99)	胎	3.43 (1.19)
軟	3.81 (1.06)	暮	2.24 (1.13)	丸	4.38 (0.69)	火	4.86 (0.37)	併	1.52 (0.89)
衣	4.81 (0.41)	敢	2.00 (0.86)	但	1.33 (0.67)	嚀	1.33 (0.49)	牙	4.95 (0.22)
袋	4.90 (0.31)	拇	2.67 (1.62)	拼	2.24 (0.98)	悅	2.24 (1.03)	化	1.19 (0.41)
紓	1.19 (0.41)	避	3.19 (1.41)	亭	4.43 (0.69)	農	3.24 (1.31)	擴	2.05 (0.72)

Note. Standard deviations are given in parentheses.

Appendix E

Percentage of HKGCNT Oral Reading Errors of C.C.H. and the Control Groups

	Grade 2 Character		Grade 3 Character	
	C.C.H.	MA Control	C.C.H.	CA Control
High frequency				
Regular				
High imageability	0.00	0.00 (0.00)	0.00	5.00 (10.47)
Low imageability	50.00	14.47 (20.94)	0.00	0.00 (0.00)
Irregular				
High imageability	11.11	1.17 (3.47)*	11.11	3.89 (5.45)
Low imageability	10.00	4.74 (6.97)	22.22	7.22 (11.03)
Medium frequency				
Regular				
High imageability	14.29	33.08 (19.63)	12.50	15.63 (16.59)
Low imageability	12.50	26.97 (24.64)	20.00	17.00 (15.29)
Irregular				
High imageability	46.67	31.58 (17.67)	58.33	24.58 (12.52)*
Low imageability	30.00	21.58 (21.67)	38.46	37.69 (15.54)
Low frequency				
Regular				
High imageability	25.00	34.21 (23.88)	42.86	27.86 (26.84)
Low imageability	62.50	46.71 (21.19)	25.00	46.88 (17.61)
Irregular				
High imageability	58.33	37.72 (21.86)	75.00	46.88 (16.07)
Low imageability	80.00	55.79 (21.43)	81.25	53.75 (18.74)

Note. HKGCNT, Hong Kong Graded Character Naming Test; MA, mental age matched; CA, Chronological age matched; Standard deviations are given in parentheses; *p < .05

Appendix F

HKGCNT Oral Reading Interaction effects

The effect of frequency on the reading performance of the MA control was qualified by a significant two-way interaction between frequency and imageability (F (2, 36) =32.23, p < .01, $\eta\rho^2$ = .642). The means of the MA control relevant to this interaction was shown Appendix E to show that 1) frequency effect was present only for low imageability characters but not present for high imageability characters in the medium- to low- frequency range. 2) Imageability effect was observed in high- and low- frequency, a slightly reverse imageability effect was found in medium-frequency. This interpretation was confirmed by analysis of simple effects corrected using a Bonferroni adjustment. The results were all significant at p < .001. For low imageability characters, there were more errors in low-frequency (*M*= 51.1%, *SD*= 4.6) than medium- frequency (*M*= 24.1%, *SD*= 5.1) and high- frequency characters (*M*= 9.6%, *SD*= 2.8). More errors were also found in medium- than high-frequency. For high imageability characters, significantly more errors were present in low- (*M*=36%, *SD*=4.5) and medium- frequency (*M*= 32.3%, *SD*= 4) than high frequency characters (*M*= 0.6%, *SD*= 0.4). The difference between low- and medium- frequency failed to reach significance, *p*= .63. Effect of imageability was significant at the .05 significance level among characters of each level of frequency, but the effect of imageability was reversed for medium frequency characters, with more errors in high- (M=32.3%, SD=4) than low imageability (M= 24.1% , SD= 5.1). For MA control, the important findings were 1) Frequency effects were always strong; 2) regular characters were not at an advantage comparing to irregular characters; 3) low imageability characters were more sensitive to frequency factors, low frequency- low imageability characters were specifically more error-prone; 4) imageability effect was generally found in high and low frequency characters.

For the CA control, a significant two-way interaction between imageability and frequency, F (2, 36) = 6.56, p = .004, $\eta\rho^2$ = .27, regularity and frequency, F (2, 36) =4.81, p= .014, $\eta\rho^2$ = .21 were also found. These two interactions were qualified by a critical three-way interaction between frequency, imageability, and regularity, F (1.42, 25.59) = 6.75, p = .009, $\eta\rho^2$ = .27, ω^2 = .59. As Mauchly's test indicated the assumption of sphericity had been violated for the three-way interaction, $\chi^2(2)$ =8.87, p=.012, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=.71). The means of the CA control relevant to this interaction was shown Appendix E. The three-way interaction showed that the imageability and frequency interaction was significant in both regular, F (2, 36) = 7.48, p = .002, $\eta\rho^2$ = .29, and irregular characters, F (2, 36) = 4.58, p = .017, $\eta\rho^2$ = .20. Regularity and frequency interaction was present only in high imageability, F (2, 36) = 5.54, p = .008, $\eta\rho^2$ = .24, but not in low imageability characters, F (2, 36) = 5.90, p = .072, $\eta\rho^2$ = .25. Therefore, regularity effect was the same across frequencies for low imageability characters. Post-hoc pairwise comparisons using Bonferroni adjusted alpha levels of .017 per test (.05/3) showed that 1) Imageability effect was found in low frequency- regular characters, t (18) =-3.65, p= .002, and medium frequency - irregular characters, t (18) =-4.09, p= .001; 2) For high imageability characters, regularity effect was only found in the low frequency range, t (18) = -3.36, p= .004. For CA control, the important findings were 1) Frequency effects were always strong; 2) low imageability characters were more error prone than high imageability characters when they are in the lower frequency range regardless of regularity; 3) irregular characters were more prone to error than regular characters at all frequency levels of low imageability characters, but only at the low frequency range for high imageability characters.

Appendix G

HKGCNT Oral reading Errors Classification

Type of Error	Description	Example
Regularization (Phonetic derivation)	The sound of the phonetic radical was used for the pronunciation of the whole character	液 /*jik6*/ → 夜 /*je6*/
Analogy	The character was pronounced as another character that shared the same phonetic, semantic component or logographeme.	Phonetic analogy: 枯 /*ku1*/ → 姑 /*gu1*/ Semantic analogy: 鮨 /*kei4*/ → 鱗 /*leon4*/ Logographeme analogy: 岳 /*ok6*/→ 屈 /*wat1*/
Visually related	The character was pronounced as another character that shared similar orthography	式 /*sik1*/→ 武 /*mou3*/
Word-related	The character was pronounced as the other character in a word.	浴 /*juk6*/ → 缸 /*gong1*/, 浴缸 is a word meaning bathtub
Semantic-related	The character was pronounced as another character having similar meaning	櫃/*kwai6*/→ 箱 /*soeng1*/, both characters mean 'box'
Tonal	The response differed from the target only in tone	奮/*faan3*/→ 墳/*faan4*/
LARC	The pronunciation of one of the logographemes was used as the pronunciation of the whole character	嗜 /*kei4*/→ 老 /*lou3*/
Did not know	The participant said they did not know how to read the character	-
Ambiguous	The error can be interpreted by a number of error patterns	斯 /*si1*/→ 其/棋/*kei4*/, which can be an analogy error or over regularization error.
Others	Errors other than the above categories	屈 /*wat1*/→ /*lik1*/

Note. HKGCNT, Hong Kong Graded Character Naming Test; LARC, Legitimate Alternate Reading of Components